Journal of Information System and Technology Management JISTM
EISSN: 0128-1666
Volume 9 Issue 36 (September 2024) PP. 90-108
DOI: 10.35631/JISTM.936006

JOURNAL OF INFORMATION SYSTEM AND TECHNOLOGY MANAGEMENT (JISTM)
www.jistm.com

DESIGN AND DEVELOPMENT OF A COMPUTER ASSISTED FMEA ANALYSIS TOOL FOR THE SEMICONDUCTOR INDUSTRY

Vi Lynn Goh[1], Hawa Hishamuddin[*2], Mohamad Hanif Md Saad[3], Dzuraidah Ab Wahab[4], Nashrah Hani Jamadon[5], Wakhid Ahmad Jauhari[6]

[1] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Malaysia
Email: a176968@siswa.ukm.edu.my
[2] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Malaysia
Email: hawa7@ukm.edu.my
[3] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Malaysia
Email: hanifsaad@ukm.edu.my
[4] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Malaysia
Email: dzuraidah@ukm.edu.my
[5] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Malaysia
Email: nashrahhani@ukm.edu.my
[6] Department of Industrial Engineering, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, Indonesia
Email: wakhidjauhari@staff.uns.ac.id
[*] Corresponding author

Article Info:

Article history:
Received date: 30.07.2024
Revised date: 20.08.2024
Accepted date: 11.09.2024
Published date: 25.09.2024

To cite this document:

Goh, V. L., Hishamuddin, H., Saad, M. H. M., Wahab, D. A., Jamadon, N. H., & Jauhari, W. A. (2024). Design and Development of a Computer Assisted FMEA Analysis Tool for the Semiconductor Industry. *Journal of Information System and Technology Management*, *9* (36), 90-108.

DOI: 10.35631/JISTM.936006

Abstract:

The use of Failure Mode and Effect Analysis (FMEA) has become widespread in various industries to address quality and reliability issues that may occur in a system or process. However, the risk assessment process using traditional FMEA is very time-consuming because it requires the evaluator to assess the risk for each identified potential failure mode one by one, based on the extracted historical data. Without proper consideration of the system or process being evaluated, the evaluator may make incorrect judgments, causing the FMEA results to be inaccurate and unreliable. In this study, an interactive FMEA tool that uses a standard risk factor input as the main reference was developed using Excel software and Tableau software. Semi-structured interviews were conducted at the initial stage of the study to obtain basic information about the existing FMEA approach in the semiconductor industry. With this information, a standard reference for risk factor input was established for the FMEA tool. The developed tool was then tested in the real semiconductor industry to validate its effectiveness and practicality. The results show that the developed interactive FMEA tool holds significant potential for industrial usage in terms of streamlining the FMEA analysis process, providing a comprehensive visualization of the identified potential failure modes, and improving information sharing within the organization.

Journal of Information System and Technology Management
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With the presence of this interactive FMEA tool, users can not only produce more accurate and reliable FMEA results based on built-in risk factor input standards, users can also view the generated FMEA results online through the Tableau dashboard.

Keywords:

FMEA, Risk Assessment, Computer Aided Risk Analysis, Semiconductor Industry, Industrial Revolution 4.0

Introduction

Failure Mode and Effects Analysis (FMEA) is widely recognized as an effective control tool for analyzing and improving the quality and reliability of systems. It assesses potential failure modes and estimates the relative impact of different failures to identify the most critical system components. In the 1950s, FMEA was introduced in the United States aerospace manufacturing department to address quality and reliability issues in military products. Its success led to widespread adoption in various industries including manufacturing, construction, automotive, oil and gas, textile, logistics, healthcare, and medicine.

The identification of all the potential failure modes in the system being analyzed is a fundamental task in FMEA implementation. This process is highly dependent on the experience of the engineers with similar systems tested in the past (Wang et al., 2018). However, different stages of a system may yield different results in identifying potential failure modes. To guide designers in improving designs, FMEA should be carried out at the product design stage, considering customer requirements and failure causality relationships (FCRs) between failure modes (Chen et al., 2022).

The wide adoption of FMEA in diverse industries aims to tackle quality and reliability concerns within systems or processes. Nevertheless, the conventional FMEA approach for risk assessment is notably time-consuming. It necessitates evaluators to individually evaluate the risks associated with each potential failure mode. This evaluation relies heavily on historical data extraction, making the process cumbersome. The complexity of analyzing historical data and the considerable reliance on evaluator judgment make the use of traditional FMEA challenging. In cases where the system or process under evaluation is not adequately considered, evaluators may make incorrect judgments, thereby compromising the accuracy and reliability of the FMEA results. Hence, this project aims to develop an interactive Failure Mode and Effect Analysis (FMEA) tool suitable for use in the semiconductor industry to potentially resolve the said issues.

The remainder of the paper is organised as follows. The literature review and methodology are presentend in the next sections. The tool development, results and discussions from the application of the computer assisted FMEA tool are elaborated in the subsequent sections. Lastly, the final section presents concluding remarks of the overall study.

Literature Review

Evaluating the risk factor levels of potential failure modes through the risk assessment process helps prioritize critical failure modes. A fuzzy probability distribution based on information quality should be incorporated into the evaluation of severity, occurrence, and detection indicators to enhance the comprehensive ranking of potential failure modes (Cao & Deng, 2019). An approach that integrates fuzzy rough number, analytic hierarchy process (AHP), and

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VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was proposed to handle uncertainty during risk evaluation and determine a more rational ranking of failure modes (Zhu et al., 2022). Hesitant uncertain linguistic Z numbers (HULZNs) can represent uncertain and hesitant risk evaluation information, while the normal density-based spatial clustering of applications with noise (DBSCAN) algorithm can classify recognized failure modes into different risk classes (Liu et al., 2021). These approaches enable the determination of critical failure modes for safety and reliability improvement.

Due to its effectiveness in prioritizing critical failure modes, FMEA is widely used in manufacturing industries to improve system reliability. An integrated approach based on interval type-2 fuzzy sets (IT2FSs) and multi-criteria decision-making (MCDM) is introduced to mitigate human errors in CNC machines (Boral & Chakraborty, 2021). In this approach, IT2FSs model the linguistic uncertainties arising from expert judgement, while MCDM methods like DEMATEL, AHP, and MARCOS identify the causes and effects of human errors, compute risk factor weights, and rank associated risks. To further enhance the accuracy of FMEA applications in the world of manufacturing, information uncertainty must be considered by integrating MCDM approaches such as TDBPA (Zheng & Tang, 2020), Z-MOORA (Ghoushchi et al., 2019), MULTIMOORA (Fattahi & Khalilzadeh, 2018), AHP (Mete, 2019), fuzzy VIKOR (Rathore et al., 2021), BWM and GRA (Lo & Liou, 2018), or IT2FSs (Qin et al., 2020) into the traditional FMEA approach. These approaches help overcome the limitations of inaccurate risk evaluation results due to uncertainty.

However, previous researchers did not investigate the difficulties and complexities of evaluating identified potential failure modes in the FMEA approach, where extensive experience is required during the risk assessment process. Therefore, this study aims to introduce a more systematic and rational FMEA approach by developing an interactive FMEA tool. The tool utilizes standardized risk factors input and the information and data entry forms to reduce assessors' analysis time and systematically assess the risk of failure modes in a system. The developed FMEA tool, created using Excel software, summarizes and presents the FMEA results on the Tableau dashboard for a clearer overview. The effectiveness and practicality of this tool in solving real industry problems are validated in the actual semiconductor manufacturing industry.

Methodology

This study was carried out in three stages. It began with the development of the standard reference for risk factors inputs by collecting data through studies and interviews, followed by the development of a computer assisted interactive FMEA tool using appropriate software. The developed tool was then tested in real semiconductor industries to validate its effectiveness and practicality. Figure 1 illustrates the overall flowchart of this study.

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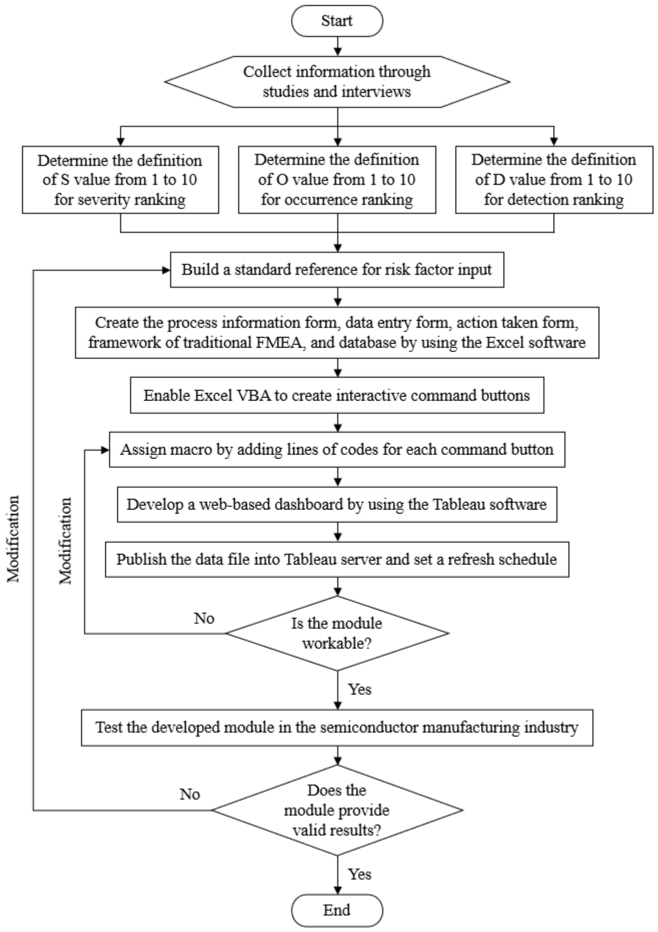

Figure 1: Methodology flowchart

Before embarking on the development of an interactive FMEA tool to address the limitations of traditional FMEA approaches, it was essential to acquire basic information about FMEA for forming a standard reference for risk factor inputs. To achieve this, interviews were conducted with four experienced engineers from the semiconductor manufacturing industry. The gathered data and information were then analyzed to construct a standard reference for risk factor inputs, forming the library of the interactive FMEA tool, which significantly eased the risk evaluation process. Excel VBA and Tableau software were utilized to develop the interactive FMEA tool. Excel VBA facilitated the identification of critical failures by using information and data entry forms, reducing dependency on evaluator experience and judgment. The predefined library in the developed FMEA tool, which is the standard reference for risk factor inputs, supplied the exact risk factor values for each identified potential failure based on user inputs, resulting in more accurate and reliable risk evaluation results. Additionally, Tableau software was used to create a web-based dashboard summarizing the FMEA results. This helps to provide engineers with a visual overview of critical failures that require immediate corrective or preventive actions, effectively enhancing their ability to avoid potential risks.

Results and Discussion

Standard Reference for Risk Factor Inputs

The standard reference for risk factor input is of vital importance in this study as it helps provide accurate risk factor values, including severity, occurrence, and detection, for each of

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the identified potential failures by serving as the library for the interactive FMEA tool. To gather the essential data for the development of a standardized risk factor input reference, a comprehensive semi-structured interview that encompasses five primary sections: demography (Section A), severity ranking (Section B), occurrence ranking (Section C), detection ranking (Section D), and understanding current FMEA practices (Section E), was conducted with four experienced engineers from three distinct semiconductor companies. Table 1 shows a summary of the background of the engineers being interviewed. The analysis of the respondents indicates a diverse range of experience levels and roles in the semiconductor industry, enabling a comprehensive analysis of the application of FMEA in this sector.

Table 1: Summary Of The Background Of The Interviewed Engineers

	Respondent 1	**Respondent 2**	**Respondent 3**	**Respondent 4**
Company	Company 1	Company 2	Company 3	Company 4
Company field	Semiconductor	Semiconductor	Semiconductor	Semiconductor
Company size	10001 to 50000 employees	1001 to 5000 employees	1001 to 5000 employees	5001 to 10000 employees
Department	Process integration	Assembly	Assembly	Testing
Position	Manager	Team leader / Supervisor	Manager	Entry-level employee
Working duration	6 to 8 years	2 to 4 years	More than 8 years	0 to 2 years
Experience in using FMEA	6 to 8 years	2 to 4 years	More than 8 years	0 to 2 years

The ranking of severity, occurrence, and detection of potential failures in the manufacturing industry, particularly in the semiconductor industry, was studied in Sections B, C, and D. In these sections, the respondents were questioned about the common factors that affect the severity of a failure, the common factors used to define the probability of occurrence of a failure, the method used to detect the presence of a failure, and the common factors used to classify the level of detection of a failure. The results obtained in these sections are presented in Table 2, Table 3, and Table 4, respectively.

Table 2: Results Obtained In Section B Of The Interview

Common factors that affect the severity of a failure:	Least severe 1. Impact on tool stability 2. Amount of yield loss 3. Impact on the production line 4. Impact on quality/reliability 5. Worker safety concerns 6. Impact on customers Most severe

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Table 3: Results Obtained In Section C Of The Interview

Common factors used to define the probability of occurrence of a failure:	1. Number of failures per time period 2. Number of failures per lot 3. Number of failures per million units

Table 4: Results Obtained In Section D Of The Interview

Methods used to detect the presence of a failure:	• Probe • Alarm • Sensor detection • Image processing • Visual inspection • Metrology inspection
Common factors used to classify the level of detection of a failure:	Easiest to detect 1. Automatic machine detection (pre-process) 2. Automatic machine detection (in-process) 3. Automatic machine detection (post-process) 4. Manual machine detection (pre-process) 5. Manual machine detection (in-process) 6. Manual machine detection (post-process) 7. Manual detection (pre-process) 8. Manual detection (in-process) 9. Manual detection (post-process) Most difficult to detect

In Section C, although the interview results suggested that several common factors are used to define the probability of occurrence of a failure, all the respondents unanimously agreed that the number of failures per million units is the most used factor to determine the likelihood of occurrence of a potential failure when further queried. By combining all the responses provided by the respondents in these sections with the FMEA risk factor references obtained from one of the respondents' companies and the findings of the studies conducted by Immawan et al. (2018), Lo & Liou (2018), and Moreira et al. (2021), the standard references for severity, occurrence, and detection input were developed. These references will be utilized as the risk factor libraries in the interactive FMEA tool, and the details of these standard references are shown in Table 5 (severity), Table 6 (occurrence), and Table 7 (detection), respectively.

Table 5: Standard Reference For Severity Input

Severity Ranking	Impact of Severity	Impact of Manufacturing	Impact on Customer
1	None	Failure has no discernible effect.	Failure has no discernible effect.
2	Very minor	Failure does not affect product performance. Failure can be corrected in line.	Failure is very minimal, and the customer will probably not detect the failure.
3	Minor	Failure may affect product performance. Defect products	Failure causes the product to function at an inconvenient

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		can be reworked without any scrap.	level. Defect noticed by more than 50% of customers.
4	Very low	Failure will slightly affect product performance with yield loss above calculated yield targets. Failure may be corrected through product sorting or rework.	Failure causes the product to function at an inconvenient level. Defect noticed by more than 75% of customers.
5	Low	Failure affects overall yield. Defect products need to be reworked, retested or rescreened, causing excessive delays and late deliveries.	Failure causes the product to function at a reduced level of performance. Customer is somewhat dissatisfied and may generate a complaint.
6	Moderate	Failure causes internal excursion leading to partial product malfunction. Special setups are required for product testing.	Failure causes the product to function at a reduced level of performance and functionality, necessitating product screening. Customer is dissatisfied and may generate a complaint.
7	High	Failure causes internal excursion leading to major and/or tool / machine / random defects. All affected products are scrapped internally with no defect lots leaving the site.	Failure causes anomalies / non-random defects in customer's product application, leading to the situation where some of the customer's systems may require sorting and/or repairing.
8	Very high	Failure causes internal excursion leading to major product malfunction and/or tool / machine / random defects. Some affected products have not been scrapped prior to the last log point within the factory, causing any portion of the defect lots to leave the site.	Failure causes anomalies / non-random defects in customer's product application, leading to the situation where all of the customer's systems may need to be rejected due to premature failure.
9	Extremely high (hazardous with warning)	Failure could jeopardize the safety of the operator with warning.	Failure with warning which causes unsafe operating conditions and/or personal injury to the customer / damages to the surrounding components, causing reliability issues on the product shipped.
10	Dangerously high (hazardous	Failure could jeopardize the safety of the operator without warning.	Failure without warning which causes unsafe operating conditions and/or personal

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without warning)		injury to the customer / damages to the surrounding components, causing reliability issues on the product shipped.

Table 6: Standard Reference For Occurrence Input

Occurrence Ranking	Possible Failure Rates	Description
1	Failure is eliminated through preventive control.	Failure is eliminated through preventive control.
2	≤ 1 per million	No failure is observed during the process without preventive control.
3	≤ 10 per million	Only isolated failures are observed during the process.
4	≤ 100 per million	Occasional failures are observed during the process.
5	≤ 500 per million	Common failures with some regularities are observed during the process.
6	≤ 2,000 per million	Chronic failures are observed on a regular basis during the process.
7	≤ 10,000 per million	Failure is uncertain with new process design/change in operating conditions.
8	≤ 20,000 per million	Failure is likely with new process design/change in operating conditions.
9	≤ 100,000 per million	Failure is inevitable with new process design/change in operating conditions.
10	> 100,000 per million	New process design with no history.

Table 7: Standard Reference For Detection Input

Detection Ranking	Likelihood of Detection	Description
1	Almost certain	Operation is disrupted due to the error / failure found in the product.
2	Very high	Alarm / machine error triggered due to failures prior the manufacturing process (pre-process). Operation stops automatically until corrective actions are completed to prevent nonconforming parts from being made.
3	High	Alarm / machine error triggered due to failures during the manufacturing process (in-process). Operation stops automatically until corrective actions are completed.

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4	Moderately high	Alarm / machine error triggered due to failures after the manufacturing process (post-process). Operation stops automatically until corrective actions are completed.
5	Moderate	Failures detected during the manufacturing process (in-process) by operator using automated measurement techniques.
6	Low	Failures detected after the manufacturing process (post-process) by operator using automated measurement techniques.
7	Very low	Failures detected during the manufacturing process (in-process) by operator using manual / visual inspection.
8	Remote	Failures detected after the manufacturing process (post-process) by operator using manual / visual inspection.
9	Very remote	Failures cannot be detected at any manufacturing process. Failures can be detected only during random checks such as reliability testing.
10	Almost impossible	Failures cannot be detected under any circumstances. Absolute certainty of non-detection in production.

A rough overview of the current practices of FMEA in the semiconductor industry was gathered in Section E. This information deepens the understanding of the application process of FMEA, drawing not only from previous studies conducted by other researchers but also from real-world experiences. In this section, respondents highlighted various challenges and barriers encountered while carrying out FMEA activities. These challenges include difficulties in defining and validating failures when the primary root cause or suspect is unknown, encountering similar defects without access to relevant information or methods, lack of connection between FMEA and inline failures or customer complaints, and the absence of historical learning in the FMEA process. These challenges have made it time-consuming for engineers to solve the issues. Additionally, all respondents agreed on the need for an interactive computer assisted FMEA tool that allows for superior and/or cross-departmental review of a system's FMEA results periodically, aiming to ease the risk evaluation process in the manufacturing industry.

Process Name	
Process Owner	

FMEA Team Members	
Revison Date	

Serial No.	Process Step or Input	Potential Failure Modes	Potential Effects of Failure	SEV	Potential Causes of Failure	OCC	Current Process Control	DET	RPN	Recommended Actions	Action Results				
											Action Taken	SEV	OCC	DET	RPN

Figure 2: FMEA Worksheet Of The Computer Assisted FMEA Tool

The purpose of the information and data entry forms is to allow users to enter information related to the identified potential failure modes for risk ranking. These forms include the Process Information Form, the Process Failure Data Entry Form, and the Action Result Form.

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Figure 3, Figure 4, and Figure 5 show the information and data entry forms designed for the interactive FMEA tool.

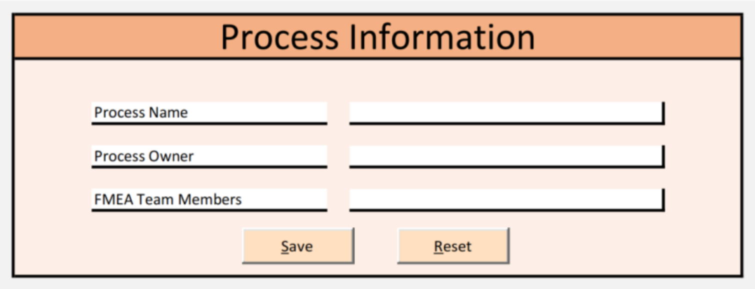

Figure 3: Process Information Form

Computer Assisted Interactive FMEA Tool
The main objective of this study is to develop an interactive FMEA tool for the semiconductor manufacturing industry. This tool aims to enhance the systematic nature of the risk assessment process in various systems, products, or processes, leading to more accurate and reliable FMEA results. In this study, the proposed tool was developed using Excel VBA and Tableau software.

At the beginning of the development of the proposed tool, several items such as the FMEA worksheet, information and data entry form, and the database, were created in the Excel software to act as the foundation of the interactive FMEA tool. The FMEA worksheet is a valuable tool used in risk management to systematically identify potential failures, their causes, and their associated consequences in a system, product, or process. In the proposed tool, the FMEA worksheet is used to present the final risk assessment result generated by the interactive FMEA tool. Figure 2 shows the FMEA worksheet developed for the interactive FMEA tool.

The function of the Process Information Form is to allow users to enter basic information related to the systems or processes being analyzed. This includes the process name, process owner, and the FMEA team members involved in the risk evaluation process. This information is then presented at the header of the FMEA worksheet, providing essential contextual details and ensuring clarity, accountability, and good collaboration throughout the FMEA analysis and subsequent actions.

The purpose of the Process Failure Data Entry Form is to enable users to enter potential failure modes identified in a system or process and to determine their related information, such as the effect, causes, and current control measures. Users can also propose recommended actions in this form to mitigate the effects of identified potential failures and improve the performance of the system or process being analyzed. To identify the criticality of the risk posed by each potential failure mode, users are presented with several questions related to the severity, occurrence, and detection of the failures. These questions are constructed based on the standard reference for risk factor input built in the previous section. With the user's responses, the interactive FMEA tool can accurately determine the ranking for each risk factor by referring to the risk factor library embedded in the tool's macro and calculating the RPN values of the potential failure modes by multiplying the values of the identified risk factor rankings.

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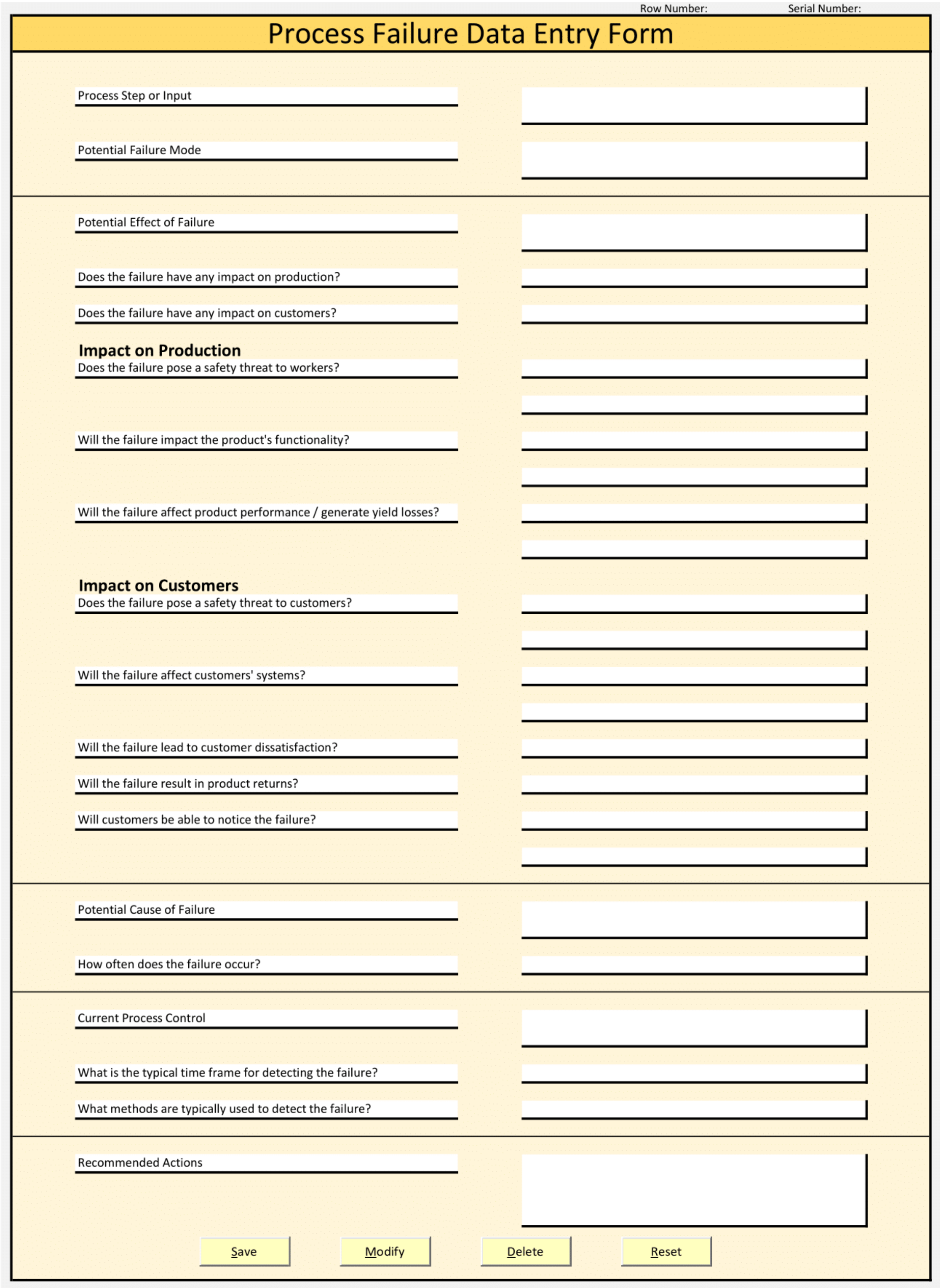

Row Number: Serial Number:

Process Failure Data Entry Form

Process Step or Input

Potential Failure Mode

Potential Effect of Failure

Does the failure have any impact on production?

Does the failure have any impact on customers?

Impact on Production

Does the failure pose a safety threat to workers?

Will the failure impact the product's functionality?

Will the failure affect product performance / generate yield losses?

Impact on Customers

Does the failure pose a safety threat to customers?

Will the failure affect customers' systems?

Will the failure lead to customer dissatisfaction?

Will the failure result in product returns?

Will customers be able to notice the failure?

Potential Cause of Failure

How often does the failure occur?

Current Process Control

What is the typical time frame for detecting the failure?

What methods are typically used to detect the failure?

Recommended Actions

Save | Modify | Delete | Reset

Figure 4: Process Failure Data Entry Form

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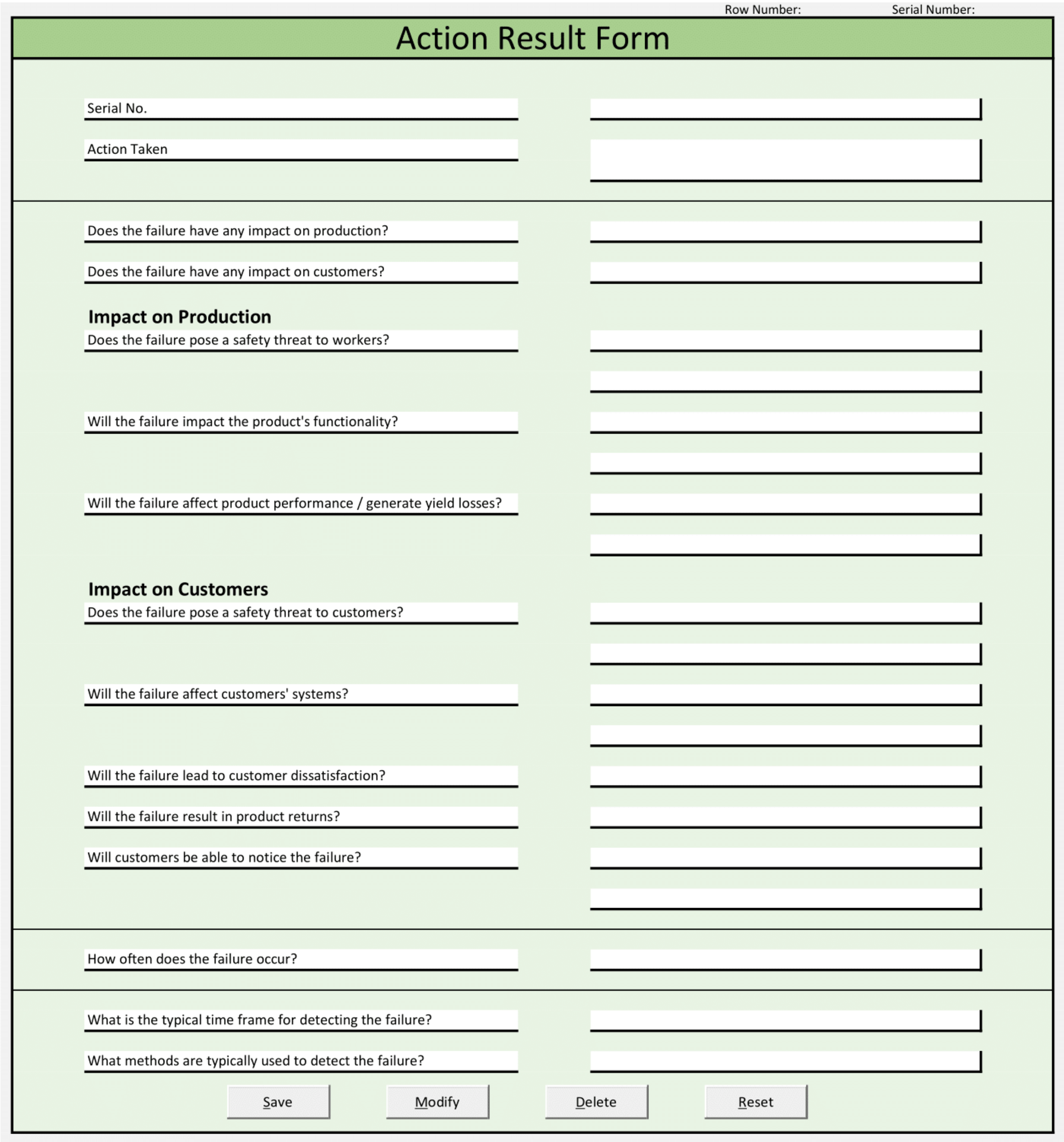

Figure 5: Action Result Form

Another form developed in the computer assisted FMEA tool is the Action Result Form, which allows users to enter the actions taken on the potential failure modes. In this form, users are required to define the serial number of the potential failure modes for which they have taken actions and clearly describe the actions they have taken to mitigate the effects of the failure modes. The same questions as in the Process Failure Data Entry Form are presented again to users in this form to reassess the severity, occurrence, and detection rankings of the failures, enabling the calculation of new RPN values.

At the bottom of each form, interactive command buttons such as ‘Save’, ‘Modify’, ‘Delete’, and ‘Reset’ are added to provide graphical user interface (GUI) elements that allow users to trigger specific actions. For instance, the ‘Save’ button in the Process Information Form allows users to save the process name, process owner, and the FMEA team members of the system being analyzed in the header of the FMEA worksheet. Meanwhile, the ‘Reset’ button clears all

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related information in the FMEA worksheet and resets the form to a blank state. For the Process Failure Data Entry Form and the Action Result Form, four interactive command buttons are incorporated. The ‘Save’ button validates the data entered by users, ensuring that it meets specific criteria or conditions before proceeding to save the information into the FMEA worksheet, identify the risk factor rankings, and calculate the RPN values. The ‘Modify’ button allows users to modify the data and information in the FMEA worksheet by retrieving the existing data and information of a specific potential failure mode from the database. The ‘Delete’ button removes all information related to a specific potential failure mode in the FMEA worksheet, while the ‘Reset’ button resets the forms to a blank state. Overall, these interactive command buttons play a major role in the interactive FMEA tool, enhancing the user experience by providing a visual and intuitive way for users to interact with the VBA macros and perform specific actions in Excel.

In addition to the FMEA worksheet and the information and data entry forms, a database has also been created in the Excel software for the purpose of data storage. All the information entered by users in the information and data entry forms will be stored in this database for data retrieval if modifications to the existing data or information in the FMEA worksheet are desired. To avoid data corruption and prevent malicious tampering, the database of the interactive FMEA tool will always be hidden. Figure 6 shows the database of an interactive FMEA tool.

Serial No.	Process Step or Input	Potential Failure Modes	Potential Effect of Failure	Does the failure have any impact on production?	Does the failure have any impact on customers?	Does the failure pose a safety threat to workers?	if yes?	Will the failure impact the product's functionality?	if yes?	Will the failure affect product performance / generate yield losses?	If yes?

Does the failure pose a safety threat to customers?	if yes?	Will the failure affect customers' systems?	if yes?	Will the failure lead to customer dissatisfaction?	Will the failure result in product returns?	Will customers be able to notice the failure?	if yes?	Potential Cause of Failure	How often does the failure occur?	Current Process Control	What is the typical time frame for detecting the failure?

What methods are typically used to detect the failure?	Recommended Actions	Action Taken	Does the failure have any impact on production?	Does the failure have any impact on customers?	Does the failure pose a safety threat to workers?	if yes?	Will the failure impact the product's functionality?	if yes?	Will the failure affect product performance / generate yield losses?	if yes?	Does the failure pose a safety threat to customers?

if yes?	Will the failure affect customers' systems?	if yes?	Will the failure lead to customer dissatisfaction?	Will the failure result in product returns?	Will customers be able to notice the failure?	if yes?	How often does the failure occur?	What is the typical time frame for detecting the failure?	What methods are typically used to detect the failure?

Figure 6: Database

After creating the FMEA Excel VBA template that can automatically generate accurate and reliable FMEA results with minimal manual effort required for analyzing historical data, the development of the interactive FMEA tool proceeds with the construction of the web-based dashboard using Tableau software. The purpose of designing this dashboard is to facilitate users by allowing them to review and monitor the FMEA analysis of a system or process remotely and in real-time. Additionally, it enhances the sharing of information among cross-departmental teams within the organization. The incorporation of several graphical illustrations in the web-based dashboard also provides a better visualization of the overall status of the systems or processes being analyzed. Information such as the total number of process steps with identified potential failure modes, the status of actions taken to mitigate the effects of

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failures, changes in RPN, the RPN reduction ratio, and other important details regarding the potential failure modes of the system can be obtained. Figure 7 shows an example of the web-based dashboard of the computer assisted FMEA tool developed using Tableau (tableau.com).

The web-based dashboard shown in Figure 7, was developed using Tableau. The layout of the dashboard was designed by incorporating suitable elements, such as pie charts, bar charts, doughnut charts, and other suitable data visualization widgets, to present the status of potential failure modes in the systems or processes being analyzed. Table 8 concludes the roles of each of the elements presented in the designed dashboard.

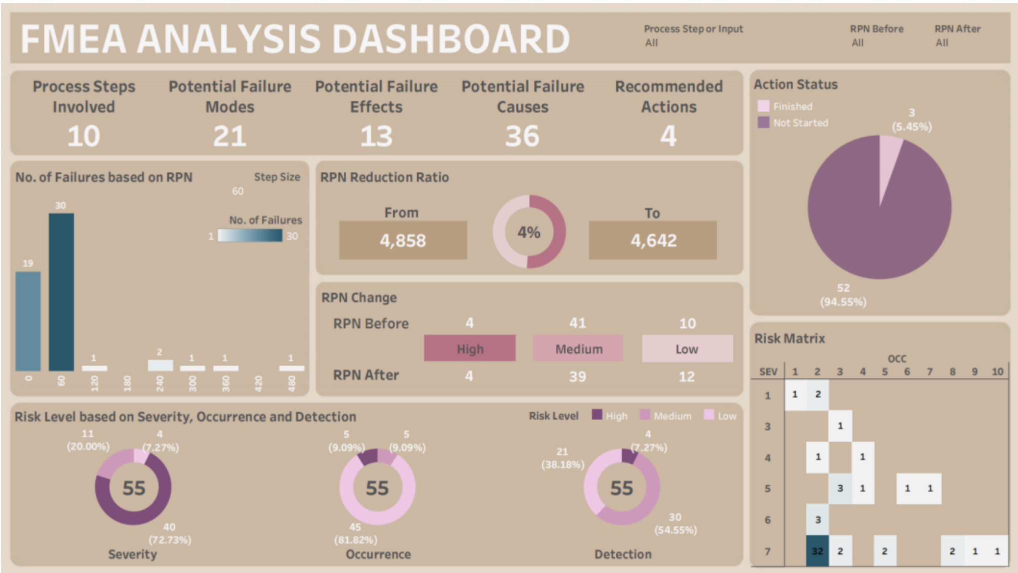

Figure 7: Web-Based Dashboard Of The Computer Assisted FMEA Tool

Table 8: Roles Of Each Element Presented In The Web-Based Dashboard

Element	Description
FMEA summary	Summarizes the total number of process steps with identified potential failure modes, the total number of identified potential failure modes, the number of potential effects, potential causes, and recommended actions that can be taken to mitigate the risk of the identified potential failure modes
No. of failure based on RPN	Presents the number of potential failure modes for different ranges of RPN values
Action status	Indicates the status of the action taken on the identified potential failure modes, showing whether mitigation actions have been implemented
RPN reduction ratio	Measures the total reduction of RPN values after implementing risk mitigation actions on the identified potential failure modes
RPN change	Visualizes the changes of RPN values before and after implementing risk mitigation actions on the identified potential failure modes

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Risk level based on severity, occurrence, and detection	Presents the risk factor level of the identified potential failure modes in three categories: high, medium, and low, based on severity, occurrence, and detection ratings
Risk matrix	Provides a visual representation of the number of potential failure modes with different levels of severity and occurrence, helping to assess the overall risk profile

The development of the web-based dashboard is then continued by connecting the data file containing the results of the FMEA analysis to the data source of the dashboard. This dashboard is then published to the Tableau server, and a data refresh schedule is set to ensure that the FMEA analysis results displayed by the dashboard are always up to date.

Now, the development of the interactive FMEA tool with an automated FMEA Excel template and a web-based dashboard has been completed. This tool is expected to be useful for industrial usage as it facilitates the users in terms of minimizing the time required to carry out the FMEA analysis, providing a more comprehensive visualization of the potential failure modes identified in the analyzed systems or processes, and enhancing the sharing of information within the organization.

First Testing of the Computer Assisted FMEA Tool

The ability and practicality of the developed interactive FMEA tool in providing valid FMEA results effectively were then tested in the real semiconductor manufacturing industry. The first testing of the tool was carried out at Engineer A’s department for one week. Due to the confidentiality of company information, Engineer A can only provide comments regarding the tool being tested instead of the actual testing results.

Several feed backs were provided by Engineer A after the first testing. For example, the developed interactive FMEA tool could be incorporated with some additional features, such as allowing the users to define customizable RPN ranges for high, medium, and low risk levels instead of using fixed ranges. This additional feature plays a major role in providing more flexibility to the developed tool, opening chances for the tool to be used in any manufacturing industry as the standard of risk level ranking may vary between companies. Other than that, Engineer A mentioned that the overall performance of the developed tool is great. The process of using the tool is smooth, and it greatly facilitates the risk evaluation process by minimizing the need for historical data analysis and reducing the time required to assess the potential risks associated with the systems or processes being analyzed.

FMEA Tool Improvements

Improvements were made to the developed interactive FMEA tool after the first testing to further enhance its performance. One significant change made to the tool is the addition of an RPN value setting section in the Process Information Form. This allows users to modify and define the ranges of RPN values for different risk levels. Figure 8 displays the improved version of the interactive FMEA tool, featuring the newly added RPN value setting section in the Process Information Form.

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Volume 9 Issue 36 (September 2024) PP. 90-108
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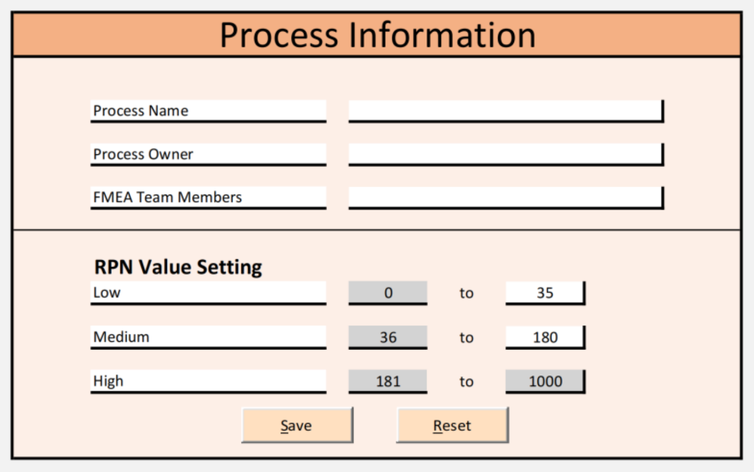

Figure 8: Process Information Form Of The Improved Interactive FMEA Tool

The improved version of the interactive FMEA tool allows users to modify the ranges of RPN values for different risk levels by adjusting the upper boundary values for low and medium risk. Modifications are restricted for other boundary values, and the cells for restricted values are locked and grayed out. These restricted boundary values are either fixed or can be automatically generated based on the upper boundary values entered by users for low and medium risk. For example, the lower boundary value for the low-risk level and the upper boundary value for the high-risk level are fixed at 0 and 1000, respectively. Meanwhile, the lower boundary values for both medium and high risk levels will be generated automatically after users have entered the upper boundary values of the low and medium risk levels.

The RPN value setting section of the improved tool is also associated with preset RPN ranges to facilitate engineers with insufficient experience in setting the RPN ranges for different risk levels. By default, the RPN ranges for low, medium, and high risk levels will be set as 0 to 35, 36 to 180, and 181 to 1000, respectively (Rezaei et al., 2018). Additionally, different color codes such as red, yellow, and green have been assigned to different ranges of RPN values to provide a better visualization of the criticality of identified potential failure modes in a system or process. Figure 9 showcases an example of the FMEA worksheet of the improved interactive FMEA tool.

Process Name	ABC Process	**FMEA Team Members**	ViLynn
Process Owner	ViLynn	**Revison Date**	19/7/2023

Serial No.	Process Step or Input	Potential Failure Modes	Potential Effects of Failure	SEV	Potential Causes of Failure	OCC	Current Process Control	DET	RPN	Recommended Actions	Action Results				
											Action Taken	SEV	OCC	DET	RPN
1	Step 1	Failure 1	Effect 1	3	Cause 1	3	Process Control 1	2	18	Recommendation 1	Action 1	1	3	1	3
2	Step 2	Failure 2	Effect 2	7	Cause 2	6	Process Control 2	3	126	Recommendation 2	Action 2	5	5	2	50
3	Step 3	Failure 3	Effect 3	8	Cause 3	7	Process Control 3	5	280	Recommendation 3					
4	Step 4	Failure 4	Effect 4	4	Cause 4	3	Process Control 4	7	84	Recommendation 4					
5	Step 5	Failure 5	Effect 5	9	Cause 5	3	Process Control 5	5	135	Recommendation 5	Action 5	6	4	5	120

Figure 9: FMEA Worksheet Of The Improved Interactive FMEA Tool

Second and Third Testing of the Interactive FMEA Tool

The enhanced interactive FMEA tool was sent to Engineer A again for the second evaluation. After testing the enhanced tool for one week, Engineer A commented that the overall performance of the enhanced tool is good, and it is now suitable to be used in any semiconductor industry due to its ability to evaluate the risks associated with any

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EISSN: 0128-1666
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manufacturing process and its flexibility in allowing users to define the RPN ranges for different risk levels.

To further verify the performance of the developed tool, it was sent to Engineer B, another engineer in Engineer A's company responsible for another manufacturing process, for the third evaluation. The purpose of Engineer B's evaluation is to confirm the tool's effectiveness and practicality in a different user context, providing additional insights into the tool's performance and usability.

The feedback provided by Engineer B after trying out the enhanced tool for one week stated that the performance of the enhanced tool is excellent. The FMEA Excel template can automate the determination of risk factor ranking, and the risk factor levels generated by the tool are mostly accurate, as they are almost similar to the company's standard. With this enhanced interactive FMEA tool, a more reliable RPN value for each of the identified potential failure modes can be computed, and users do not have to refer to the historical data and risk evaluation guidelines developed by the company during the FMEA analysis. This significantly reduces the time required to evaluate the potential failure modes identified in a system or process. Additionally, the web-based dashboard in the interactive FMEA tool aids in displaying a better visualization of the risk assessment results. It allows managers, cross-departmental teams, and other related personnel to understand the status of the identified system or process risks more easily during presentations and group discussions.

Overall, the enhanced interactive FMEA tool holds significant potential for industrial usage. Its ability to streamline the FMEA analysis process, provide a comprehensive visualization of the identified potential failure modes, and enhance information sharing within organizations makes it a valuable tool for risk assessment in the semiconductor manufacturing industry and beyond.

Potential Improvements of the Enhanced Tool

Although the feedback provided by both Engineer A and Engineer B on the enhanced interactive FMEA tool developed in this project is positive, there is still room for improvement to further enhance the performance of the proposed tool. Since FMEA is a quality control process commonly used in various industries to identify, analyze, and mitigate potential failures or risks in a system or process, quality improvement tools such as a Pareto chart can be incorporated to identify and prioritize the factors contributing to a problem or failure.

A Pareto chart is a visual tool that helps analyze and prioritize data by displaying the relative importance of different factors. It is based on the Pareto principle, also known as the 80/20 rule, which suggests that roughly 80% of the effects come from 20% of the causes (Harvey & Sotardi, 2018). By incorporating a Pareto chart in the web-based dashboard of the interactive FMEA tool, the most significant potential failure modes that contribute to the major loss of a system or process can be identified, allowing users to implement preventive actions prior to the occurrence of the failure so that the potential effects of the identified potential failure modes can be mitigated. The Pareto chart is commonly used in various fields, such as quality control, project management, and problem-solving, to provide valuable insights by highlighting the critical few factors that contribute the most to a particular problem or failure. By incorporating this quality tool in the interactive FMEA tool, the evaluators can make informed decisions and focus their efforts and resources on the areas that will yield the greatest improvement or impact.

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Conclusion

This study has contributed to the development of the current FMEA technology by introducing an interactive computer assisted FMEA tool suitable for use in the semiconductor industry. This tool has improved the effectiveness, accuracy, and reliability of the existing FMEA approach by incorporating a standard reference for risk factor inputs that provides a comprehensive tool for assessing the severity, occurrence, and detection of potential failures in the semiconductor industry. This standardized reference serves as a valuable library for the interactive FMEA tool, allowing the ranking of risk factors for the identified potential failure modes in any system or process to be generated automatically based on the responses provided by the users in the information and data entry forms. Meanwhile, the web-based dashboard of the interactive FMEA tool presents a summary of the FMEA analysis by incorporating suitable data visualization tools, allowing users to review the risk assessment results of a system or process remotely and in real time.

The interactive FMEA tool is suitable for use in any semiconductor industry due to the generality of the constructed standard reference for risk factor input and the flexibility of the RPN ranges setting for different risk levels. With this developed tool, users can analyze the risk associated with any systems or processes much faster, improving the time-consuming nature of the traditional FMEA approach as they do not have to deal with extensive data analysis. Overall, the interactive FMEA tool developed in this study enhances the risk assessment process by providing a user-friendly interface and reliable risk assessment results, contributing to improving the reliability, safety, and performance of systems and processes in the semiconductor manufacturing industry.

Acknowledgement

The authors would like to express gratitude to Universiti Kebangsaan Malaysia (UKM) for supporting this project.

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