Vaasan yliopisto
UNIVERSITY OF VAASA

MANMEET SINGH

Preventing data loss in PFMEA; a digital solution

School of Technology and Innovations

Master’s Thesis in Industrial Management

Vaasa 2021

ACKNOWLEDGEMENTS

Working on this master's thesis is a feeling of satisfaction and joy. As a sincere engineering student and professional, I wanted to reimburse by filling up a process gap through this thesis and solving an industry problem. This is my graduation thesis, master's Programme in Industrial Management, University of Vaasa.

I would like to express gratitude and appreciation to my supervisor, professor Ville Tuomi. He has always been a great support and source of knowledge for me during the whole process of my studies and masters thesis. His knowledge sharing, out-of-the-box support, and constant availability helped me design and complete this thesis. Moreover, he also taught be problem-solving, creating reliability and validity.

Finally, I would like to thank my mother, my elder brother, sister-in-law, sweet nephew and last but not least, my friends; I could not have finished my studies this easy without their support.

Manmeet Singh
April 2021

UNIVERSITY OF VAASA
School of Innovations & Technology

Author: Manmeet Singh
Title of the Thesis: Preventing Data Loss in PFMEA; A Digital Solution
Degree: Master of Science in Economics and Business Administration

Programme: Industrial Management

Supervisor: Professor. Ville Tuomi
Year: 2021 Pages: 84

ABSTRACT:

Kaizen, a Japanese term, defines continual improvement or a scope of improvement that exists in each process, has motivated the author for this research. The fourth industrial revolution has high demands for lean productivity, reducing waste activities and eliminating defect generation possibilities. PFMEA, a tool known for analysing potential risks is not much developed in the past few years in its knowledge handling capabilities. One of the significant input required for PFMEA generation is PTDB; perhaps, the PTDB is maintained on spreadsheets or Microsoft Excel in general by many organisations and has been proven ineffectiveness in research and events globally in the past few years.

However, no development is witnessed in PTDB knowledge handling processes, both in academia and industry. Thus the current thesis aims to answer the basic research question of the study – "What are the advantages of using software-based PTBD over traditional spreadsheet-based PTDB for PFMEA"?

The study empirically evaluated the disruptiveness in spreadsheets and its impact on data quality and decision making, linking the possible challenges for PFMEA. In addition, the study intends to capture industry voice and opinion on a digital solution for PTDB. Semi-structured interviews and online surveys were conducted with industry professionals globally to answer the research question. Data has been analysed through content analysis and it was found that, spreadsheets are inefficient in big data handling due to its list of risks, such as; calculation and formatting errors, data security and data transfer issues. Whereas, the industry respondents welcomed the idea of a better but economical digital solution.

To overcome the challenges, the author has designed a conceptual framework capable of big data handling, delivers security and flexibility. The framework has an inbuilt PFMEA template that eliminates the possibility of data loss, saves time and deliver quality PFMEA. The future scope exits with the design and trial run of the framework.

KEYWORDS: Past Trouble Data Base, Process Failure Mode Effective Analysis, Challenges, Spreadsheets, Root Cause Analysis, Continual Improvement, Risk Assessment, Risk Analysis

Table of Contents

Figures

Tables

List of Abbreviations

3M	Continual Improvement Tool
5S	Continual Improvement Tool
5W1H	Continual Improvement Tool
8D	Continual Improvement Tool
AIAG	Automotive Industry Action Group
CAPA	Corrective And Preventive Action
CI	Continual Improvement
DFMEA	Design Failure Mode Effective Analysis
ERP	Enterprise Resource Planning
FMEA	Failure Mode Effective Analysis
FMECA	Failure Mode Effective Critical Analysis
FTA	Finnish Tax Administration
ICT	Information And Communication Technology
NASA	National Aeronautics And Space Administration
NPD	New Product Development
NSCEP	National Service Centre For Environment
PDCA	Plan Do Check Act
PFD	Process Flow Diagram
PFMEA	Process Failure Mode Effective Analysis
PHE	Public Health England
PTDB	Past Trouble Data-Base
RCA	Root Cause Analysis
SFMEA	System Failure Mode Effective Analysis
SME	Small And Medium-Sized Enterprise
SOP	Standard Operating Procedure
TQM	Total Quality Management
U.K.	United Kingdom
U.S.	United States

1 Introduction

1.1 Background

In the year 1980, a revised document from 1949 introduced by the United States of America - Department of Defence, a procedure to perform Failure Mode Effects and Critical Analysis (FMECA) (appendix -1) (Department of Defence, 1980). Since 1965, the U.S. National Aeronautics and Space Administration (NASA) used FMECA for its space programs, such as Apollo, Viking, Voyager, Magellan, and Galileo (Apollo Reliability and Quality Assurance Office National Aeronautics and Space Administration, 1965; National Aeronautics and Space Administration, 1970). In 1974 NASA first used the term Failure Mode Effective Analysis (FMEA) for its program named Skylab (Program, Nasa, & Marshall, 1974) Over the period, the industrial revolutions and technological improvements pushed the FMEA to reached its Fourth Edition in 2008, and the last amendment was done in 2019 named The AIAG & VDA FMEA Handbook. The FMEA are of three types; Design FMEA (DFMEA), Process FMEA (PFMEA) and System FMEA (SFMEA) (Automotive Industry Action Group, (AIAG), 2008). The application of FMEA is performed in three primary cases, mentioned below:

> "*Case 1: New design, new technology or new process*
> *Case 2: Modification of existing design or process*
> *Case 3: Use of existing design or process in a new environment.*" (Automotive Industry Action Group, (AIAG), 2008)

The essence of FMEA is the assessment of potential risk in the product, process or system. In other words, the fundamentals of FMEA is to prognosticate the highest probability of things that could go wrong. The events causing the unpleasant issues should be identified in depth; furthermore, design the actions that could prevent the defect occurrence or restrict the defective part's outflow towards the following process (Munro, Ramu, & Zrymiak, 2014). "*A stitch in time saves nine*" (Ballinger, Craig, Cross, & Gray, 2011) FMEA is a continual improvement tool to archive company-wide quality control or total quality control for new product development. Many other continual and continuous improvement tools are practised within the industry, explained in chapter 2.1. Among the list of tools, FMEA is the only risk assessment and problem-solving tool that captures widespread process knowledge; redistributes the knowledge learned to empower New Process Development (NPD). FMEA is not only a risk assessment tool but also a method for organisational learning. With it, organisations create and achieve ambience towards Total Quality Management (TQM). Effective implementation of FMEA reduces non-conformities in the process, resulting in improved production operations and indicators of the same will save the cost of poor quality (rejection and rework) (Doshi & Desai, 2017; Lipol & Haq, 2011; Syahputri, Sari, Rizkya, Alona, & Zati, 2019; Tavana, Shaabani, & Valaei, 2020)

FMEA is a data-based knowledge process that utilises data to make new product development decisions. FMEA is not subjected to one industry type; in 1972, NASA published FMEA for petroleum exploration projects (Dyer et al., 1972) and in 1973, National Service Center for Environmental Publications (NSCEP) from the U.S. highlights the applications of FMEA in wastewater treatment plant (U.S. Environmental Protection Agency, 1973). Due to FMEA's focused approach towards preventive control of defects, its popularity increased; hence in the current fourth industrial revolution, many industry segments use FMEA as a risk assessment and a continual improvement tool such as Power Plants, Oil Industries, Information Technology, Construction, Sustainable energy (Wind Turbines), Hospitals, Food products and many more. (Feili, Akar, Lotfizadeh, Bairampour, & Nasiri, 2013; Hekmatpanah, Shahin, & Ravichandran, 2011; Silva, de Gusmão, Ana Paula Henriques, Poleto, Silva, & Costa, Ana Paula Cabral Seixas, 2014).

PFMEA is designed to strengthen the competency of the process to reduce non-conformities. Since its existence until the fourth industrial revolution, PFMEA practices have not changed much. The data handling (recording, consolidation, analysis and data transfer) is performed on a non-digital platform or software like spreadsheets or Microsoft Excel in general (Bradley & McDaid, 2009). The generation of a new PFMEA requires some prerequisites such as; DFMEA, Process Flow Diagram (PFD), design/process requirements, cross-functional team and Past Trouble Data-Base (PTDB). The PTDB is a consolidated data bank of non-conformities reported in previous design and production processes; each non-conformity in PTDB simultaneously contains eight to ten data variable points. These points are a detailed description of the defect and analysis part. Thus, PTDB is seen as the knowledge (lessons learned) from past similar or cross-functional processes to NPD.

Even due to the high demand for the PFMEA tool, there is very little or no digital transformation evident in its operation. No past studies were found to modify the PTDB data handling process. However, studies were done on errors in Excel and spreadsheets; refer to chapter 2.3 and 2.4. Perhaps, organisations are more vigilant towards their operations and focused on achieving lean manufacturing; such a mindset lets organisations bring quality in their business strategies. Organisations do realise the "*cost saved is profit earned*." (NGUYEN, 2017) Small and medium-sized enterprises (SME) such as tier one or tier two suppliers are unwilling to put money on high-end software solutions due to financial constraints. These companies are small-sized; thus, they deal in small profit margins. SME suppliers do not have Standard Operating Procedures (SOPs); they work on best practices. On the other hand, digital solutions has high implementation and maintenance cost. Most of the available digital solutions are resource-intensive, making it hard for SME's to cope with (Booth, Matolcsy, & Wieder, 2000; Laukkanen, Sarpola, & Hallikainen, 2007; Venkatraman & Fahd, 2016). The abovementioned data handling process and unavailability of an economical and user-friendly digital solution have created an opportunity for a new digital framework, particularly for PTDB, an input for PFMEA.

1.2 Research gap, problem, and objectives

There have been a number of impactful studies on the functionality, performance and analytical methods of PFMEA in both technical and economic frames (Cao & Deng, 2019; Keskin & Özkan, 2009; Shahin, 2004; Stamatis, 2003). Recently experimental researches were conducted to transform the entire end-to-end process of PFMEA into a digital tool

(Sader, Husti, & Daróczi, 2020; Zhang & Li, 2013). Perhaps the outcome did not stand as expected due to human-based audits required for a root cause analysis (RCA); this could be seen as a future research topic. During the literature review, there were no studies found on the prerequisite PTDB of PFMEA. This area has high significance for the generation of PFMEA and NPD. However, several studies conducted with evident empirical data about the errors in spreadsheets, Refer chapter 2.3 and 2.4 (Cook, 2020; Hermans, Sedee, Pinzger, & Deursen, 2013; O'Beirne, 2008; Panko, Raymond, 1998; Panko, Raymond R., 2006; Powell, Baker, & Lawson, 2009; US, 2002).

The author has more than ten years of industry experience, specifically in Quality Assurance and Systems as a team member of PFMEA and an internal and external auditor for technical compliance. During the professional experience, the auditor has learned about the mismatching of data between various documents and processes, such as; PTDB, PFMEA, Control Plan, Process evaluation Check-sheet, Work Instructions, and Quality Matrix. The general cause of miss-match or lack of data in all these documentation is due to incompetent data handling process, done through spreadsheets based PTDB. The process requires manual data sorting from a big data bank and without the use of any digital technology, it is copy-pasted from one software to another or one datasheet to another. The process to generate PFMEA requires past defects (PTDB) to eliminate defects re-existence; thus, the data handling process should be competent enough to transmit error-proof data. There is a scope of improvement and a need for a digital transformation over traditional spreadsheet-based PTDB. Therefore the study will try to answer the fundamental research question: “What are the advantages of using software-based PTBD over traditional spreadsheet-based PTDB for PFMEA?” The study is focused on its research objectives stated below:

- To evaluate the problems and errors related to traditional spreadsheet-based PTDB
- To evaluate the advantages of a digital framework over the traditional PTDB

1.3 Structure of the thesis

The research structure was designed in a systematic process for meaningful understanding. Starting with chapter one – introduction, explains the research background, research gap, research question followed by objectives. The second chapter includes past relevant studies, industry news and events to establish the concrete argument to support research. This chapter also talks about the challenges and impact created due to the poor performances of spreadsheets. And why a digital solution is a better possible solution.

Research methods, process, design, and strategy used in the study was discussed in chapter three. It has also highlighted the research instrument, the population of the research, the sampling technique, and the demographical details of the respondents.The fourth chapter explains the outcome of the primary and secondary study. The chapter has analysis technique, analysis outcome, and presented results through content analysis.

The fifth chapter is the conceptual framework – a solution designed for process improvement for the PFMEA knowledge handling process. In this chapter, a detailed functional performance is explained, including the characteristics of the framework.The last chapters of the study conclude the analysis and results and provide the scope for future research.

2 Theoretical background

2.1 A brief overview of FMEA, PFMEA and PTDB

Continual improvement is a dynamic process to improve a product, process, service, or system quality. The industrial revolutions brought many continual improvement tools, for example, Corrective and Preventive Action (CAPA), Gamba Walks, 5W1H, 3M, 8D, 5S, Kanban, Plan Do Check Act (PDCA) and FMEA. FMEA is an effective and significant method to prevent or minimise failure modes occurrence in manufacturing organisations. Furthermore, suggesting the best possible controls to avoid or minimise failure effects. FMEA is a widely used tool for risk analysis in different industries such as Power Plants, Oil Industries, Information Technology, Construction, Sustainable energy (Wind Turbines), Hospitals, Food products and many more. (Feili et al., 2013; Hekmatpanah et al., 2011; Silva et al., 2014). FMEA is the standard name from the Automotive Industry Action Group (AIAG); however, it is also known as risk analysis and continual improvement tool. FMEA has three variants, Design FMEA, Process FMEA and System FMEA. Process Failure Mode Effective Analysis (PFMEA) is the approach used to design process controls. An ideal PFMEA is expected to; design an error-proof process, completed before the start of production, attention to each process activity and effectively use Past Trouble Data-Base (Automotive Industry Action Group, (AIAG), 2008)

A PFMEA is a document of an operational process. Its generation requires understanding and availability of some significant prerequisites. The primary input for PFMEA are; Process Flow Diagram (PFD), Design Failure Mode Effective Analysis (DFMEA), Drawings and Design records, Bill of Process, Interrelationship (characteristic) Matrix, Quality and Reliability History and Internal and External (customer) non-conformance (defect history data) also known as Past Trouble Data-Base (PTDB). The PTDB is a significant prerequisite for a PFMEA, as explained in AIAG - FMEA Fourth Edition (2008) (Automotive Industry Action Group, (AIAG), 2008). The current study focuses on one of the most critical prerequisite of PFMEA, namely PTDB.

A PTDB is a live document updated each time a new defect or cause reported. PTDB is a bank of past defects from a similar process or product. In the industry and the regulatory standards, defects are written as non-conformance: a particular process, part of process or product, which does not match its requirements. The non-conformance recording is done during the design (trail stages) or production stage of manufacturing. The major and critical defects need to be analysed to establish a root cause, to take necessary actions. This stage is known as lessons learned from past defect (Automotive Industry Action Group, (AIAG), 2008)

A PTDB is a data-gathering process explained in figure 1 (designed by the author). It is a process diagram of an assembly line. The second quality check station detected the non-conformity—the number of defects and the types of defects recorded at this stage. Furthermore, the defects are categorised into critical, major and non-critical defects as per their severity of hazardousness. Critical and major nonconformities must be analysed to their depth to find the root cause, as stated in FMEA - Fourth Edition. *"The cause should be detailed as concisely and completely as possible"* (Automotive Industry Action Group, (AIAG), 2008). As per ISO 9000 Quality Systems Handbook – Fourth Edition, critical non-conformities are *"a departure from the requirements which renders the product or service unfit for use"* (Hoyle, 2018). Also, the major nonconformities are *"a departure from the requirements included in the contract or market specification"* (Hoyle, 2018). A professional can perform an RCA soon after the defect/non-conformity categorisation.

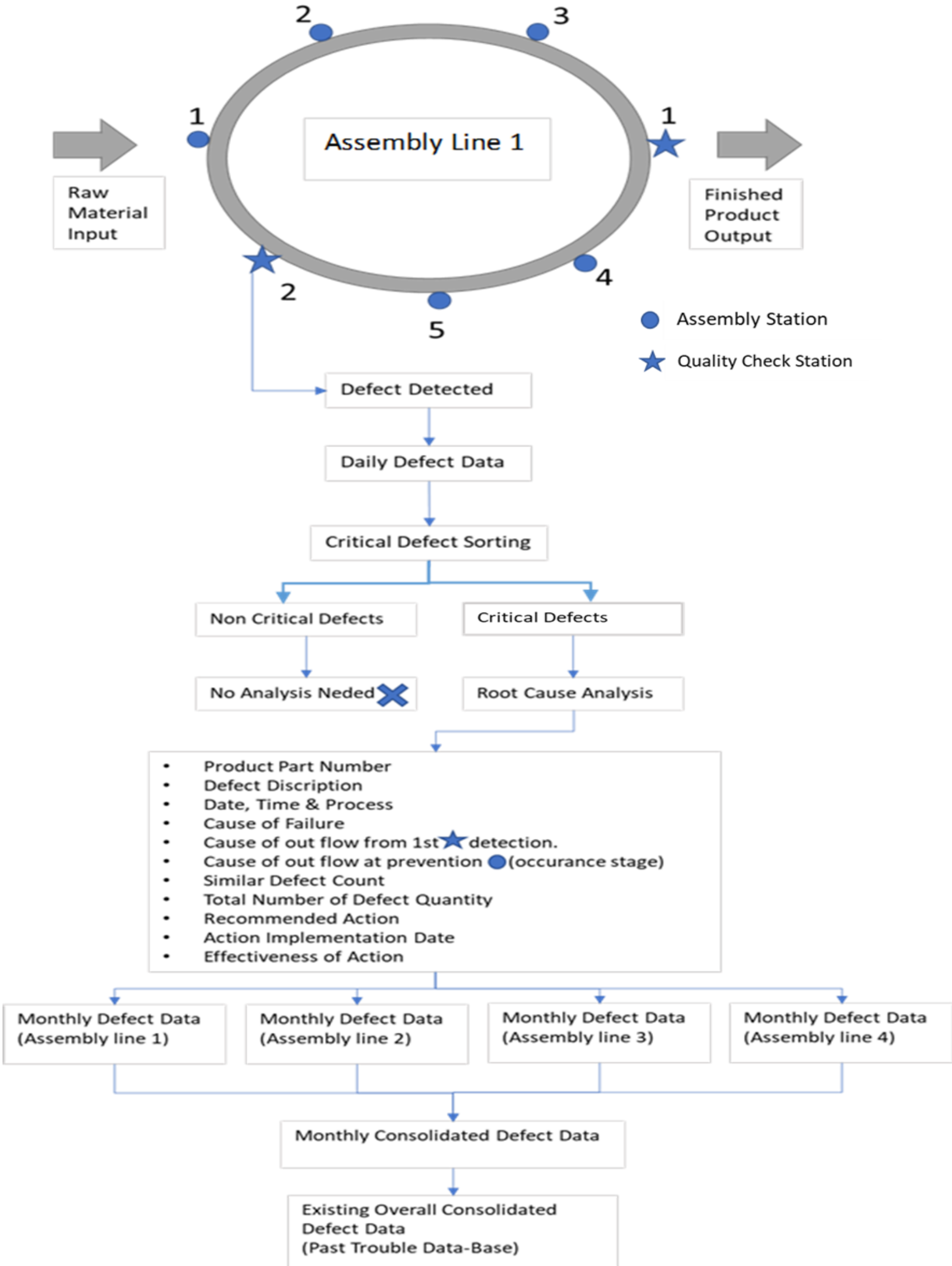


Figure 1 PTDB Generation Process Flow

2.2 Significance of RCA & PTDB for PFMEA

The root cause analysis stands utter importance in creating PTDB and later a significant input for PFMEA, providing the base for preventive action. A root cause analysis (RCA) is a process of audit that, explains defect occurrence, causing non-conformance in a process. The process is then designed with new controls to permanently mitigate the cause through effective process improvement. (Munro et al., 2014). The elements of RCA are of high importance for the creation of PTDB. The RCA data is consolidated frequently by organisations at a defined time; it could be monthly or weekly. Thus, this data is known as Past Trouble Data – Base (PTDB). The information an RCA provides is: Defect description (b), Defect Occurrence – Process name (a1), Cause of Failure (f), Performance or Preventive and Detection Control (h) and Recommended Actions (k). All these elements will later become a significant part of PFMEA; please find Appendix 1.

Some of the RCA and problem-solving tools practised within industries are; 8 discipline (8D), 5 Whys, Six Sigma—DMAIC (define, measure, analyse, improve, control), Drill Deep and Wide (DDW) (Ford Motor Company), Cause-and-Effect Diagram (Fishbone Diagram), Is/Is Not Comparative Analysis, Cause-and-Effect (X–Y) Relational Matrix and Root Cause Tree (Munro et al., 2014). Thus, the RCA problem-solving tools troubleshoot the problems and let the professionals suggest effective corrective actions. The next step is to register defects and causes of defects into PTDB. This data transfer process is performed manually from the daily defect spreadsheets into a single spreadsheet.

PTDB is a data bank of defects captured during past projects in many years. Organisations rely on this type of knowledge for internal training and to create PFMEA. However, most of them do not have a standard process to capture, restore, and retrieve past project learnings (Von Zedtwitz, 2002). Past project learnings should focus on capturing process knowledge rather than regular projects reviews and audits (Duffy & Thomas, 1989; Neale & Holmes, 1990). Perhaps a dynamic link of knowledge transfer is now evident within RCA, PTDB and PFMEA.

2.3 Motivation to innovate Past Trouble Data-Base (PTDB)

It is essential to realise the Past Trouble Data-Base primary function is to collect and transfer knowledge from past defect for future design projects to prevent or control failure situations. This knowledge transfer is of high importance for organisational learning: a piece of essential knowledge for future actions. Organisations take actions based on interpretations of knowledge sharing from the past rather than forecasting the future (Levitt & March, 1988). In industry practices, spreadsheets are for data handling, analysis and storage. However, studies conducted in 2009 by Dartmouth College students, USA, show the error percentage of 0.87 to 1.79% in spreadsheets' cells (Powell et al., 2009). Similarly, Raymond R. Panko (2005) performs an in-depth study of errors in spreadsheets; they found out that spreadsheet data is exposed to multiple imperfections that can cause organisations huge loss (Panko, 1998).

Most of the organisation's domains use spreadsheet programs, ranging from logistics, finance, marketing, and production to research and development, making spreadsheet data a high-value asset. However, spreadsheets are vulnerable to human errors (intentionally or unintentionally), and these errors can potentially cause huge financial and business losses. For example, in the year 2003 TransAlta, lost US$24 Million due to a copy-paste error. The company chief executive told the media "*a cut-and-paste error that we did not detect when we did our final sorting and ranking of bids prior to submission*". Whereas in 2002, John Rusnak, a rogue trader, tempered spreadsheet-based data resulting Allfirst Bank a total loss of US$691 million (Cook, 2020). Unsecured and non-error proof data-handling questions the integrity of spreadsheets usage. O'Beirne questioned the spreadsheet data quality in 2008, stating that the spreadsheets are a data tempering tool and used to bypass I.T. development's counter-measures (O'Beirne, 2008).

There is a less but significant amount of studies and actions taken by regulatory authorities in many countries. The United States passed a federal law Sarbanes–Oxley Act of 2002, forcing all U.S. public, management and public accounting companies to monitor their spreadsheet use in financial reporting (Panko, 2006; US, 2002). The study shows the data is not secure to store and transmit through spreadsheets; an intentional or unintentional act can spoil data quality. It is clear to organisations that spreadsheets' data is not safe. However, due to formula dependency, organisations ignored data's hazardousness (Hermans et al., 2013).

2.3.1 Learning organisation to adapt continual improvement

Learning organisation is a part of the organisation culture. Its beliefs and practices change in response to its experience through two primary mechanisms. The first is the organisational search. An organisation works on alternative routines and picks the best practices when discovered (Radner, 1975). The second mechanism is trial and error—increased frequency of practices that can deliver results compared to those associated with failure (Cyert & March, 1963).

The PTDB is a consolidated data bank from different processes. It contains vital information for future projects, which on effective implementation can let the organisations achieve continual improvement. Thus, PTDB transfers knowledge to PFMEA to achieve Continual improvement (CI). CI is a philosophy that asks organisations to learn from their experiences and implement effective counter-measures in future projects to avoid repetitive non-conformance. CI is a foundation for organisational learning and communicates information for effective decision making. For instance, the examinations, analysis, results, feedback, experiments, trials, and other sources create an information data-base; such data are high packs of substantial knowledge (International Organisation for Standardization, 2015). This type of learning is evident in cumulative production organisations' (Dutton & Freedman, 1985). An organisation willing to adapt continuous improvement must make it a part of the organisational strategy, employee involvement, technology, and learning culture from all organisation levels. Where undoubtedly, technology plays a significant role.

2.3.2 An interpretation and data (knowledge)

The lessons learned will always be drained out of past failures. A process is a mechanism of various variables. Thus, it will have variations in performance within and beyond tolerances. Capturing a variation and making it a part of organisational learning is relatively small in numbers and complex to observe. A process required-output will mostly be different from its actual-output. Nevertheless, professional interpretation of an event can vary within the organisations that can classify outcomes as good or bad (Thompson, 2003)

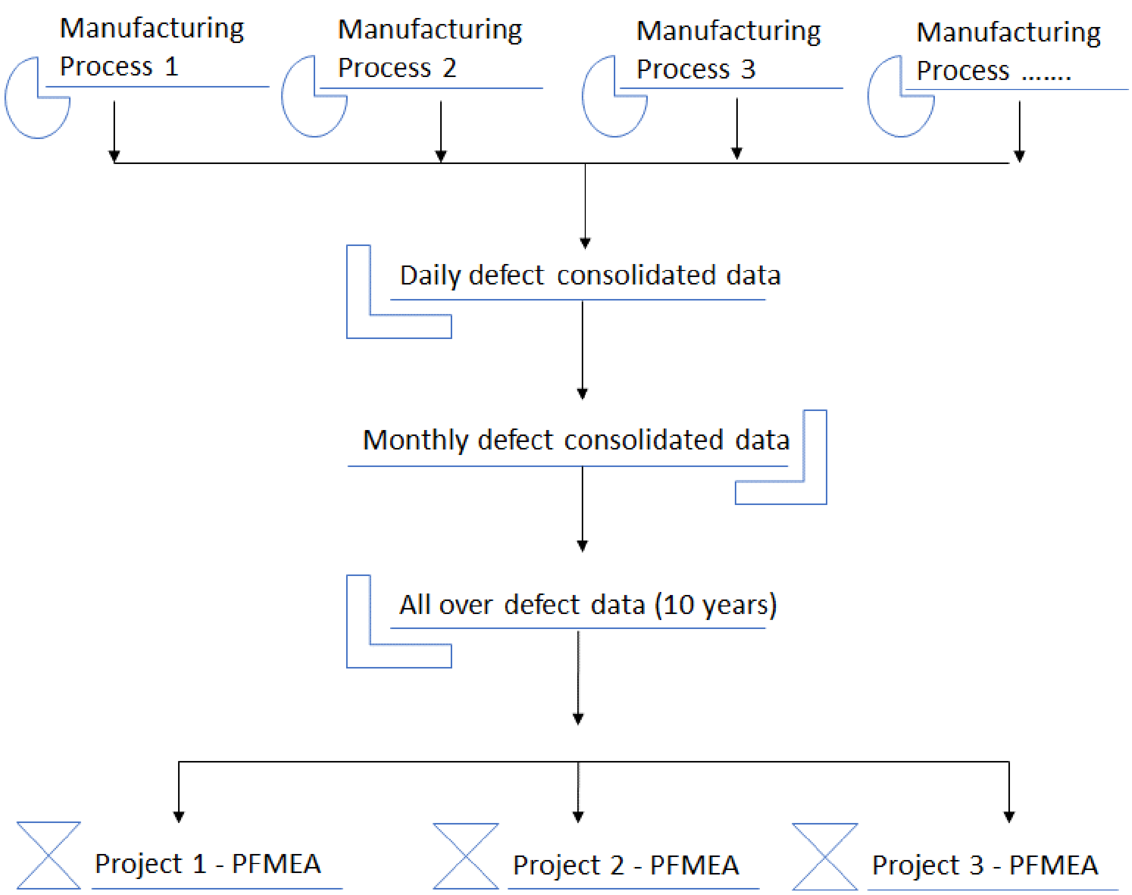


Figure 2 Defect Handling System

Human-based interpretation of data or knowledge transfer has variations with each individual. As it has observed, humans are not exemplary in statistics (Tversky & Kahneman, 1974). An adequate interpretation of functional requirements, specifications, scope, quality and time target is a challenge at the organisations structural level—results in decreased quality of deliverables (Fielding, 2006). In current practices, many organisations are dependent on manual data-transferring from PTDB to PFMEA. The process includes many steps at different levels of the organisation, and most organisations do not have a standard operating procedure for such kind of knowledge transfer; please refer to Figure 2 (designed by author).

2.3.3 Recording of data in spreadsheets

Figure 2 magnifies the defect data-handling process of a manufacturing organisation. The organisation has sixteen processes that operate in three shifts and generates four defects in each shift. Capable of producing one hundred and ninety-two defects in a day. Resulting, a total of five thousand and eighteen defects a month and over sixty thousand in a year. However, the data is later added into an overall defect data bank. As an example, the number of defects in 10 years would be more than six hundred thousand. Keeping in mind, all these steps of data handling are done in spreadsheets by many organisations. In this process, only critical and major defects will be considered for RCA, as mentioned in Figure 1. Nonetheless, each root cause analysis creates a data pack, consist of variables explained in chapter 2.2.

The final data stored in the data bank is known as the past trouble data-base (PTDB). Above all, to create a PFMEA, data handling is done manually. Thus, it needs spreadsheets based PTDB sorting in search of feasible data, which is inefficient and time-consuming. The process explained in Figure 2 has countless snags. Searching of data in a spreadsheet-based program and transfer it to a different software for PFMEA. This type of data handling, data processing raises alarming alerts of inefficiency, vulnerability, data legitimacy, data loss, and data tampering. Certain properties affect the interpretation of data and knowledge, which leads to systematic biases. Systematic errors were made in the recording of events by historiance, and presumed big problems have big causes (Einhorn & Hogarth, 1986; Slovic, Fischhoff, & Lichtenstein, 1977; Starbuck & Milliken, 1988). That makes data a high significant asset for the organisation. If the data is not handled in a defined and secured form, its interpretation will be made wrongly.

2.3.4 Recording of knowledge

Organisations generate documents, records, laws, and standard operating procedures as interpretations of past projects' lessons; in organisations physical and social structure; in standards of best practices; in the culture of the organisation lessons of development; and unanimous perceptions of, the right way of doing things around here. Perhaps, within the organisation itself, it is not clear the defined process to record, learn, convey and retrieve knowledge (Levitt & March, 1988). Acknowledge a potential situation of knowledge is the first step; later comes its recording. Furthermore, if the procedure to record knowledge is not standardised, it may be lost, tempered, wrongly interpreted, misused or shared with competitors in case of classified information.

Knowledge is a high valued input to create a new process, so it does not repeat past failure situations. To create a PFMEA, potential and past trouble data is necessary. In practice, new projects are often missing with qualitative and quantitative defect data. As a result, an ineffective PFMEA later, with poor process controls (Schein, Popescul, Ungar, & Pennock, 2002). Most of the organisations are capturing the daily defect data, root cause analysis (RCA), past trouble data-base (PTDB) and process failure mode effective analysis (PFMEA) in spreadsheets and a study showed 90% of them has Microsoft-Excel installed in them (Bradley & McDaid, 2009). Spreadsheets or Microsoft excel has a history of errors, as discussed in chapter 2.3. These types of errors can manipulate an organisational learning culture. However, when it comes to PFMEA, the traditional process to design PFMEA has limitations in knowledge capturing, retrieving and reusing (Teoh & Case, 2004).

2.4 Spreadsheets (Excel) causing disruptiveness

A process with problems in its operation and performance due to multiple causes has disruptiveness; the root-cause could be the reason for the process's disruptive nature (Merriam-Webster, 2021a). The history of events that happened in the industry reflects the incompetency of spreadsheets. This chapter's data has scientific significance for this study and is gathered from around the world news. Due to spreadsheets errors, the organisations faced innumerable losses such as; loss of reputations, penalties/ fines, budgeting errors, data leakage, misinterpretation of scientific data, life-threatening hazards (Covid-19 patients data lost), considerable financial losses and bankruptcy.

	# of Deals per Advisor			
Financial Advisor	2016 Rank	2015 Rank	# of Deals	Change in # of Deals
KPMG	1	2	172	-62 ▼
Rothschild	2	5	145	12 ▲
PricewaterhouseCoopers	3	1	123	-132 ▼
Lazard	4	7*	100	-7 ▼
JP Morgan	5	15	97	24 ▲
Houlihan Lokey	6	11	87	-13 ▼
Deloitte	7	4	85	-61 ▼
Mizuho Financial Group	8	13	80	0 -
Ernst & Young LLP	9	3	79	-101 ▼
Morgan Stanley	10	7*	69	-38 ▼

	# of Deals per Advisor			
Financial Advisor	2018 Rank	2017 Rank	# of Deals	Change in # of Deals
KPMG	1	1	507	-34 ▼
PricewaterhouseCoopers	2	2	428	32 ▲
Deloitte	3	6	381	81 ▲
Rothschild & Co	4	3	324	-31 ▼
Ernst & Young LLP	5	5	298	-20 ▼
Houlihan Lokey	6	8	273	17 ▲
BDO	7	7	252	-6 ▼
Sumitomo Mitsui Finl Grp Inc	8	13	223	31 ▲
Goldman Sachs & Co	9	11	211	-8 ▼
Lazard	10	10	206	-20 ▼

	# of Deals per Advisor			
Financial Advisor	2017 Rank	2016 Rank	# of Deals	Change in # of Deals
KPMG	1	1	481	-42 ▼
PricewaterhouseCoopers	2	2	350	-74 ▼
Rothschild & Co	3	3	339	5 ▲
Ernst & Young LLP	4	4	273	-24 ▼
Deloitte	5	5	243	-14 ▼
BDO	6	6	238	-13 ▼
Goldman Sachs & Co	7	12*	215	43 ▲
Industrial & Comm Bank China	8	12*	213	41 ▲
Lazard	9	8	206	9 ▲
Houlihan Lokey	10	7	199	-40 ▼

Year	Ranking
2015	7
2016	4-8 ⇩
2017	9-10 ⇩
2018	10

Figure 3 Lazard Ltd, M&A Rankings (Balogh & Reuters, 2016; Reuters & Zvulun, 2018; Zvulun & Reuters, 2017)

2.4.1 Case 1: Calculation error

Risk: Lost Reputation

One of the world's most prominent financial institutions, Lazard Ltd, from the year 2016, financial advisor for SolarCity Corporation, had a 2.6 billion U.S. dollar sale to Tesla Motors and due to a computational calculation error in the spreadsheet, the bank had faced world's embarrassment. The mistake was caught during a board meeting by Elon Musk, the co-founder of SolarCity. Lazard wrongly calculated the equity of SolarCity by doublecounting some of the company's projected indebtedness. None of the organisation spoke anything about the event. However, it became a piece of big global news and the aftereffects caused Lazard to drop by two positions in Thomson Reuters Americas M&A league – World Ranking (figure 3) (Baker, L. B., 2016; Balogh & Reuters, 2016; Reuters & Zvulun, 2018; Zvulun & Reuters, 2017).

2.4.2 Case 2: Data Leakage

Risk: Financial and Data loss

A known error in the spreadsheet is hidden data, causing organisations embarrassment, financial losses, and penalty in this case. In the year 2014, Blackpool Teaching Hospitals NHS Foundation Trust, in the U.K., has simultaneously published confidential and personal data of 6,574 workers on an open portal with their annual equality and diversity metrics. The data was in the spreadsheets hiddle format and can be accessed with a double click on the tab. It consists of details like pay scale, national insurance number, disabled status, ethnicity, religious belief, and sexual orientation. Lancashire hospital trust was fined 185,000 Euro (BBC, 2016).

2.4.3 Case 3: Misinterpretation of scientific data

Risk: Decision Making

On a default setting, Microsoft Excel programs auto-converts gene symbols as dates or numbers. Gene symbol is a format used to standardise gene nomenclature commonly used in the medical field; for example, NARROW LEAF 1 is NAL1. MatchMiner and GoMiner two programs were under simulation in 2003, when the researchers found the issue of some gene symbols were modified into dates or numbers by the excel program; for example, “*DEC1 [Deleted in Esophageal Cancer 1] was being converted to '1-DEC.'*“ (Zeeberg et al., 2004) An empirical study conducted in 2016 on eighteen published journals between 2005 to 2015 cross-checked 35,175 Excel files containing 7,467 gene list for 3,597 published papers. The error was reported in 987, 16% of gene articles and 704, 3% of total files; please refer to figure 4 (Appendix – 3) (Zeeberg et al., 2004).

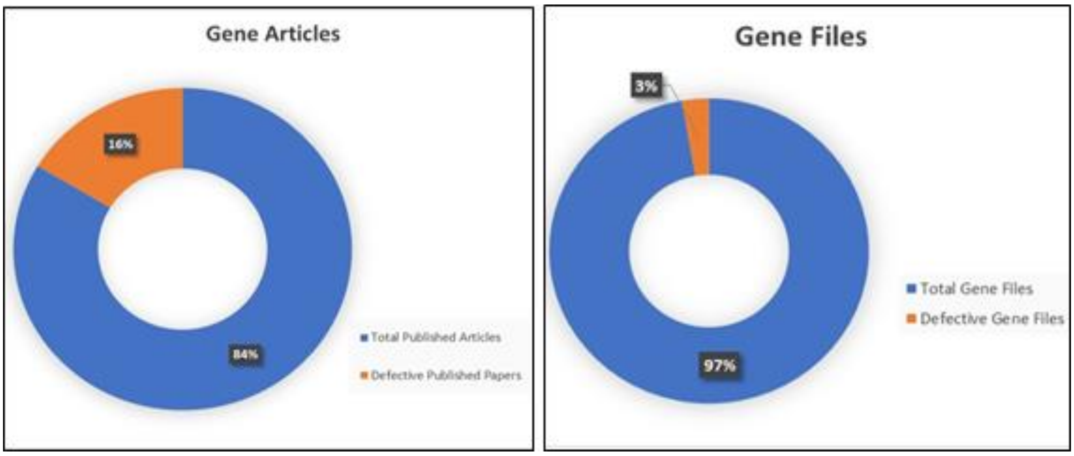


Figure 4 Error Data in Gene Files (Ziemann, Eren, & El-Osta, 2016)

2.4.4 Case 4: Covid-19 patients data loss

Risk: Life-Threatening

In the current situation, Covid-19 is a hot topic; all measures are implemented to prevent its spread. However, in some cases, due to incompetent methods, it becomes challenging. A similar situation happened in England when Public Health England (PHE), responsible for gathering the test data from private parties (hospitals) to create a centralised data-base. However, PHE developers choose Microsoft Excels older version XLS file format that was incapable of extensive data handling—resulting in 65,000 rows of data rather than a million rows. As per the BBC News report; data from gov.uk, 50,786 tests between 25th September to 2nd October were underreported by 15,841 cases due to software incapability. This mistake leads thousands of people unaware of their exposure to Covid-19, creating a life-threatening situation (Public health england.; Kelion, 2020).

2.5 Learning from others experience

Many of us belives organisations do not share their data to protect confidentiality. However, that is not true; organisations, even industries, learn from other industries experiences. A global and digital environment lets organisations share their industry experiences through technologies sharing, procedures, codes, routines (Argote, Ingram, Levine, & Moreland, 2000; Dutton, Thomas, & Butler, 1984). Experience sharing is becoming more often to share knowledge and create a learning culture. It has high significance due to its advantages in cost-saving, increased quality, decreasing hazardousness and other opportunities. Similarly, the experience from past defects is of high importance for new projects. Perhaps, a slow-performing software such as spreadsheets can affect an organisations competitiveness. A knowledge process starting from defect till PFMEA is shown in Figure 5 ((designed by author).

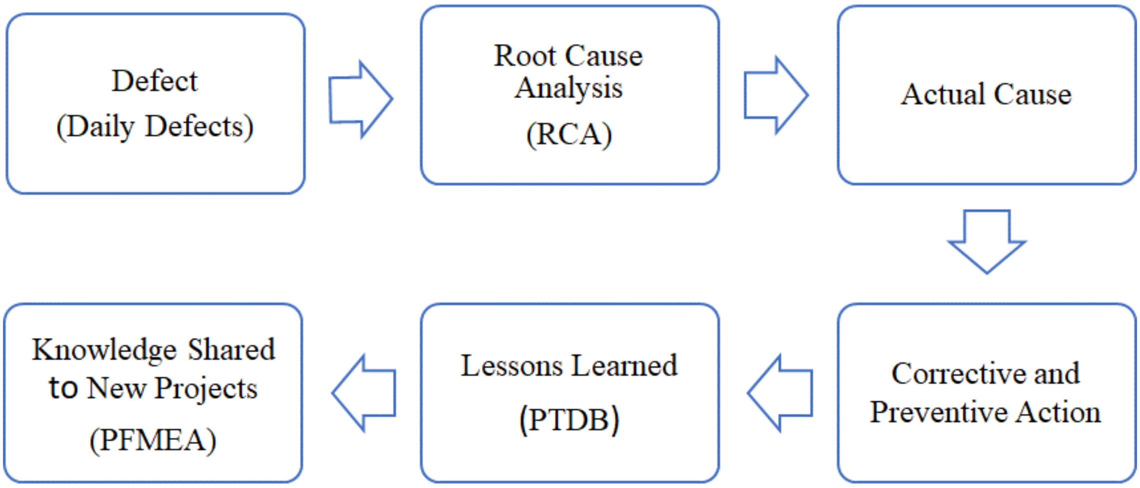


Figure 5 Learning from Defects

Learning from experience does not only brings knowledge. The knowledge must be on time; a delay in knowledge sharing or delay in retrieving the information will result in a lost opportunity. For instance, the information to design PFMEA is not available due to the high extraction time; searching and sorting a large amount of data; information in computer system got corrupt; data file lost and the list goes on: will not be useful for effective process improvement. A PFMEA must be completed before the start of production. A recent example is a Covid-19 situation that spread through Wuhan, China. Many news articles support the theory of Corona Virus spread due to lack and late information shared by China and later by the World Health Organisation (WHO), which lead to the spread of the virus in other countries (CBA, 2020; Diplomat, ; News, 2020). This lack of information or delayed information resulted in the outflow of the Corona Virus. Thus, on-time information is of high significance, or it will be of no use.

Learning from others experience is a vital piece of knowledge. Their defect situation could be a potential failure situation for a new similar process. The airline industry is a perfect example to understand, learning from others experiences. In 1952 a de Havilland Comet aircraft broke into pieces. Also, in 1953 and 1954, until the design engineers learned about structural fatigue. Thus, a structural failure was avoided due to the same cause in new aircrafts. British-owned airlines BOAC experienced the disaster but due to knowledge sharing within the industry. Other airliners effectively learned and implemented the design change (Baker, S., 2019).

In a similar situation, Toyota was found guilty in the cause of a fatal car accident in 2009, causing four family members' deaths in the United States. Toyota soon changed the floormats design and material which was the cause of the accident (BBC, 2010). Hence, every disaster in history has brought experience. An effective RCA of the disaster will bring up the cause or causes of defects. Later, adequate controls on the cause can prevent defect occurrence or will control the outflow. This process will bring leanings for other projects, organisations and industries.

2.6 Challenges in PFMEA

PFMEA is a process improvement and risk analysis tool capable of capturing potential failure situations and possible solutions to its control. PFMEA has many prerequisites explained in chapter 2.1. The study will analyse one of the prerequisites: the Past Trouble Data-Base, commonly known as PTDB and its challenges. A PTDB is a bank of big data and sorting such data bank for feasible information is challenging. Having the ability to understand, sort, analyse and interpret the data for decision making is essential (Labrinidis & Jagadish, 2012; Levitt & March, 1988). However, a traditional spreadsheet-based data bank cannot deliver such efficiency (Hermans et al., 2013; O'Beirne, 2008; Panko, 1998; Panko, 2006; Powell et al., 2009).

A PFMEA could face multiple issues at a time. These issues or challenges could lower the deliverables of a PFMEA. Studying AIAG - FMEA 4th Edition and past research papers, some of the major challenges a PFMEA establishment can face are; less time, absence of a cross-functional team member, insufficient defect data, knowledge and skill set of team members, low data quality, clerical mistakes, data tempering and analytical errors due to spreadsheets (Breiing & Kunz, 2002; Cook, 2020; Feili et al., 2013; Hekmatpanah et al., 2011; O'Beirne, 2008; Panko, 2006; Powell et al., 2009; Silva et al., 2014; US, 2002). A traditional way of data handling, analysis and storage through spreadsheets is also a major drawback.

2.6.1 Decision-making under time-constrained

Time is a measuring scale that can influence decision making, and a decision under a shorter time limit situation can affect the decision's quality. However, in the real world situation, decisions are finalised under some form of time constrain, starting from deploying brakes in a vehicle to the landing of an aircraft or making a decision to lock down a city to restrict the spread of coronavirus. Does the project managers make decisions in less time than what is needed?. Does it influence the quality of the decision (Mikulak, McDermott, & Beauregard, 2017)? Past studies suggested that the decision-making process must be simple and decision-makers should change the decision strategy under a time-constrained situation (Krisher, 1994; Smith, Mitchell, & Beach, 1982; Svenson & Benson, 1991; Svenson, 1996; Wright, 1974).

PFMEA also needs to design under a defined time limit before the production stage, explained in AIAG - FMEA 4th edition. This time limit serves the primary function of the PFMEA to control the nonconforming situation. Hence, late PFMEA compliance will not be able to implement adequate controls during production. It is a challenging situation for an organisation to complete a PFMEA before production. The use of a spreadsheet program adds on more delays due to manual data searching and sorting. A digital solution is needed to speed up things (Wang, Li, Chen, He, & Li, 2014).

2.6.2 Absence of a cross-functional team member

Organisations witness conflicts in teams where team members have not worked together before. It could be due to biases or differences in individuals knowledge about the work. Decision making becomes problematic, and knowledge conflicts can arise with a substitute team member in case of a missing member from the cross-functional team of PFMEA. A multi-disciplinary team is the first step towards a PFMEA design. The leader of the PFMEA picks the team based on their experience, knowledge in PFMEA design and knowledge about the project. Hence a missing or changed team member can bring a variation in the development thought process of PFMEA (Automotive Industry Action Group, (AIAG), 2008).

Each department of a manufacturing organisation creates daily defect data. It could be from production, quality control, maintenance, marketing, validation, testing or calibration. The daily defect data is a daily entry of data that involves all nonconformities on that day, and It could also be shift specific. Mostly of a member from each of the departments mentioned above participates in PFMEA design. A missing member could be due to resignation from the job resulting in missing daily defect data to PTDB. Hence, a change in cross-functional team could cause loss of data or knowledge conflict in PFMEA design (Majchrzak, More, & Faraj, 2012).

2.6.3 Insufficient past defect data for decision making

Recently in the past few years, data become the centre point of many industries and accused of influencing decision making. Industries, academia, and governments are trying to understand the repercussions of data and its influence on decision-making. Similarly, insufficient data can lead to wrong interpretation or decision-making (Jin, Wah, Cheng, & Wang, 2015). However, the probability of uncertainty always exists in decision making, which is inevitable in PFMEA design while gathering, interpreting big data. In industries, the processes are complex and sometimes are not easy to understand; such processes require years of high precision experience and knowledge; for example, Airbag manufacturing is a highly critical process with the highest hazardousness ratting of ten on the severity rating from AIAG - FMEA 4th Edition. Thus, the decision making for such a process is not easy; please refer to appendix 2.

Insufficient data for a complicated process creates possibilities of error resulting from it can lead to human fatality. However, a lack of values, codes and data could lead to incomplete information and cause poor process controls. A PTDB has high significance in decision-making when designing a new PFMEA for a similar or cross-functional knowledge transfer. It reflects past behaviour, patterns, and frequencies; hence, data is essential in decision-making after it is analysed. In current practice, many organisations are dependent on the spreadsheets data-base, which are not secure to store or transfer data; thus, it could lead to data loss explained in chapter 2.3.

2.6.4 Knowledge retrieval and retention

Learning organisation culture is feasible when the organisation's employees create, store, and transfer knowledge for future projects. Hence, in this process, employees are the essential source of information and knowledge creator to competing in a competitive environment, making each organisation unique in its industry segment (Templer & Cawsey, 1999). It is challenging to employ and retain intellectual capital; a highly-skilled cadre is in demand since industrialisation. An educated, skilful individual is an asset to human resource and can innovate, develop, improve, amend and restore technology and knowledge for an organisation. Employees' knowledge mostly comes through their involvement in the process; working and following standard operating procedures brings out process variations. However, knowledge is nothing but studying these variations and keeping adequate controls to achieve the target (Martins & Meyer, 2012).

Knowledge is an intangible asset of an organisation; hence, to make it worthy, it needs to be transferred into a tangible source of knowledge such as reports, documents, presentations, history data and other forms or organisation data documentation. A company does not want an employee to work in an organisation for years and leave it without making a newcomer learn from it (Nonaka & Takeuchi, 2007). Perhaps, learning must be documented for it to be a part of organisational memory; nonetheless, recording history will not serve its purpose until it can be retrieved on time for future projects (Johnson, M. K. & Hasher, 1987). Even within a consistent practice, knowledge gathering and storage for an organisational memory is less likely to be retrieved at a particular time or a particular location. Likewise, Linda Argote (1987) study shows the variation of data retention in some parts of the organisations. The availability of such data or knowledge is associated due to its usage of routine. Thus, a knowledge or data-base that is not used frequently can cause data retention problems (Argote, Beckman, & Epple, 1990). An organisation with an intelligent approach towards organisational learning will focus on knowledge gathering; nonetheless, the organisation will also ensure the path of knowledge retrieval and retention (Johnson, H. T. & Kaplan, 1987).

Ensuring the knowledge transfer without error and biases is hard to achieve when the knowledge is transferred manually or without any digital source. However, it is desired "*that explicit knowledge is translated back into tacit knowledge that will then go on to yield yet another innovative solution*." (Nonaka & Takeuchi, 2007) Hence, consistent quality is maintained with less human intervention in the knowledge transfer process. Not only the spreadsheets have errors, but they are not designed to consolidate required data and transfer it to a different form of software.

2.6.5 Knowledge and low skill set of team member

An organisation has professional teams for projects, as per individual skillsets and core competency: job responsibilities and team are defined (Delaney & Huselid, 1996). These teams are the building blocks of the organisation's performance, and perhaps, each individual has a specific role to play to contribute to their team accomplishing the project's set target (Wilson, Goodman, & Cronin, 2007). On the other hand, an individual's low skill can affect his daily work and the team's performance, thus hampering the project's performance. However, AIAG - FMEA 4th Edition, in chapter "Impact on Organisation and Management" asks about individuals' relevant expertise for being a PFMEA team member (Automotive Industry Action Group, (AIAG), 2008). An individual can also cause a team's effectiveness and efficiency by transferring poor knowledge and skill to other team members through team meetings, hence causing teams collective learning process (Ellis et al., 2003).

FMEA is a team-based job; perhaps an individual brings out significant information to its collective approach. An individual does an RCA and thus, its competency in the analysis is mandatory; biased information generated from RCA can lead to wrong data collection on PTDB. Similarly, individuals represent their functional departments, expressing unique knowledge about the department's process; thus, no one else can validate the information transmitted in the PFMEA meeting and hence will be taken into consideration as input for PFMEA design. Though selecting an erudite team member is crucial for an effective PFMEA generation.

2.7 Gap Analysis

Organisations learn from their history made up of failures, and success is a perspective of organisational change; perhaps it also exhibits corporate intelligence. However, studies by case observations and theoretical analysis support the idea that self-assessment learning improves organisations' performance. Since the research focuses on the process of learning and knowledge transfer, it supports the argument in chapter 2.2, 2.3 and 2.4; furthermore, it creates a foundation for organisational learning culture and opens opportunities to improve organisational intelligence (Duncan, 1979; Starbuck & Dutton, 1974). As it is known, however, organisational learning, learning from experience, creating ways to capture, store and reuse the knowledge are not enough to achieve a continual improvement stage until a possibility still exists in which data or knowledge cannot be used desirably due to its unavailability at the time of use. Hence, a need for a better digital platform of data handling is required to fill up the gap of unsecured data; nonetheless, it should also transmit the data to the next stage of use, eliminating the possibility of data loss.

Since the above chapters explained the process of data handling from a newborn defect to RCA, to PTDB and later an effective use of the knowledge for PFMEA; however it also highlighted the possibilities of errors or problems with spreadsheets use. Thus, it diagnosed a gap, hence also creates an opportunity for process improvement in knowledge capturing and retrieval for PFMEA. Since the spreadsheet program does not deliver the desired data handling, storage, and retrieval system, it can not transfer knowledge digitally due to its incompetency with other software. An upgrade in technology is needed with features to understand the need for the process; for instance, to achieve the five stages of process measurement such as; quality, time, efficiency, utilisation rate and effectiveness, technology should be capable of transmitting information to its following process (Nurminen, 2007; Tuomi, V., 2008). A technology change has always brought new ways to solve problems, increase productivity and efficiency (Grübler, 2003).

2.8 Overview of digitalisation over spreadsheets

A practice with potential, possible and evident errors, should be replaced by a better version. Since the first time, Robert Wachal (1971) talked about society's digitalisation and how employees cannot change their practices (Wachal, 1971). Digitalisation has evolved into each segment of life, including industrial and social life; however, a consultancy I-SCOOP in 2016 pen down a to-the-point digitisation definition:

> *"Digitalisation means the use of digital technologies and of data (digitised and natively digital) in order to create revenue, improve business, replace/transform business processes (not simply digitising them) and create an environment for digital business, whereby digital information is at the core."* (i-SCOOP, 2021; Schallmo & Williams, 2018)

Why digitalisation is needed and how does it helps in achieving process improvement? Well, digitalisation is not just a piece of technology and its implementation can bring a better performing process; perhaps digitalisation effective adoption can deliver high-end improved manufacturing systems with flexibility and sustainability. However, its consistency can help organisations in cost-saving (Demartini, Evans, & Tonelli, 2019). The big question is which method or technology to choose for a specific process that brings continual process improvement and saves organisations cost. Undoubtedly, high-end artificial intelligence, automation and robotics-based solutions are available. Why are many organisations still struggling to develop effective organisational, an end-to-end learning system? The answer is that many of these high-end technologies cost high in the process to adopt, execute and maintain. Many organisations, such as small and medium-sized enterprise (SME), see quality as a non-constructive process; and its output is not as significant as manufacturing processes. Though, it restricts the organisation to invest in costly technologies to improve the process.

PFMEA is a complex process requiring a cross-functional team, time, past trouble data, and a few more resources; thus, some organisations do not perform such activities and copy-paste the past data on to new PFMEA. Hence, it does not achieve its deliverables. Many organisations miss a vital point; a lower process rejection saves rework and scrap costs. On the other hand, it is to be understood that a required solution should be cost-effective and achieve process improvement capabilities and overcome the data handling challenges in spreadsheets. A need for a new framework to deliver desired results for a specific process has been witnessed.

Sustainability can be achieved by consistency in performance, supported by less or no variation in process practices. Thus, to attain sustainability, preventive error-proofing is required to eliminate process variation. The spreadsheet-based PTDB has variations and fluctuates the quality and deliverables of PFMEA. However, an intelligent digital solution is needed to fill up the gap of inconsistency caused by traditional spreadsheet-based PTDB. The conceptual framework in chapter 5 delivers preventive error-proofing for PFMEA design and the actual production process that is the desired PFMEA deliverable. Furthermore, with the implementation of this framework, a consistent process function will exist. Process digitalisation has the capability to customise an effective solution for the above spreadsheets related issues explained in chapter 2.3, 2.4, 2.5 and 2.6.

2.8.1 Digitalisation a need for transformation

Staying competitive in the twenty-first century is a great challenge for businesses in both the public and private sectors, given the constantly evolving business climate, the effects of globalisation, and digitalisation. The use of various information technology techniques and practices has become a major influence since the information society or knowledge-based society came to the fore. Although the complexity of the relationship between technology and sustainable development, there is no doubt that knowledge is a critical tool for achieving sustainability. United Nations in 2015 General Assembly explained the importance of knowledge and digitalisation to achieve sustainability. The report talks about the future implications of digitalisation in different social and commercial segments with Information and Communication Technology (ICT); Please refer to Figure 6 (Accenture, 2017; 赵建文, 2015).

"*Success is the sum of small efforts, repeated day in and day out*." (Collier, 2009). Similarly, countries like Finland took the initiative by implementing small but good digitalisation practices towards a sustainable goal. As known to us, Finland brought us the technology of communication through NOKIA phones. Over 19 years, Finnish inventors obtained more than 651 patents per one million people, outperforming their counterparts in South Korea (525), Sweden (524), Japan (405) and the United States (259) in the fourth industrial revolution (Teivainen, 2020). Many organisations recognise that digitalisation is synonymous with technology. Whereas, Kristiina Söderholm, Head of Nuclear Research and Development at Fortum, understands digitalisation as:

> *"Adopting the right tools for business development, innovation and cultural evolution. We want to bring the ownership of initiatives to the business units."* (Horo, 2017)

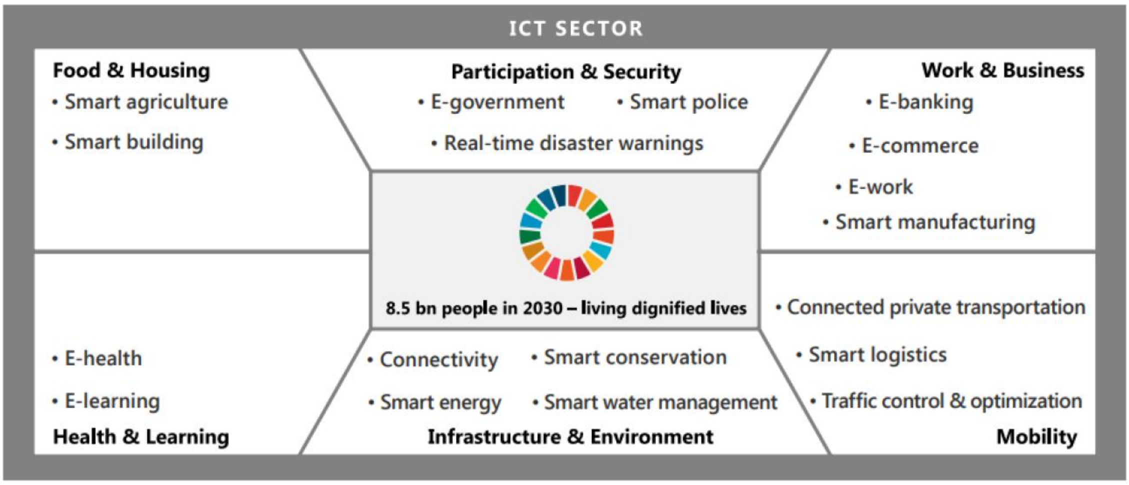


Figure 6 Overview of Digitalization on Industries (Accenture, 2017)

As per Microsoft and PWC, Finland recognises and implement the digitalisation strategy in almost every organisation, big or small. As per their report in 2017, 19 out of 22 organisations made digitalisation their top priority. This list includes five public and seventeen private organisations, including Finnair and Wärtsilä. Verohallinto, The Finnish Tax Administration (FTA) celebrates more than twenty years of digitalisation experience and 80% of their operations have automation (Horo, 2017). Hence, this explains the competitiveness gained by effective digitalisation in process improvements. A similar understanding is required to develop the PFMEA process and its prerequisite PTDB. A significant data source should not be operated manually.

2.9 Challenges towards digitalisation

What is digitalisation? Does digital transformation have ascendancy in data analytics, the internet of things, cloud computing and big data banks over traditional or manual operations? Is artificial intelligence and machine learning are the only competitive solution for the fourth industrial revolution? Can industry-wide organisations pick high-end software as part of their business improvement plan? Does cost hurdles organisations in adapting process improvement technologies? As per the 2020 ERP Software Path report, the average budget per user for ERP operations in organisations cost 9000 USD (figure

7). In contrast, the cost of programs like Microsoft Excel is significantly less; however, it has multiple issues, as discussed in Chapter 2.3, and do not have effectiveness.

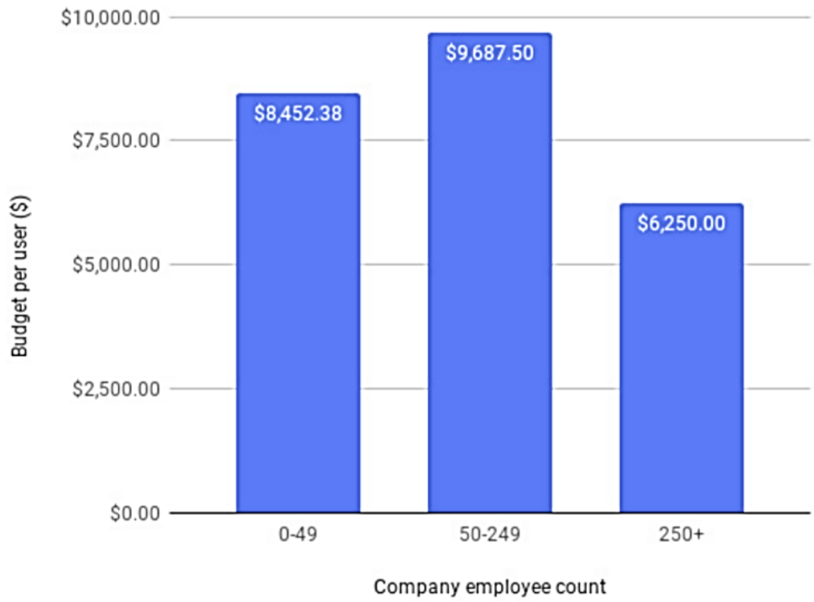


Figure 7 Budget Per User ($) by Company Size (Software Path, 2020)

A small and medium-sized enterprise (SME) cannot afford high-cost third-party software programs. The past studies explain the high cost of implementation; maintenance is one significant factor in the rejection of ERP type software by SME. However, the empirical data from past studies also present the resource planning softwares have many other issues, such as alignment with other software programs, alignment with operational processes, customised training and hidden charges; this creates constraints between SME practices and software solutions. Data handling and planning software are resource-intensive, demands a dedicated workforce, intensive customised training and management commitments. The challenges faced by SMEs are shown in figure 8 (Booth et al., 2000; Laukkanen et al., 2007; Venkatraman & Fahd, 2016)

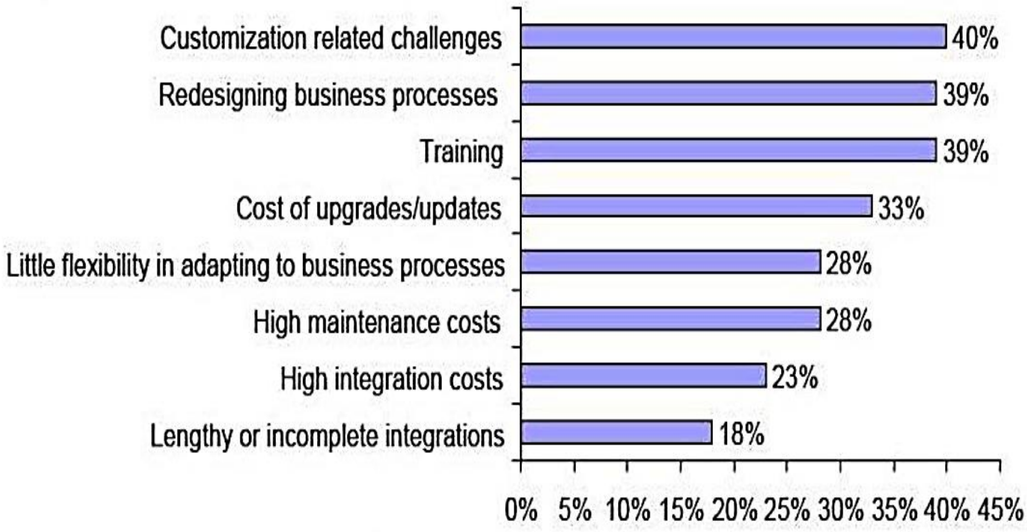


Figure 8 Challenges faced in implementing and maintaining ERP (Venkatraman & Fahd, 2016)

3 Methodology

3.1 Research process and research design

The research process and design are the core of a research project; its primary function is to create a systematic approach to data collection through reasonable means, analysis, and present results statistically. The study should not be influenced; moreover, the data collection and the interpretation of the results should be unbiased. The researcher has used a qualitative method approach for this study, the data collection was done through secondary and primary research methods. The secondary study has collected scientific data from past researches, case studies, and industry events. In addition, the primary research involves semi-structured interviews and online surveys of the professional through video calls (Zoom), audio calls (Whatsapp) and online forms to deeply comprehend the concepts. Qualitative methodology is a broad term that narrates and explains respondents behaviour, interaction, experience and social context (Pathak, Jena, & Kalra, 2013; Strauss & Corbin, 1990)

This study aims to understand the issues with the traditional spreadsheet-based PTDB and whether it needs a replacement with a custom-designed digital solution by conducting a qualitative case study research strategy. As per the English dictionaries, the term “explore” defines investigation, discovery, study, or analysis(Merriam-Webster, 2021b). The exploratory study requires a two-dimensional ratio, flexibility in search of data and open-mindedness of where to look for data. Hence, the related linked study becomes evident in the research process to form a commutative grounded theory (Stebbins, 2001). In this study, the researcher has used a deductive research approach to view “spreadsheets problematic behaviour as a possible cause of issue for PTDB”. However, exploration and inductive reasoning are important in science in part because deductive logic alone can never uncover new ideas and observations (Flew, 1984; Stebbins, 2001).

3.2 Qualitative research methods

A qualitative research study is designed to capture professionals' voice and document their experience, beliefs, and opinions into a tangible source of knowledge. Qualitative research is an umbrella of broad concept and has a variety of study designs such as; explanatory, exploratory, descriptive, multiple-case study, intrinsic, instrumental and collective (Baxter & Jack, 2008). Hence, the application of the research plan depends on the research problem and research questions. Similarly, there are three distinct ways of data collection in quantitative studies; interview-based, textual or document analysis and observational studies (Pathak et al., 2013). Out of which, interviews-based data collection is widely practised (Robinson, 2014). As the word suggests, Interview-based data collection is done by asking questions and getting the interviewees' response, which could then be collected by recording (audio or video) or making notes; however, the recording practice is significantly high due to its efficiency (Britten, 1995).

Keeping in mind the aspects of the exploratory research, the author has studied past linked studies of related topics such as performance of spreadsheets based data-base, problems in usage or spreadsheets, data security, vulnerability, data extraction and others; the exploration of study lead the author towards industrial incidents caused due to poor performance of spreadsheets based data-base. However, during the exploratory research, the pursued information was collected from legitimate sources such as; scientific journals and news.

3.3 Data collection methods and participants

The qualitative data collection is done through online semi-structured interviews, online surveys and telephonic interviews. Respondents were industry professionals responsible for designing and implementing PFMEA concept at the organisational levels. The online semi-structured interviews allow the researcher and the interviewee with a range of flexibility and a safe distance in Covid-19 situation, saves time and cost. On the other hand, some respondents did not give their consent for the recorded interview due to company policy and confidentiality agreement. We learned few of our respondent were not even allowed to take smartphones or any personal electric device on company premises due to classified work. However, other possible challenges like internet speed and network were taken care of in advance, with a backup source.

As we know from the literature study, PFMEA is used in almost every industry segment for risk analysis or as a continual improvement tool, including manufacturing, service, consulting, construction, food, oil, hospitals and the list goes on. The data collection method was designed to get response globally and from different industries, avoiding the biasness in results influenced by one or two industry types. However, not all professionals replied to the research interview on time. The chosen respondents has extensive knowledge of PFMEA methodology and have years of professional experiences. Before the interview process, respondents were asked to fill in consent and basic details form, including their designation, years of experience and organisations type, to ensure the respondents' credibility. A total of 5 experts were selected out of 8 responded to the research interview based on the relevant experience, knowledge of PFMEA and Industry type; however, more than 50 professionals were contacted through emails and LinkedIn.

By following an ethical process, permission for interview recording was taken beforehand. Some respondents did not agree with the recording. In this case, the respondents agreed to share no-recorded data with the academic evaluation team and for academic purposes only but without disclosing their involvement. The notion behind the selection of experienced professionals who had in-depth knowledge in PFMEA is because experienced professionals can provide meaningful input for the research topics such as existing challenges, existing technology, issues in the current process, the need for technology change and change implementation. However, an inexperienced or an employee with less experience do not have such critical knowledge. Each interview lasted nearly an hour;

however, the survey form was filled by respondents on their own. Two of the respondents made an audio call to the researcher during form fillup, which allowed the researcher to entertain their queries and explain the related requirements.

All participants are working in different industries practising unique products and processes, stands in a range of 7 to 26 years in experience and everyone has a significant role in PFMEA generation. Moreover, these individuals have a variety of knowledge and are well aware of the end-to-end PFMEA process. As discussed earlier, to serve the research aim, it was decided to capture different industries' voice to avoid biasness. One of Finland's most prominent organisations, dealing in marine power-diesel engines, became a respondent to this research and shared their best practices on PFMEA generation. Thus, having different organisations, industries, variety of experiences, members of various departments as samples respondents enriched the quality of the study and provided a comprehensive view on the data handling process of PTDB for PFMEA.

Some giant organisations' participation played a significant role in this study but are not limited to marine power-diesel engines, composite fabrics, space agencies, auto-electrical part manufacturers, and food processing. However, all these organisations have suppliers and clients, with whom they collaborate their work and allied processes to deliver results. Their links with SMEs and original equipment manufacturers (OEM) will include a grid of industry segment; hence, a future prediction for the process improvement can be leaned from their responses. The researcher also believes the diversity and versatile knowledge of respondents is beneficial to understand the challenges of traditional spreadsheet-based PTDB. Moreover, It will help the researcher design a digital, conceptual framework to overcome traditional PTDB challenges. Thus, respondents are a critical part of the research. Table 1 contains the details of the participants.

The exploratory study runs on the same idea avoiding the presence of biasness by focusing on different case studies from earlier researches. However, no specific studies were done on the past trouble data-base (PTDB) or the data handling process for PFMEA.

Thus, the investigation started with a search of keywords like challenges in spreadsheets, errors in spreadsheets, industrial events due to improper data handling process and more. These key terms were searched on scientific data portals, such as google scholar, science direct, google books, springer, researchgate, elsevier, IEEE, medspace and news sites. The exploratory study is performed with a wide-angle multiple-case study strategy that can pick the most relevant research data. The search with keywords, came up with a wide range of results from a variety of industries, presenting a diverse list of problems in spreadsheet-based data-bases. During the data collection, the most relevant cases were picked to highlight the data handling process gaps.

3.4 Data analysis technique

Once it is decided, the research question is best answered with the case study strategy, under which a multiple-case study and exploratory design will be applied. The results will be presented using content analysis for a multiple-exploratory-case study design. As discussed earlier, an exploratory approach is used in cases where no past studies were evident; however, linked studies can build a concrete argumentation (Stebbins, 2001; Yin, 2003). Furthermore, the strategy includes multiple industries from different countries, dealing in various products and processes to avoid a single industry or country's influence. Hence, it requires a multiple-case study design (Baxter & Jack, 2008; Eisenhardt, 1989; Yin, 1984)

Company	*Respondents Position*	*Industry Type*	*Respondents Experience*	*Country*	*Data Collection Method*
A	Supplier Development Engineer	Marine Power, Diesel Engines	26 years	Finland	Interview (recorder)
B	Director Global Manufacturing Engineering-Operations	Auto- Electrical Parts Manufacturing	27 years	Sweden	Survey form
C	Scientist-SC (Antenna Mechanical Designer)	Space Agency	18 years	India	Survey form and telephonic conversation
D	Product Scientist	Composite Textile	11 years	Australia	Interview
E	Assistant Manager - Quality Systems	Food processing	7 years	USA	Survey form and telephonic conversation

Table 1 Participant Details.

3.5 Reliability and validity

Achieving reliability and validity is always important in both qualitative and quantitative research. However, a criterion for reliability in the context of qualitative research differs as compared to quantitative studies (Stenbacka, 2001). The practice of reliability and validity is suggested in qualitative strategies (Golafshani, 2003). Accordingly, Healy & Perry, (2000) suggest reliability relates to the quality of the study, and quality is ensured by the relevancy of research terms to the research paradigm. The current study relies on literature review and primary research through qualitative interviews. To ensure reliability and validity of the current study, an extensive literature review was conducted to review major concepts related to FMEA and PFMEA published in peer review journals. The research objectives, research questions, and data collection methods were aligned to concisely acknowledge a wide-angle view of relevant data collected from; past research, industry incidents, global news, interviews, and surveys. To enhance congurence between the research question and component of the study, the research instrument was designed based on the literature review results. The research instrument is ensured based on central concepts derived through literature review. Moreover, to further ensure internal and external validity of the construct, the research instrument was reviewed by industry experts to increase the relevancy of the instrument in relation to FMEA and PFMEA. Based on the suggestion, minor changes were made to the initial research questionnaire to achieve clarity and common understanding of the questionnaire items.

Respondents of the study were selected through convenient sample due to time and resource limitations. A total of 50 respondents were invited for semi-structured interviews and eight experts agreed to participate. It was ensured all participants have at least five years of relevant experience in PFMEA and FMEA and working in a technical position. Moreover, participants belong to different industries to eliminate the possibility of a single point of view from a single type of industry. The sample population represents the application of PFMEA in the following industries in table 1. Furthermore, it also contains the voice of their linked stakeholders, such as clients and suppliers.

The collected data were analysed to evaluate the issues in the traditional process of PFMEA and its data handling process based on PTDB. Unanimous answers witnessed in interviews, such as; all the respondents use Microsoft Excel as their PTDB, spreadsheets are inefficient in data transferring, need for an improved framework and will welcome a custom-designed tool for PTDB and PFMEA. The responses were critical for the research and created a link between the reviewed literature study and collected data, building a strong sense of reliability and validity.

4 Results

There were two key questions in this research. First, what are the problems and errors related to traditional spreadsheet-based PTDB? Second, what are the advantages of a digital framework over the traditional PTDB? To answer it, a two-step method was adapted. The first step includes studying past researches focusing on the errors in spreadsheets such as calculation errors, data security, data vulnerability, wrong interpretation of data, challenges in PFMEA generation and other issues. The second step is through surveys and semi-structured interviews with industry professionals. However, to display the results effectively, the data is presented in tables and charts. The data presentation techniques were learned from past scientific research papers (Eisenhardt, 1989; Tuomi, Ville, 2012)

4.1 Chronicle assessment

A multiple-exploratory case study strategy is performed for data collection from past studies and global events, is illustrated in table 2. As discussed, this research has two primary objectives; thus, these are numbered in the result evaluation format for better understanding.

1. To evaluate the problems and errors related to traditional spreadsheet-based PTDB
2. To evaluate the advantages of a digital framework over the traditional PTDB

When we look at table 2, several issues related to spreadsheets usage is presented alongside their impacts. The data is collected through past research and industry news. It highlights the major incidents and problems held in the past few years due to spreadsheet errors (excel). Perhaps it put forward examples like Allfirst Bank, which had a total loss of US$691 million because of intentional data tampering. Similarly, TransAlta lost US$24 million this time due to an unintentional error, but again, exposed data was the cause of the problem.

Source	Issue	Impact	Data Collection Method	Research Question
(Powell et al., 2009) (Panko, 1998)	Error in spread-sheet	Decision Making	Journal Article	1
(Cook, 2020)	Error in spread-sheet	Financial loss	News Article	1
(O'Beirne, 2008) (US, 2002) (Panko, 2006)	Data Tempering	Decision Making	Journal Article Law	1
(Hermans et al., 2013)	Data security	Decision Making	Journal Article	1
(Baker, 2016) (Balogh & Reu-ters, 2016) (Zvulun & Reu-ters, 2017) (Reuters & Zvulun, 2018)	Calculation Error	Lost Reputation	News Article Yearly Reports: 2016, 2017, 2018	1
(BBC, 2016)	Data security	Personal Data Leak Reputation Lost Financial Penalty	News Article	1
(Zeeberg et al., 2004) (Ziemann et al., 2016)	Error in spread-sheet	Wrong Interpre-tation Decision Making	Journal Article	1
(Public health england.) (Kelion, 2020)	Software Incapa-bility	Life-Threatening	News Article	1

Table 2 Secondary Research Data.

The spreadsheets errors are not limited to financial losses or clerical issues. The evaluation of past studies concluded that the spreadsheet changed the medical code languages from gene names to dates and numbers by an error of 19.6%. The horror stories contain the increasing rate of these errors. Figure 9–a, shows the percentage of published papers with gene name errors in excel files, and 9–b, displays the increase of gene name error by years (Ziemann et al., 2016). Researcher R.R. Panko has been an expert in evaluating spreadsheets performances in the last few years, and his study demonstrates multiple types of errors in spreadsheets, excel in general (Panko, Raymond R. & Halverson, 1996) As the research support, financial losses are not the only type of losses. It has caused organisations embarrassment; for example, Lazard Ltd, a bank listed in the world's top ten rankings, faces mortification in its deal with SolarCity Corporation, a Tesla Motors company and felt in the world ranking by two stages.

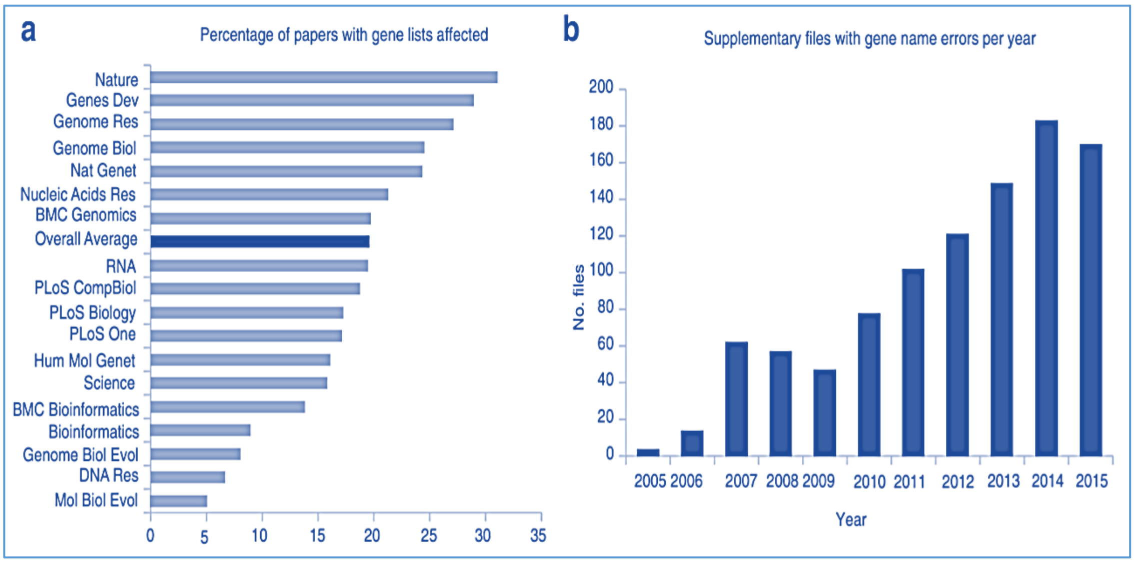


Figure 9 Errors in Gene Names (Ziemann et al., 2016)

Persistent concerns were encountered in spreadsheets. Incidents include; calculation errors, data beach, errors in spreadsheets formulas, data formatting and capability issues. Thus, the application is not efficient in handling high-value data. The data used in PTDB contains multiple variables and has significant value for a new product or process stage, which later design controls in the process. A piece of wrong or missing information can impact hazardous situation leading to substantial financial, reputational or human life losses. Perhaps, a better data handling framework is required for PFMEA.

4.2 Industry voice and facts

Qualitative semi-structured interviews and surveys were conducted to capture industries voice and requirements. Table 3, is a matrix presentation of interviewees responses. The data is gathered from five different organisations globally in different industrial product segments such as; Marine Power, Diesel Engines, Auto- Electrical Parts Manufacturing, Space Agency, Composite Textile and Food Processing. The sample population was chosen based on their diverse product, process, use of FMEA and experienced professionals. However, more than fifty organisations were approached for the research process and out of which eight responded. Three organisations were not included in the research process due to their unimpressive knowledge and compliance with PFMEA.

The organisations are named A to E in Table 3, similar to table 1. The X marks in Table 3 represents the respondent's answer in the survey form or during the semi-structured interviews. The questionnaire was designed with multiple choice and open-end questions; however, no choices were given to respondents and answers were recorded as an elaborated one during the interviews and on-call discussions. The research questions were designed to cover the objectives, stated as number 1 and 2 for research objective one and two.

Table 3 Interview Responses

Research Questions		Options	Organisation Reply					Research Question
			A	B	C	D	E	
1	Challenges in PFMEA	Time Consuming	X	X		X	X	1
		Insufficient Past Trouble Data	X	X		X	X	1
		Loss of Data (while knowledge transfer)	X			X	X	1
		Team Communication		X	X			1
		Team knowledge and skillset						1
2	Data Handling Technology for PTDB	Microsoft Excel	X	X	X	X	X	1
		Google Sheets						1
		Apple Numbers						1
		Quip						1
		EtherCalc						1
		Zoho Sheets						1
		Any Other	X		X			1
3	Issue with Spraedsheets	Vulnerable to Fraud					X	1
		Susceptible to trivial human errors		X	X	X	X	1
		Difficult to troubleshoot or test						1
		Obstructive to regulatory compliance			X			1
		Not designed for collaborative work	X				X	1
		Hard to consolidate	X			X	X	1

4	Isses in data transfering from PTDB to PFMEA	Unavailability of Data (data lost)	X			X	X	1
		Inefficent Practice (manual data transfer)	X	X	X	X	X	1
		Time Consuming	X					1
5	Is there a need to modify the data handling system for PFMEA	Yes	X	X	X	X	X	2
		No						2
		Maybe						2
6	Can a customised software for the PFMEA data handling process be better than a traditional spreadsheet	Yes	X	X	X	X	X	2
		No						2
		Maybe			X			2
7	How implementing the above software program can help an organisation	Improved Data Handling	X			X	X	2
		Time Saving	X	X	X		X	2
		Quality of PFMEA	X			X	X	2

PFMEA design-challenges, were where most of the organisation has trouble. To design a new PFMEA an organisation has to involve resources such as; a professional team, time and technology. Thus, the unavailability of these resources can sometimes create a problematic situation. Figure 10 presents the graphical view of the organisation's challenges during PFMEA generation, the y-axis represents the numbers of respondents and the x-axis is the types of challenges. The bar chat reports, time consumption, insufficient data, and data loss during data transfer are crucial issues during PFMEA generation.

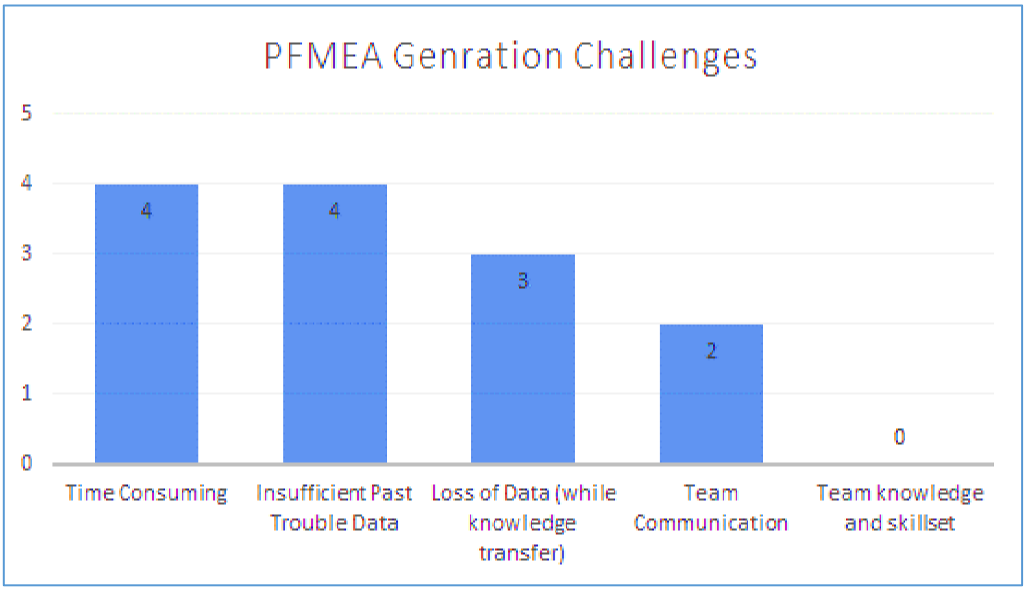


Figure 10 All major challenges that occur during the design of PFMEA

As per an earlier literature review, 90% of the organisations use Microsoft Excel as their main spreadsheet program (Bradley & McDaid, 2009). The result in this study is quite the same. However, two of the organisations has other programs for PTDB. In which the space agency has a self-designed a digital platform for defect data handling. Whereas, the marine power, diesel engines organisation has switched from excel to ERP and Power-BI, an ERP section program, four years from now. This was a significant input for this research as it explains the industrial need and demand for a better program. During the recorded interview, the respondents expressed unfaithful and inefficient performance of excel software. Quoting the respondents answer, for instance, *"It is tricky and not so easy to find the right data when using excel due to manual search tasks."*

Issues and errors in spreadsheets are the primary cause of the problem, picked by respondents during the interview. Four out of five respondents agreed, spreadsheets are susceptible to trivial human errors, and from the literature study, we are aware of the financial losses Allfirst Bank and TransAlta had due to the same reason. When asked about the data transfer process from PTDB to PFMEA. According to the answer of three respondent's (quote-unquote), *"the excel program is not compatible with other software programs, so it is not easy to transfer data from Microsoft Excel to other software."* Furthermore, five out of five respondents answered that the current practice is inefficient and does not deliver quality results. In the case of Marine power, diesel engine, the question was asked about the past practices when the organisation was using excel as PTDB.

All participants responded yes to modification in the data handling process for PFMEA. Similarly, all of them were in favour of a new, better digital solution rather than spreadsheet use; please refer to Table 3. When asked, how do they see the use of the new framework for their suppliers, three out of five responded (quote-unquote), *"the suppliers do not use high-cost software like ERP."* The same we have learned in the literature review in chapter 2.9. The answer was a quality input for the research.

A digital framework is capable of creating problem-solving techniques. The study results revealed that, a better digital framework could improve the data handling process for PFMEA, can save time in the process and deliver quality PFMEA. Through the primary and secondary research design, the researcher has learned about the complications related to spreadsheets, security issues, manual data sorting, problems in collaboration with other software, unavailability of low-cost digital solution and data transferring problems from PTDB to PFMEA. This a valuable information; keeping all as an input, the researcher has designed a conceptual framework, a data-handling process for PFMEA in chapter 5.

5 Conceptual framework; a digital solution

"*When digital transformation is done right, it's like a caterpillar turning into a butterfly, but when done wrong, all you have is a really fast caterpillar*" (Vaz, 2021). According to Chapter 2, spreadsheets were valuable, but they cannot deliver the desired output as per the fourth industrial revolution's process requirements. Digitalisation can resource innovative capabilities into a process to increase its efficiency and cost-saving capabilities. A conceptual framework is constructed to overcome the issues discovered in the literature review and the conducted Interviews. The framework's primary aim is to store big-data variables, sort and provide output as per the required input variable to minimise the human data handling process; furthermore, the framework is expected to deliver in specific competitive dimensions stated below:

a) Productivity: improved process performance by avoiding defect repetitions;
b) Sustainability: continual improvement by strengthening the PFMEA process;
c) Cost-saving: low rework and rejection cost, with fewer defects generated;
d) Flexibility: data extraction becomes more resilient.

5.1 Step one; similar past project data lookup

Digitalisation enables a process to improve performance with less or no human intervention. However, a centralised system-level implementation of digital information and communication technology estimates an increase in productivity by 32%, a study conducted on Greman metal and electrical industries (Jeske, Weber, Würfels, Lennings, & Stowasser, 2018) The suggested framework strengthens the data handling system specifically for PFTBD and its input for PFMEA. The framework will allow the user to extract specific past trouble defect data from each process with all of its variables; furthermore, it will provide error-proof relevant data for each project type based on the family of product or process (refer to figure11). The author designed the framework figures in this chapter for a better understanding.

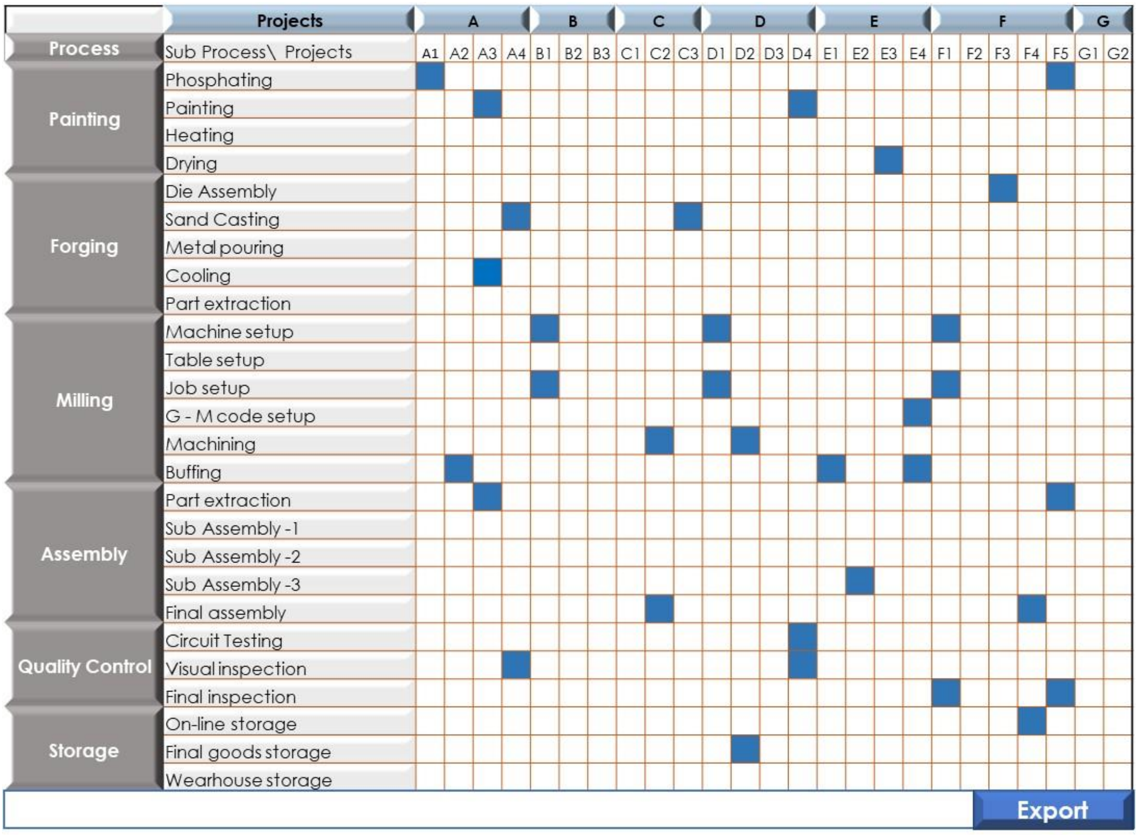


Figure 11 Project and Process Lookup

The vertical length in figure 11 represents the manufacturing processes, whereas; the horizontal section describes the number of projects. Each project lies under the project's family, such as A1 till A4 falls in the projects' family A. For better understanding, all Samsung Galaxy phones are from the family of Galaxy phones. The family of product could be categorised as per the features, name, characteristics or technology used. For example, Galaxy phones can also have a subfamily of foldable phones or phones with a Fast-charging feature. The same family of products has some similar design and manufacturing processes. This categorisation helps design teams to learn and implement within cross-functional projects.

In the first step, when a new project comes and due to its characteristics, it will fall into the F group of family. The new project shall be named as F6. Things to learn can be seen in figure 11. F group of products had trouble in two manufacturing processes; phosphating in painting and part extraction in assembly; followed by the defects were encountered at the quality check station, and issues were also reported at this project's storage section. The framework allows the user to clearly see and understand the past project's performance from a similar family. This step broadcasts the PTDB of a family of the projects rather than manual sorting of multiple spreadsheets. It also eliminates the possibility of loss or miss data due to a spreadsheet or human error.

5.2 Step two; Export PTDB to PFMEA

"*Digitalisation has (positively as well as negatively) incalculable potential to help achieve sustainability*" (Seele & Lock, 2017) Step two allows the user to magnify the specific areas of the problem in PTDB. A simple click on the F5-phosphating process will reveal the details of the defect. The step displays a list of data such as; defect description, process name, cause of failure, preventive control failure, detection control failure, recommended actions, defect quality, product part number, previous risk priority number (RPN) ratting, action completion date and revised risk priority number (RPN), (see figure 12 and 13). To obtain comparable data for the assembly process defect, the design team has a provision to acquire part data extraction from the software. However, in organisations, each project and process has multiple defects. Thus, a manual spreadsheets search in such big data is inefficient. With a new framework, the author is trying to simplify the input process of PTDB into PFMEA.

This data is highly significant for a new process design, also known as PFMEA. PFMEA uses the above data to implement new or same process controls to restricts defect occurrence or defect outflow possibilities. At the end of this stage, the design team has specific details of past defects from similar projects and their exiting process controls' performance. The decisions of new process controls rely on the interpretation of past defects, making it is necessary to communicate a quality input to a new PFMEA. At the end of step one and two, the framework allows the team to export the data to a new

PFMEA project, for example, PFMEA templet F6. It can be performed by selecting a process (row) or project (column) and click the ‘export’ tab to export the detailed data into a new PFMEA template. The PFMEA design team can move the past defect details of a family of projects from F1 to F5 or just a single project F2. Similarly, specific process data can also be transferred to the PFMEA template.

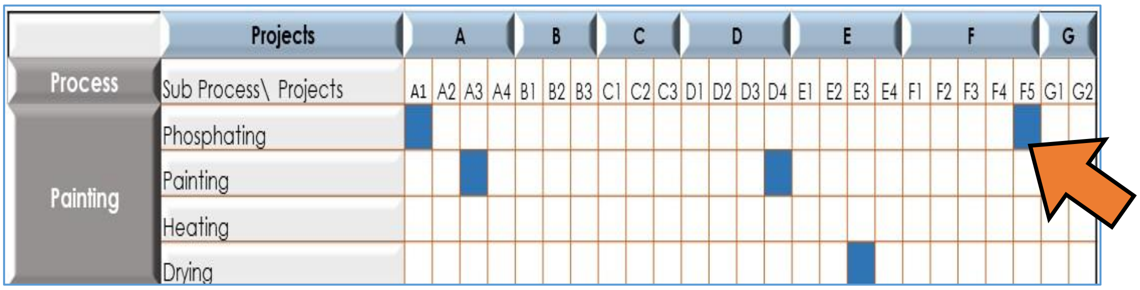


Figure 12 Magnify Defect Details

Family	F
Project	F5
Defect Occurrence Date	XX/XX/XX
Process Name	Phosphating
Part Number	XXX231
Defect Quality	XX
Defect Description	Improper phosphating
Cause of Failure	Low temperature of phosphating solution
Preventive Control	No preventive control available
Detection Control	Manual quality check by operator
Previous RPN	XX
Recommended Actions	Temperature control sense and Alarm system
Action Completion Date	XX/XX/XX
Action Owner	Mr XXXXX
Revised RPN	XX

Figure 13 Defect Detail

5.3 Step three; PFMEA design process

A digital data transfer system is efficient, secure, and has a higher transmission rate. It also restricts the possibilities of loss of data compared to manual transfer. In step three, the PFMEA design team can transfer the past defect data into the F6 PFMEA template. The framework has an incorporated PFMEA template, which strengthens the software and avoids the use of other software programs. Three steps of the framework can overcome the spreadsheet PTDB related issues and its manual transmission to PFMEA.

5.4 Characteristics of conceptual framework

Due to a rich industry experience, the author has witnessed the data handling system of a PFMEA design and understands the requirement of data flexibility for organisational learning and PFMEA design. The framework's characteristics fulfil the functionality, efficiency, reliability, usability, maintainability, and portability components to deliver desired results (International Organisation for Standarization, 2003). The framework has a cross-network design within each variable that allows the user to extract relevant data; refer to figure 14.

The cross-network design will create a linkage between variables; this networking type will let the organisation see data in different orientations. For example, by executing a command, the design engineer can see, the five years of defect that were missing with preventive controls in all the projects. Organisational learning will get stronger with such kind of information system, not just for PFMEA but also for training and audits purposes. Hence, Improved methods through self-learning and assessment techniques will help organisations save rejection and rework cost.

The conceptual framework is designed, keeping in mind the SME's perspective. Thus, the entire process of defect data collection will be the same. The only change will be implemented at the data entry level. Avoiding data entry in excel and to a new framework, and when needed, the data can be extracted to training or exported directly to the

PFMEA template. In this way, the SME's operations will not be disturbed much, as compared to ERP implementation.

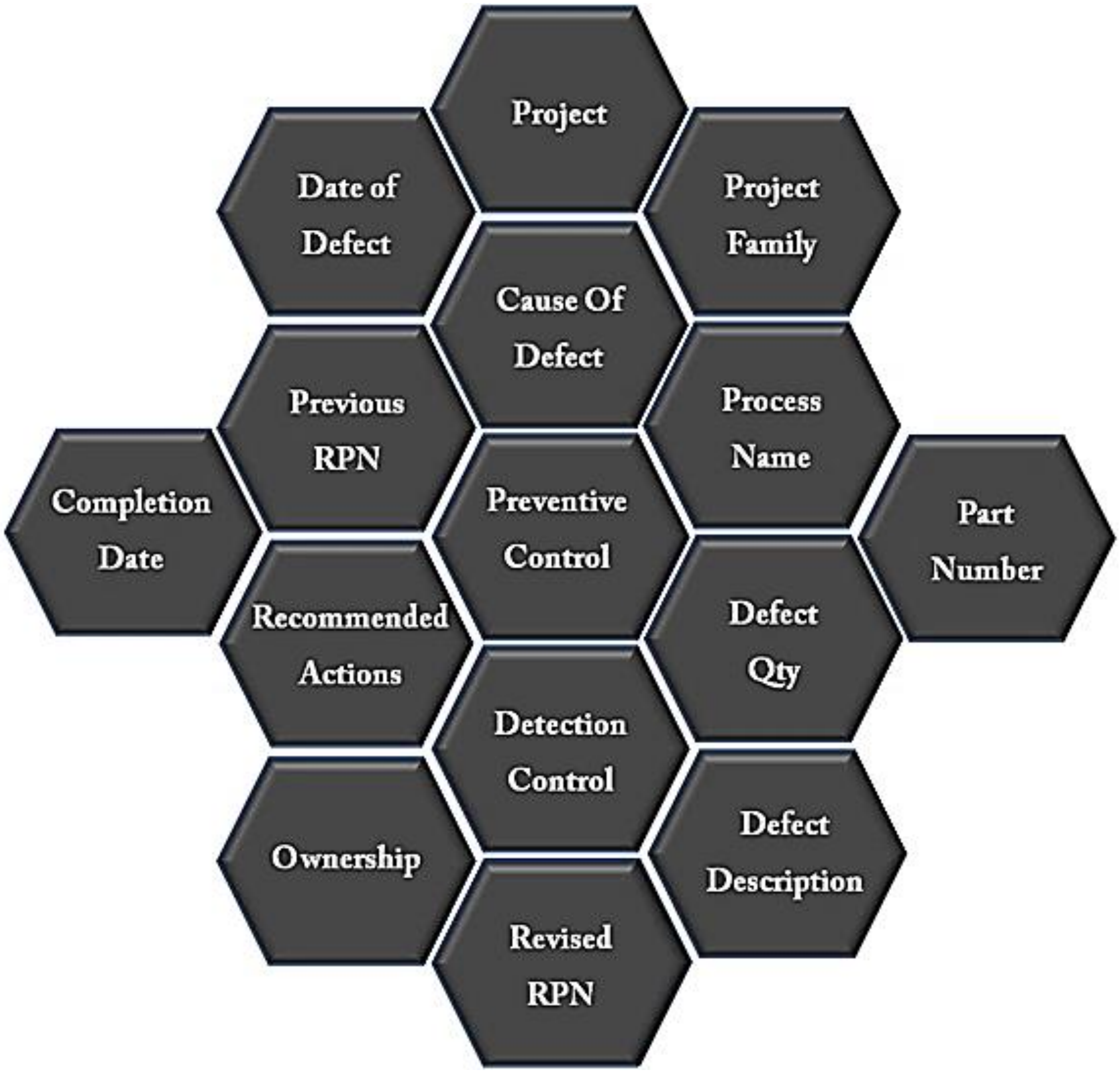


Figure 14 Cross-Network Information System

6 Conclusion

This chapter comprises the conclusion and results summary. The study aimed to answer the primary research question: "What are the advantages of using software-based PTBD over traditional spreadsheet-based PTDB for PFMEA?". The outline of the research was divided into two significant objectives.

- To evaluate the problems and errors related to traditional spreadsheet-based PTDB
- To evaluate the advantages of a digital framework over the traditional PTDB

A systematic research process design was followed to address the research question and its objectives. The basic point of view was to identify the issues in the traditional process of PTDB practised in spreadsheets and the advantages of a digital framework over it, through planned semi-structured interviews with industry experts and evidence of past studies. An effort was also made by designing a conceptual framework specifically for PTDB and PFMEA.

The research investigated the advantages of a digital framework over the spreadsheet-based data handling system. It was done by finding the performance factors of spreadsheets in organisations through semi-structured interviews and literature review. Conversations and discussions made with industry professionals, including past studies and industry events, revealed meaningful information such as; errors in spreadsheets (calculation and format), incompetency in big-data handling, data security and incompetence in data transferring. However, research has also communicated the advantages of a digital solution with improved performance, time-saving, and desired results. The results has high significance because of respondents input and expression towards the need for a better solution for PTDB. Whereas one of the respondent organisations has developed PTDB data handling from spreadsheets to ERP, a need for improvement was still sensed when a different program is used for PFMEA generation.

The responses highlighted more factors that were initially not under investigation. However, during the diagnostic process, issue revealed such as; high-cost factor of the current digital solution, makes it difficult for SME organisations to adapt and implement such solutions. While conducting a review of past studies, a critical and significant amount of errors were witnessed in data handling spreadsheets programs, supported by industry incidents; please refer to chapter 2.4 and 2.6.

7 Discussion

The study was an idea to develop the existing data handling process of PTDB for PFMEA. Hence, a literature review designed and performed aligned to the research question and objectives. Furthermore, a research plan was designed to capture industry voice through interviews and surveys. The data from both sources supported the argument of spreadsheets limitation and imperfections in data handling and security. The research plan included respondents from different industries to maintain the generalizability and broad-angle view. An aligned process was maintained throughout the research between research question, research objectives, methodology, data collection, and data analysis.

The study has opened two new areas of research possibilities: first is developing the conceptual framework considering the features and characteristics of the design from chapter 5 into functional software. The research should partner with an organisation dealing in day-to-day defect generation and its data handling process for an effective process trail run. Incorporating with an organisation will allow the researcher to work on the actual PTDB process and use the software for PFMEA generation. However, during the development stage of the framework, the cost factor must be considered to be implemented by SME. The author suggests it to be on an open source for better adaptation. Secondly, research can also be implemented on DFMEA and SFMEA, where the process is almost the same.

References

Accenture. (2017). *How digital solutions will drive progress towards the sustainable development goals*

Apollo Reliability and Quality Assurance Office National Aeronautics and Space Administration. (1965). *NASA apollo* National Aeronautics and Space Administration.

Argote, L., Beckman, S. L., & Epple, D. (1990). The persistence and transfer of learning in industrial settings. *Management Science, 36*(2), 140-154.

Argote, L., Ingram, P., Levine, J. M., & Moreland, R. L. (2000). Knowledge transfer in organizations: Learning from the experience of others. *Organizational Behavior and Human Decision Processes, 82*(1), 1-8.

Automotive Industry Action Group, (AIAG). (2008). Potential failure mode effective analysis - FMEA reference manual fourth edition. Retrieved from https://www.aiag.org/quality/automotive-core-tools/fmea

Baker, L. B. (2016, "Sep 1, "). SolarCity adviser lazard made mistake in tesla deal analysis. *Reuters* Retrieved from https://www.reuters.com/article/us-solarcity-lazard-idUSKCN11635K

Baker, S. (2019). The boeing 737 max crisis could mark a seismic shift for the aviation industry. here are the other disasters that have changed the way we fly. Retrieved from https://www.businessinsider.com/airline-disasters-crashes-that-changed-aviation-2019-5

Ballinger, G., Craig, E., Cross, R., & Gray, P. (2011). A stitch in time saves nine: Leveraging networks to reduce the costs of turnover. *California Management Review, 53*(4), 111-133.

Balogh, L., & Reuters. (2016). *MID-MARKET M&A REVIEW FINANCIAL ADVISORS first half 2016.* ().Thomson Reuters Americas M&A.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13*(4), 544-559.

BBC. (2010, "Dec 23, "). Toyota pays $10m to fatal lexus crash family. *BBC News* Retrieved from https://www.bbc.com/news/business-12072394

BBC. (2016, "May 04, "). Blackpool hospital trust fined for posting workers' private details online. *BBC News* Retrieved from https://www.bbc.com/news/uk-england-lancashire-36203807

Booth, P., Matolcsy, Z., & Wieder, B. (2000). The impacts of enterprise resource planning systems on accounting practice–the australian experience. *Australian Accounting Review, 10*(22), 4-18.

Bradley, L., & McDaid, K. (2009). Using bayesian statistical methods to determine the level of error in large spreadsheets. Paper presented at the *2009 31st International Conference on Software Engineering-Companion Volume,* 351-354.

Breiing, A., & Kunz, A. (2002). Critical consideration and improvement of the FMEA. Paper presented at the doi:10.3929/ethz-a-006042074 Retrieved from http://hdl.handle.net/20.500.11850/151908

Britten, N. (1995). Qualitative research: Qualitative interviews in medical research. *Bmj, 311*(6999), 251-253.

Cao, X., & Deng, Y. (2019). A new geometric mean FMEA method based on information quality. *IEEE Access, 7*, 95547-95554. doi:10.1109/ACCESS.2019.2928581

CBA. (2020). China delayed releasing coronavirus info, frustrating WHO, documents and recordings reveal | CBC news. Retrieved from https://www.cbc.ca/news/health/who-china-coronavirus-covid19-investigation-1.5594578

Collier, R. (2009). *Riches within your reach!* Penguin.

Cook, S. (2020). Energy trading: Spreadsheets vs automated software | smart energy | energy digital. Retrieved from https://www.energydigital.com/smart-energy/energy-trading-spreadsheets-vs-automated-software

Cyert, R. M., & March, J. G. (1963). *A behavioral theory of the firm* Englewood Cliffs, NJ.

Delaney, J. T., & Huselid, M. A. (1996). The impact of human resource management practices on perceptions of organizational performance. *Academy of Management Journal, 39*(4), 949-969.

Demartini, M., Evans, S., & Tonelli, F. (2019). Digitalization technologies for industrial sustainability. *Procedia Manufacturing, 33*, 264-271.

Mil-std-1629a, ProcedureU.S.C. (1980).

Diplomat, T.China delayed releasing coronavirus info, frustrating WHO. Retrieved from https://thediplomat.com/2020/06/china-delayed-releasing-coronavirus-info-frustrating-who/

Doshi, J., & Desai, D. (2017). Application of failure mode & effect analysis (fmea) for continuous quality improvement-multiple case studies in automobile smes. *International Journal for Quality Research, 11*(2)

Duffy, P. J., & Thomas, R. D. (1989). Project performance auditing. *International Journal of Project Management, 7*(2), 101-104.

Duncan, R. (1979). Organizational learning: Implications for organizational design. *Research in Organizational Behavior, 1*, 75-123.

Dutton, J. M., & Freedman, R. D. (1985). External environment and internal strategies: Calculating, experimenting, and imitating in organizations. *Advances in Strategic Management, 3*(5), 39-67.

Dutton, J. M., Thomas, A., & Butler, J. E. (1984). The history of progress functions as a managerial technology. *The Business History Review,* , 204-233.

lle applicability of nasa contract quality management and failure mode effect analysis procedures to the usgs outer continental shelf oil and gas lease management program, (1972).

Einhorn, H. J., & Hogarth, R. M. (1986). Judging probable cause. *Psychological Bulletin, 99*(1), 3.

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review, 14*(4), 532-550. doi:10.2307/258557

Ellis, A. P., Hollenbeck, J. R., Ilgen, D. R., Porter, C. O., West, B. J., & Moon, H. (2003). Team learning: Collectively connecting the dots. *Journal of Applied Psychology, 88*(5), 821.

Feili, H. R., Akar, N., Lotfizadeh, H., Bairampour, M., & Nasiri, S. (2013). Risk analysis of geothermal power plants using failure modes and effects analysis (FMEA) technique. *Energy Conversion and Management, 72*, 69-76. doi:https://doi.org/10.1016/j.enconman.2012.10.027

Fielding, M. (2006). *Effective communication in organisations* Juta and Company Ltd.

Flew, A. (1984). *A dictionary of philosophy: Revised second edition* Macmillan.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report, 8*(4), 597-607.

Grübler, A. (2003). *Technology and global change* Cambridge university press.

Hekmatpanah, M., Shahin, A., & Ravichandran, N. (2011). The application of FMEA in the oil industry in iran: The case of four litre oil canning process of sepahan oil company. *African Journal of Business Management, Vol. 5(8)*, 3019-3027. Retrieved from https://www.academia.edu/1370767/The_application_of_FMEA_in_the_oil_industry_in_Iran_The_case_of_four_litre_oil_canning_process_of_Sepahan_Oil_Company

Hermans, F., Sedee, B., Pinzger, M., & Deursen, A. v. (2013). Data clone detection and visualization in spreadsheets. Paper presented at the 292-301. doi:10.1109/ICSE.2013.6606575 Retrieved from http://dl.acm.org/citation.cfm?id=2486827

Horo, P. (2017). *How finland is embracing digital transformation2.* ().Microsoft.

Hoyle, D. (2018). *ISO 9000 quality systems handbook* (7th ed.) Routledge. doi:10.4324/9781315642192 Retrieved from https://www.taylorfrancis.com/books/9781315642192

International Organization for Standardization. (2015). *ISO 9001:2015(en) quality management systems — requirements* (4th ed.). US: International Organization for Standardization.

International Organization for Standarization. (2003). *ISO standard 9126: Software engineering –*

product quality. Geneve: International Organization for Standarization.

i-SCOOP. (2021). Moving from digitization to digitalization. Retrieved from https://www.i-scoop.eu/information-management/moving-digitization-digitalization/

Jeske, T., Weber, M., Würfels, M., Lennings, F., & Stowasser, S. (2018). Opportunities of digitalization for productivity management. Paper presented at the *International Conference on Applied Human Factors and Ergonomics,* 321-331.

Jin, X., Wah, B. W., Cheng, X., & Wang, Y. (2015). Significance and challenges of big data research. *Big Data Research, 2*(2), 59-64.

Johnson, H. T., & Kaplan, R. S. (1987). The rise and fall of management accounting [2]. *Strategic Finance, 68*(7), 22.

Johnson, M. K., & Hasher, L. (1987). Human learning and memory. *Annual Review of Psychology, 38*(1), 631-668.

Kelion, L. (2020, "Oct 05, "). Excel: Why using microsoft's tool caused covid-19 results to be lost. *BBC News* Retrieved from https://www.bbc.com/news/technology-54423988

Keskin, G. A., & Özkan, C. (2009). An alternative evaluation of FMEA: Fuzzy ART algorithm. *Quality and Reliability Engineering International, 25*(6), 647-661.

Krisher, A. S. (1994, Speculative materials selection : Adapting to time constraints. *Materials Performance, 33*, 60-61.

Labrinidis, A., & Jagadish, H. V. (2012). Challenges and opportunities with big data. *Proceedings of the VLDB Endowment, 5*(12), 2032-2033. doi:10.14778/2367502.2367572

Laukkanen, S., Sarpola, S., & Hallikainen, P. (2007). Enterprise size matters: Objectives and constraints of ERP adoption. *Journal of Enterprise Information Management,*

Levitt, B., & March, J. G. (1988). Organizational learning. *Annual Review of Sociology, 14*(1), 319-338.

Lipol, L. S., & Haq, J. (2011). Risk analysis method: FMEA/FMECA in the organizations. *International Journal of Basic & Applied Sciences, 11*(5), 74-82.

Majchrzak, A., More, P. H., & Faraj, S. (2012). Transcending knowledge differences in cross-functional teams. *Organization Science, 23*(4), 951-970.

Martins, E. C., & Meyer, H. W. (2012). Organizational and behavioral factors that influence knowledge retention. *Journal of Knowledge Management,*

Merriam-Webster. (2021a). Definition of DISRUPTIVENESS. Retrieved from https://www.merriam-webster.com/dictionary/disruptiveness

Merriam-Webster. (2021b). Definition of EXPLORE. Retrieved from https://www.merriam-webster.com/dictionary/explore

Mikulak, R. J., McDermott, R., & Beauregard, M. (2017). *The basics of FMEA* CRC Press.

Munro, R. A., Ramu, G., & Zrymiak, D. J. (2014). *The certified six sigma green belt handbook, second edition*. Milwaukee: ASQ Quality Press. Retrieved from https://ebookcentral.proquest.com/lib/[SITE_ID]/detail.action?docID=5302460

National Aeronautics and Space Administration. (1970). *Practice no. pd-ap-1307 preferred page 1 of 2 reliability practices failure modes, effects and criticality analysis (fmeca)*

Neale, C. W., & Holmes, D. (1990). Post-auditing capital projects. *Long Range Planning, 23*(4), 88-96.

News, A. P. (2020). China delayed releasing coronavirus info, frustrating WHO. Retrieved from https://apnews.com/article/3c061794970661042b18d5aeaaed9fae

NGUYEN, P. (2017). Cost saved is profit earned: Cost management strategies for FSCs. Retrieved from http://asia.blog.terrapinn.com/aviation/2017/01/10/cost-saved-is-profit-earned-cost-management-strategies-for-fscs/

Nonaka, I., & Takeuchi, H. (2007). The knowledge-creating company. *Harvard Business Review, 85*(7/8), 162.

Nurminen, H. M. (2007). Hoitoprosessin suorituskyvyn mittaaminen, analysointi ja kehittäminen.

O'Beirne, P. (2008). Information and data quality in spreadsheets. *arXiv Preprint arXiv:0809.3609,* Panko, R. (1998). What we know about spreadsheet errors. *Journal of Organizational and End User Computing, 10*(2), 15-21. doi:10.4018/joeuc.1998040102

Panko, R. R. (2006). Spreadsheets and sarbanes-oxley: Regulations, risks, and control frameworks. *Communications of the Association for Information Systems, 17*(1), 29.

Panko, R. R., & Halverson, R. P. (1996). Spreadsheets on trial: A survey of research on spreadsheet risks. Paper presented at the *Proceedings of HICSS-29: 29th Hawaii International Conference on System Sciences, , 2* 326-335.

Pathak, V., Jena, B., & Kalra, S. (2013). Qualitative research. *Perspectives in Clinical Research, 4*(3)

Powell, S. G., Baker, K. R., & Lawson, B. (2009). Errors in operational spreadsheets. *Journal of Organizational and End User Computing (JOEUC), 21*(3), 24-36.

Program, S., Nasa, O., & Marshall, G. C. (1974). *NASA TECHNICAL MEMORANDUM NASA TM X-64913 MSFC SKYLAB EXPERIMENTER' s REFERENCE*. Alabama: National Aeronautics and Space Administration. Retrieved from https://ntrs.nasa.gov/api/citations/19750010198/downloads/19750010198.pdf?attachment=true

Public health england. Retrieved from https://www.gov.uk/government/organisations/public-health-england

Radner, R. (1975). A behavioral model of cost reduction. *The Bell Journal of Economics,* , 196-215.

Reuters, & Zvulun, R. (2018). *MID-MARKET M&A REVIEW FINANCIAL ADVISORS full year 2018.* ().Thomson Reuters Americas M&A.

Robinson, O. C. (2014). Sampling in interview-based qualitative research: A theoretical and practical guide. *Qualitative Research in Psychology, 11*(1), 25-41.

Sader, S., Husti, I., & Daróczi, M. (2020). Enhancing failure mode and effects analysis using auto machine learning: A case study of the agricultural machinery industry. *Processes, 8*(2), 224.

Schallmo, D. R. A., & Williams, C. A. (2018). *SPRINGER BRIEFS IN BUSINESS digital transformation now! guiding the successful digitalization of your business model*

Schein, A. I., Popescul, A., Ungar, L. H., & Pennock, D. M. (2002). Methods and metrics for cold-start recommendations. Paper presented at the *Proceedings of the 25th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval,* 253-260.

Seele, P., & Lock, I. (2017). The game-changing potential of digitalization for sustainability: Possibilities, perils, and pathways. *Sustainability Science, 12*(2), 183-185.

Shahin, A. (2004). Integration of FMEA and the kano model. *International Journal of Quality & Reliability Management,* Silva, M. M., de Gusmão, Ana Paula Henriques, Poleto, T., Silva, L. C. e., & Costa, Ana Paula Cabral Seixas. (2014). A multidimensional approach to information security risk management using FMEA and fuzzy theory. *International Journal of Information Management, 34*(6), 733-740. doi:https://doi.org/10.1016/j.ijinfomgt.2014.07.005

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1977). Behavioral decision theory. *Annual Review of Psychology, 28*(1), 1-39.

Smith, J. F., Mitchell, T. R., & Beach, L. R. (1982). A cost-benefit mechanism for selecting problem-solving strategies: Some extensions and empirical tests. *Organizational Behavior and Human Performance, 29*(3), 370-396. doi:10.1016/0030-5073(82)90251-3

Software Path. (2020). *ePROMIS ERP secures top position in gartner FrontRunners ERP report 2020 by software advice.* (). New York: PR Newswire Association LLC. Retrieved from ProQuest Business Collection (Alumni Edition) Retrieved from https://search.proquest.com/docview/2432837962

Stamatis, D. H. (2003). *Failure mode and effect analysis: FMEA from theory to execution* Quality Press.

Starbuck, W. H., & Dutton, J. M. (1974). *Designing adaptive organizations* IIM.

Starbuck, W. H., & Milliken, F. J. (1988). Executives' perceptual filters: What they notice and how they make sense.

Stebbins, R. A. (2001). *Exploratory research in the social sciences* Sage.

Stenbacka, C. (2001). Qualitative research requires quality concepts of its own. *Management Decision,*

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research* Sage publications.

Svenson, O. (1996). Decision making and the search for fundamental psychological regularities: What can be learned from a process perspective? *Organizational Behavior and Human Decision Processes, 65*(3), 252-267. doi:10.1006/obhd.1996.0026

Svenson, O., & Benson, L., III. (1991). *Framing and time pressure in decision making* Retrieved from http://catalog.crl.edu/record=b1680682

Syahputri, K., Sari, R. M., Rizkya, I., Alona, I., & Zati, V. D. A. (2019). Analysis of risk priorities in a medical record unit at the hospital. Paper presented at the *2019 International Conference on Sustainable Engineering and Creative Computing (ICSECC),* 19-23.

Tavana, M., Shaabani, A., & Valaei, N. (2020). An integrated fuzzy framework for analyzing barriers to the implementation of continuous improvement in manufacturing. *International Journal of Quality & Reliability Management,*

Teivainen, A. (2020, -12-21T06:06:19+00:00). Finland leads world in new technology patents per capita in 2000s. *Good News from Finland* Retrieved from https://www.goodnewsfinland.com/finland-leads-world-in-new-technology-patents-per-capita-in-2000s/

Templer, A. J., & Cawsey, T. F. (1999). Rethinking career development in an era of portfolio careers. *Career Development International,*

Teoh, P. C., & Case, K. (2004). Modelling and reasoning for failure modes and effects analysis generation. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 218*(3), 289-300.

Thompson, J. D. (2003). *Organizations in action: Social science bases of administrative theory* Transaction publishers.

Tuomi, V. (2008). Sydänaseman kehittämispäivä 22.1. 2008. prosessimittarit ja niiden laadinta. vaasan yliopisto. vaasa. *Finnish, Not Published,*

Tuomi, V. (2012). Quality management in public sector.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*(4157), 1124-1131.

U.S. Environmental Protection Agency. (1973). *Application of selected industrial engineering techniques to wastewater treatment pant*. Washington D.C.:

US, F. L. (2002). *Sarbanes-oxley*

act of 2002.

corporate

responsibility. public law 107-204 107th congress an act US Federal Law.

Vaz, N. (2021). *Digital business transformation: How established companies sustain competitive advantage from now to next* Retrieved from https://trito-nia.finna.fi/uva/PrimoRecord/pci.vlebooksAH37732146

Venkatraman, S., & Fahd, K. (2016). Challenges and success factors of ERP systems in australian SMEs. *Systems (Basel), 4*(2) doi:10.3390/systems4020020

Von Zedtwitz, M. (2002). Organizational learning through post–project reviews in R&D. *R&D Management, 32*(3), 255-268.

Wachal, R. (1971). Humanities and computers: A personal view. *The North American Review, 256*(1), 30-33.

Wang, Y., Li, K., Chen, H., He, L., & Li, K. (2014). Energy-aware data allocation and task scheduling on heterogeneous multiprocessor systems with time constraints. *IEEE Transactions on Emerging Topics in Computing, 2*(2), 134-148.

Wilson, J. M., Goodman, P. S., & Cronin, M. A. (2007). Group learning. *Academy of Management Review, 32*(4), 1041-1059.

Wright, P. (1974). The harassed decision maker: Time pressures, distractions, and the use of evidence. *Journal of Applied Psychology, 59*(5), 555.

Yin, R. K. (2003). Case study research design and methods third edition. *Applied Social Research Methods Series, 5*

Yin, R. K. (1984). *Case study research : Design and methods* Sage.

Zeeberg, B. R., Riss, J., Kane, D. W., Bussey, K. J., Uchio, E., Linehan, W. M., . . . Weinstein, J. N. (2004). Mistaken identifiers: Gene name errors can be introduced inadvertently when using excel in bioinformatics. *BMC Bioinformatics, 5*(1), 1-6.

Zhang, J., & Li, G. Q. (2013). A novel model-based method for automatic generation of fmea. Paper presented at the *Applied Mechanics and Materials, , 347* 2605-2609.

Ziemann, M., Eren, Y., & El-Osta, A. (2016). Gene name errors are widespread in the scientific literature. *Genome Biology, 17*(1), 1-3.

Zvulun, R., & Reuters. (2017). *MID-MARKET M&A REVIEW FINANCIAL ADVISORS full year 2017 REUTERS / coldagh kilcoyne.* ().Thomson Reuters Americas M&A.

赵建文. (2015). Following the charter of the united nations: The basic guarantee for the realization of the right to Development——From the perspective of transforming our world: The 2030 agenda for sustainable development. *Human Rights : China's First Magazine on Human Rights,* (5), 485-508. Retrieved from http://lib.cqvip.com/qk/88415X/201605/82678987504849544853484855.html

Appendices

Appendix 1. United States of America - Department of Defence FMECA

MIL-STD-1629A

FAILURE MODE EFFECTS AND CRITICALITY ANALYSIS
MAINTAINABILITY INFORMATION

SYSTEM ____
INDENTURE LEVEL ____
REFERENCE DRAWING ____
MISSION ____

DATE ____
SHEET ____ OF ____
COMPILED BY ____
APPROVED BY ____

IDENTIFICATION NUMBER	ITEM/FUNCTIONAL IDENTIFICATION (NOMENCLATURE)	FUNCTION	FAILURE MODES AND CAUSES	FAILURE EFFECTS			SEVERITY CLASS	FAILURE PREDICTABILITY	FAILURE DETECTION MEANS	BASIC MAINTENANCE ACTIONS	REMARKS
				LOCAL EFFECTS	NEXT HIGHER LEVEL	END EFFECTS					

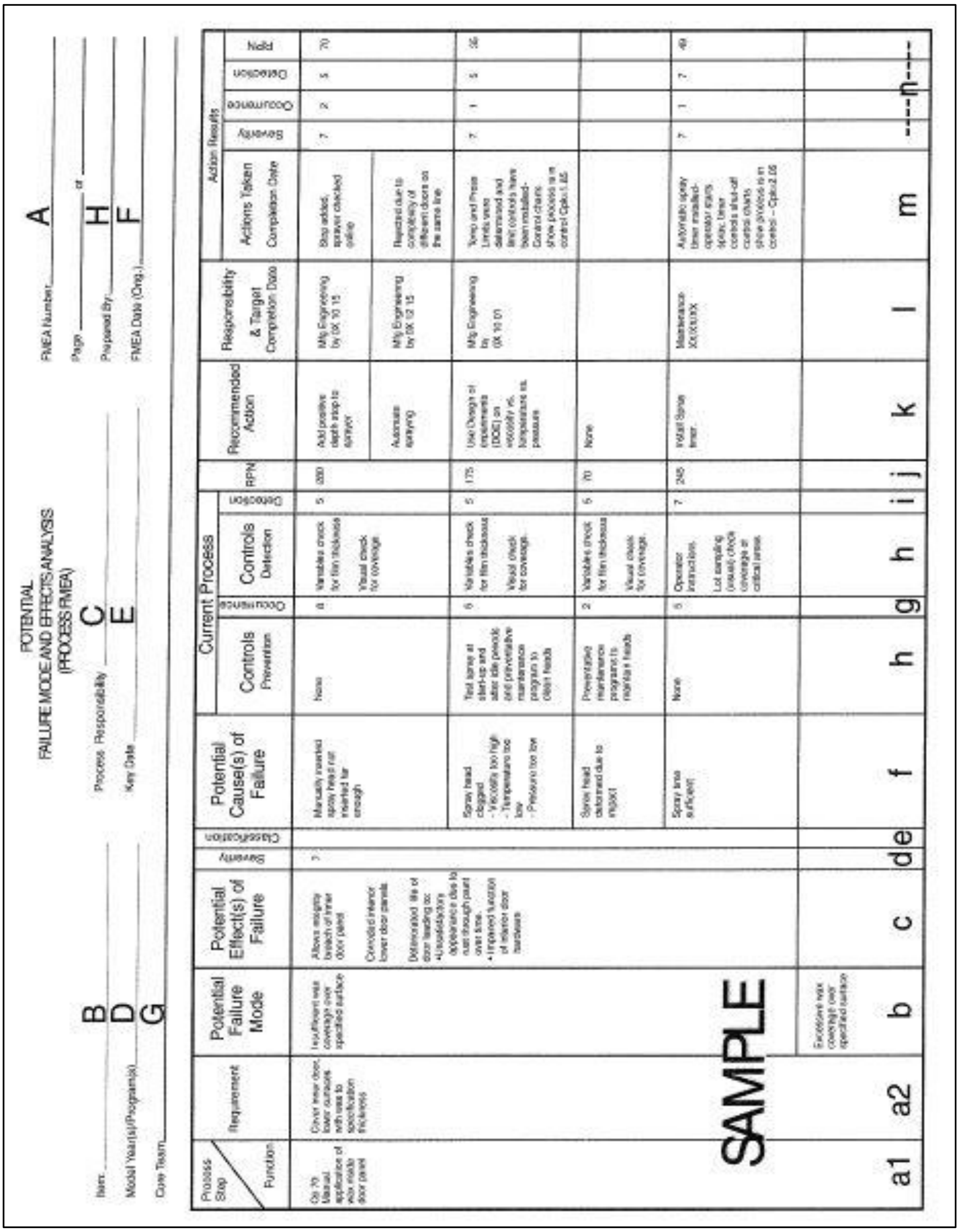
Figure 103.1 Example of FMECA-maintainability information worksheet format

TASK 103

103-3

24 November 1980

Appendix 2. AIAG FMEA 4th edition PFMEA template, minimal information elements & example entries



Appendix 3. List of errors in gene names

Table 1 Results of the systematic screen of supplementary Excel files for gene name conversion errors

Journal[a]	Number of Excel files screened	Number of gene lists found	Number of papers with gene lists	Number of supplementary files affected	Number of papers affected	Number of gene names converted
PLoS One	7783	2202	994	220	170	4240
BMC Genomics	11464	1650	801	218	158	4932
Genome Res	2607	580	251	114	68	3180
Nucleic Acids Res	2117	540	315	88	67	1661
Genome Biol	2678	664	257	97	63	1878
Genes Dev	932	395	190	75	55	1593
Hum Mol Genet	980	372	168	48	27	1724
Nature	482	150	74	27	23	1375
BMC Bioinformatics	1790	235	152	26	21	534
RNA	569	127	77	20	15	1341
Nat Genet	264	70	37	12	9	178
Bioinformatics	731	112	67	11	6	339
PLoS Comput Biol	177	79	32	6	6	46
PLoS Biol	143	54	29	7	5	206
Mol Biol Evol	995	112	79	7	4	56
Science	172	36	19	7	3	451
Genome Biol Evol	490	32	25	2	2	121
DNA Res	801	57	30	2	2	6
Total	35175	7467	3597	987	704	23861

[a]**The 18 journals investigated are ordered by the number of papers affected by gene name conversion errors**

Appendix 4. AIAG FMEA 4th edition, PFMEA severity evaluation criteria

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank	Effect	Criteria: Severity of Effect on Process (Manufacturing/Assembly Effect)
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	**10**	**Failure to Meet Safety and/or Regulatory Requirements**	May endanger operator (machine or assembly) without warning.
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	**9**		May endanger operator (machine or assembly) with warning.
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	**8**	**Major Disruption**	100% of product may have to be scrapped. Line shutdown or stop ship.
	Degradation of primary function (vehicle operable, but at reduced level of performance).	**7**	**Significant Disruption**	A portion of the production run may have to be scrapped. Deviation from primary process including decreased line speed or added manpower.
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort / convenience functions inoperable).	**6**	**Moderate Disruption**	100% of production run may have to be reworked off line and accepted.
	Degradation of secondary function (vehicle operable, but comfort / convenience functions at reduced level of performance).	**5**		A portion of the production run may have to be reworked off line and accepted.
Annoyance	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by most customers (> 75%).	**4**	**Moderate Disruption**	100% of production run may have to be reworked in station before it is processed.
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by many customers (50%).	**3**		A portion of the production run may have to be reworked in-station before it is processed.
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by discriminating customers (< 25%).	**2**	**Minor Disruption**	Slight inconvenience to process, operation, or operator.
No effect	No discernible effect.	**1**	**No effect**	No discernible effect.

Appendix 5. Evaluation and consent form for interview

Online Questionnaire and Consent Form

Background Information:

1) Kindly make your introduction

    - Name of your company:
    - Your designation in the company, since when you are working with this organisation?
    - Your total work experiences?

2) Can you explain your organisation business and main products? (Is your organisation an SME or a large enterprise?)

3) Confidentiality Disclosure:

    The interview will be recorded and the researcher in discussion and the supervisor will have the exclusive access. However, you may use a pseudonym for your introduction and your anonymity will be ensured.

    You have the right to withdraw at any moment and you may request to destroy your information.

    Agree ____________

    Disagree ____________

Appendix 6. Interview questions

1) Please select all major challenges that occur during the design of PFMEA
   - Time Consuming
   - Insufficient Past Trouble Data
   - Loss of Data (while knowledge transfer)
   - Team Communication
   - Team knowledge and skillset

2) What kind of technology is used by your organisation to handle Past Trouble Data?
   - Microsoft Excel
   - Google Sheets
   - Apple Numbers
   - Quip
   - EtherCalc
   - Zoho Sheets
   - Any Other____________________

3) What type of problems do you face with spreadsheet programs?
   - Vulnerable to Fraud
   - Susceptible to trivial human errors
   - Difficult to troubleshoot or test
   - Obstructive to regulatory compliance
   - Not designed for collaborative work
   - Hard to consolidate

4) What type of problems do you face during data transfer from Past Trouble Data to PFMEA?

5) Is there a need to modify the data handling system for PFMEA?

6) In your opinion, a customised software which can store and retrieve past trouble defect data for PFMEA (based on the defect, cause, part number, process, cause of outflow and frequency) can be better than current spreadsheet use?

7) How do you think implementing the above software program can help your organisation?