EMGT 835 FIELD PROJECT:
Human Factors Process Failure Mode and Effects Analysis (HF PFMEA) Application in the Evaluation of Management Risks

By

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Executive Summary

Human errors in engineering processes do not usually get analyzed and evaluated in terms of their risks, much less management errors. Not much effort is expended on management errors and risks analysis, probably because not many have come to realize the connection between those errors and the product functional problems.

Product functionality is influenced by a number of factors, including its design and production. Design and production are controlled by humans: operators, engineers and managers. Operators run production. Engineers create product designs and systems for production. Managers come into play with their supervision, planning, task scheduling and decision making.

This research aims to answer Felix Redmill's call for research on the evaluation and estimation of management risks. This work suggests that manager's errors indeed contribute to issues that lead to product functional problems. These errors and issues need to be addressed. The result of which is beneficial in the achievement of total quality.

The research employed the Human Factors Process Failure Mode and Effects Analysis (HF PFMEA) methodology to get to the root causes of product issues. Results from the research project revealed that management errors, in resources management and development and in project planning and communication tasks, contribute to product functional problems. The research method also allowed management risks to be evaluated in terms of priority number values that are helpful and important in determining priorities for improvement action plans.

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Chapter 1 – Introduction

In engineering processes, human errors rarely get analyzed and evaluated in terms of their risks, much less management errors. To the author's knowledge, based on her research and her eleven years of work experience as a Product Development Engineer, not much effort has been given to the analysis of the connection between management errors and product functional problems.

Product functionality is influenced by a number of factors, including design and production. Design and production are controlled by humans: operators, engineers and managers. Humans obviously influence product functionality. Operators run the systems in product manufacturing, while engineers create the product designs and the systems used. Managers come into play in supervising the operators and engineers, in planning and taking care of task schedules, and in making decisions related to the product and its production.

In this research, the author made use of the indirect connection between management errors and the product functional problems. That indirect connection or link is composed of the engineers and their tasks. The engineers have direct influence on product functionality through their tasks. The managers have direct influence on engineers and their tasks. That link therefore, was used as the starting point to conduct and employ the systematic method of Human Factors Process Failure Mode and Effects Analysis (HF PFMEA) to analyze the human errors in the engineering processes that caused product

functional issues. The same method and data was then used to determine and evaluate the management errors and risks that led to product functional issues.

Felix Redmill, a self-employed consultant on risk management, project management and quality improvement, and a Member of the Institute of Quality Assurance, wrote in 2002 that risk analyses force analysts to identify and enquire into risks and their causes and consequences. In his papers, which cover human factors risk analysis, he argues for the need of attention toward the analysis and understanding of the risks posed by management. He notes that, historically, the risks posed by management are neither addressed by risk analysis nor included in safety cases (Redmill, 2002).

The author agrees with Redmill that not addressing the risks posed by all human operators, including engineers and managers, means that risk analyses are necessarily underestimates (Redmill, 2002). If management's issues are included in risk analyses and are addressed, not only would there be a truer representation of risks, but "*there would also be a basis for the assessment and improvement of an organization's corporate governance*" (Redmill, 2006).

The research here reported was conducted to answer Redmill's call for research on the evaluation and estimation of management risks.

This research was conducted at one of the leading semiconductor companies in the country. The data and information used in the research analysis were gathered from one of the company's factories through the help of 15 of its Product Engineers and Group Leaders. The research concentrated on issues encountered in Product Engineering.

Chapter 2 – Literature Review

Presented in the first two sections of this literature review chapter is developed information relating to the definition of total quality, and the obstacles in achieving TQM. The definition of total quality is important in understanding the quality management concept. Knowing the obstacles to TQM is helpful in achieving TQM.

In the third section is a concise discussion of the concept of continuous improvement. Among the benefits from FMEA is continuous improvement. It is also a key component in achieving total quality.

The last three sections of the chapter contain fundamental information on HF PFMEA and FMEA methodology and components. Understanding the FMEA components is important in gathering good and valid FMEA data.

2.1. Total Quality

Quality is one of the fundamental concerns of management. As defined in the American Management Association's Management Handbook, *"quality is conformance to standards or requirements"* (Fallon 1983, 4-107). The standards of performance are set by management based on their interpretation of the demands of the market. Successful companies have expanded the definition of quality to include design and service quality by "*incorporating the requirements of the customer into the product design and service while retaining conformance quality*" (Brunetti, 1993, 3). Companies and organizations

now translate customers' words and ideas into product design and service specifications. This is total quality.

Customers are the important factors in this total quality definition. A classical sense of customers that most people had is that they are the ones who pay directly for the product and services offered. This also has expanded. Nowadays, the most widely used definition is that the customer is the next process (Brunetti, 1993, 3). This is the expansion of the classical idea of the customers to include not only those who were traditionally called customers, but also the myriad of internal customers, i.e., employees. Thus, this definition of total quality includes those whose work-product is an integral part of satisfying the ultimate customer's requirements.

2.2. Obstacles to Total Quality Management (TQM) Success

Total Quality Management (TQM) is a management approach for long-term success through customer satisfaction. All members of the organization must participate in the TQM efforts to improve processes, products, services and even their culture (Brunetti 1993, 21).

Several studies have developed instruments to measure quality management or TQM (Tari, Molina and Castejon, 2005). Rose Sebastianelli and Nabil Tamimi, from the University of Scranton, performed a study in 2003, wherein they conducted a survey-based research. Their research focused on the obstacles associated with managing the

TQM transformation. Their factor analysis on managers' ratings of frequently cited barriers to TQM revealed five underlying constructs:

1. Inadequate human resources development and management.
2. Lack of planning for quality.
3. Lack of leadership for quality.
4. Inadequate resources for TQM.
5. Lack of customer focus.

The two benefits from the FMEA methodology used in this research are problem prevention and continuous improvement. In order to achieve improvement, and eventually TQM, problems must be realized and analyzed. In the analysis, root-causing problems are critical. Root causes must be detected at the earliest point possible, if they cannot be totally prevented (Khuram 2003).

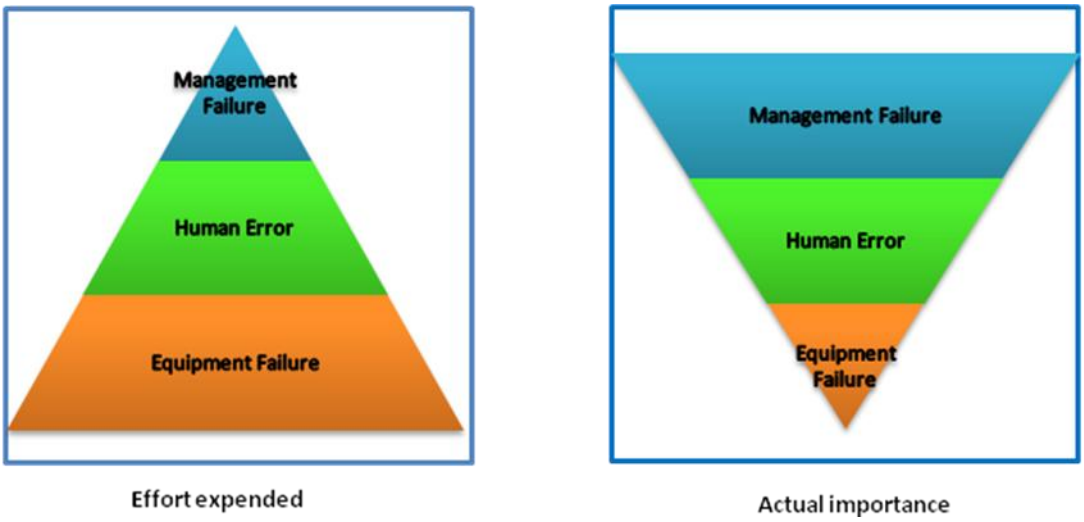
2.3. The Concept of Continuous Improvement

Continuous improvement on everyone's work is the main concern of TQM (Brunetti, 1993). A central principle of it is mistakes may be made by people. Most of them are caused or at least permitted, either by faulty systems and/or processes. As such, the root cause of those mistakes can be identified and eliminated. Repetitions can also be prevented by changing or improving the process. Continuously improving capabilities, people, processes, technology, and machine capabilities all lead to continuously improving overall results (Khuram, 2003).

There is no denying that most companies and organizations allocate time and resources for their people development. Engineers get required to attend to more and more trainings as preventive measures for possible errors they could commit.

Figure 1 is an illustration of the effort expended on different causes of accidents and their actual importance. This illustration was used by Redmill in his article, "*Human Factors in Risk Analysis*", published in 2002. His intention was to show that the effort expended on the improvements on management failures is relatively smaller than its actual importance. Based on the author's observations, from her eleven years of work experience as a Product Engineer, she sees this illustration as relevant and applicable not only on safety issues but also on engineering process and/or product issues.

Figure 1. The effort expended on different causes of accidents and their actual importance (Redmill, 2002).



2.3.1. Mechanisms of Prevention

Having a quality culture does not mean that one can never go wrong. It implies that there should be mechanisms in place to detect errors and problems. Corrections are made and they are made at the root cause. Not doing so means merely covering up the problem symptoms.

The three major mechanisms of prevention are (Khuram, 2003):

1. Preventing mistakes from occurring.
2. Where mistakes can't be absolutely prevented, detecting them early to prevent them being passed down the value added chain.
3. Where mistakes recur, stopping production until the process can be corrected, to prevent the production of more defects.

The following remaining sections of the chapter provide the review of the HF PFMEA and FMEA concepts and methodology that were used in the research. Understanding the components of FMEA is helpful in understanding the method and results of the research.

2.4. Human Factors Process Failure Mode and Effects Analysis (HF PFMEA)

Failure Mode and Effects Analysis (FMEA) is a standardized and systematic methodology for evaluating ways in which failures can occur in a system, design, process, equipment, or service. It is a known risk management tool that when used correctly eliminates risk in a process, equipment or service. Benefits from FMEA are problem prevention and continuous improvement (Bolanos, 2007).

Human Factors Process Failure Mode and Effects Analysis, HF PFMEA, is the application of FMEA on human factors. It provides a systematic way of analyzing human errors and their risks. It involves the analysis of tasks within a process to identify the human errors that may lead to failures, and the worst-case effects of those errors. HF PFMEA is based on the philosophy that human errors must be accounted for and can be controlled. It can be done by managing the performance shaping factors affecting the human performance (Dunkle, 2005). HF PFMEA also provides a generic method that can be applied to a variety of processes.

Table 1 shows the FMEA template that was used in the data collection for this research.

Table 1. The FMEA template used for the research (Source: Failure Modes and Effects Analysis Training. FMEA – IQT008191 Rev. 6.0. Oct. 2001.).

Process	Process Function/ Requirement	Potential Failure Modes	Potential Effect(s) of Failure	Severity	Potential Cause/ Mechanism of Failure	Occurrence	Current Process Controls (Prevention)	Current Design Controls	Detection	RPN (Risk Priority Number)
Your Operation, Module Team, Work Area_Main Area.	Sub Area, Step with in your operation, Sub Module, Sub Component of your module	What will go wrong or could go wrong or how would you identify that something is wrong at this operation	What will happen to the product/the factory if this happens? What is the consequence of this happening?		Is this because of a Human Error or mis process, is there the slightest possibility that a human committed this error or is the cause of the error. In what step of the operation the operator committed the mistake. Include all possible situations where a human can cause this failure mode or event in the factory.		Are you relying on a human to prevent this from happening (preventing column F), is your prevention mechanism a human intervention at some point in the process, either this same operation or an operation downstream	Are you relying on a human to Detect this from happening (preventing column F), is your detection mechanism a human intervention at some point in the process, either this same operation or an operation downstream		

2.5. FMEA Components

To fully understand the FMEA methodology, it is important to first understand its key components. The following sub-sections discuss the FMEA components.

2.5.1. Failure Mode

The potential failure mode is defined as the manner in which the process could potentially fail to meet the process requirements or design intent (Bolanos, 2007). In order to do so, tasks within a process need to be identified. In this research, the tasks considered, to get the failure modes, are the tasks involved in the test program implementation process.

2.5.2. Effect and Severity

Potential effects of the failure are defined as the effects of the failure mode on the product and/or on the customer. Severity is the rank associated with the most serious effect for a given failure mode. It is a relative rank that measures, in an objective manner, the impact that may result if the failure mode happens (Bolanos, 2007). Table 2 lists the severity ranks used for the evaluations and analyses done in the research.

Table 2. Severity ranks. (Source: FMEA Ranks' reference criteria tables, rev04a. Internal Publication. Bolaños, E. J. CR AT. 2006.)

Rank	Severity (%loss) * per unit of measurement	Criteria (commonly used)	Comments (commonly used)
1	0.0000 – 0.00009	No Fallout, Negligible	0 devices lost. Key Word: Zero, once, one.
2	0.0001 – 0.4999	Very low yield fallout, almost	1-5 devices lost among many.

		unnoticeable. Low line yield loss	Key words: Two, couple and few (3-5).
3	0.5000 – 0.9999	Noticeable yield fallout. Minor yield fallout, but not meeting yield issue (YI) criteria	More than five but less than 10 devices. Key words: Several
4	1.0000 – 4.9999	Significant line yield loss. Major Yield loss. Meeting YI criteria	More than 10 devices. Key Words: Many, level excursion
5	5.0000 – 9.9999	Major Yield hit	High level excursion
6	10.000 – 24.999	Major Yield hit	Required re-screening
7	25.000 – 49.999	Major Yield hit	Required re-screening
8	50.000 – 74.999	Major Yield hit	Required re-screening
9	75.000 – 99.999	Major Yield hit	Required re-screening
10	100.00%	Complete loss of material	Scrap 100% of the devices

2.5.3. Cause and Occurrence

Potential causes are defined in terms of why the failure could occur. They are described as something that can be corrected or can be controlled (Bolanos 2007). The most important considerations in the analysis of this component include the definition and listing of all the possible failure causes assignable to each and every single potential failure mode.

Occurrence is the rank associated with the root cause of the potential failure mode. It is the measure of the frequency of occurrence. In an objective parameter it is called the probability of occurrence (Bolanos 2007). In this research, this parameter was defined as a function of a complete calendar year against the amount of working shifts the factory has in that year. It was calculated based on the occurrence per unit time. Table 3 describes in detail the ranks of the probability of occurrence used for this research.

Table 3. Occurrence ranks. (Source: FMEA Ranks' reference criteria tables, rev04a. Internal Publication. Bolaños, E. J. CR AT. 2006.)

Rank	Occurrence [max occurrence per year]	Criteria [events/time unit] (commonly used)	Comments (commonly used)
1	0.01%	Once per Year	Key words: Remote, Once ever
			Probability of 0.000009 to 0.000115741
2	0.05%	Once per quarter	Key words: Very Low
			Probability of 0.000116 to 0.000462963
3	0.14%	Once per Month	Key words: Low
			Probability of 0.000463 to 0.001388889
4	0.23%	Few (5) per Quarter. 3-5 events per qtr	Key words: Low-Moderate
			Probability of 0.00139 to 0.002314815
5	0.60%	Once per week	Key words: Mid-Moderate
			Probability of 0.002315 to 0.005952381
6	1.39%	Several (10) per month. 5-10 events per month	Key words: High-Moderate
			Probability of 0.006 to 0.013888889
7	2.98%	Few (5) per week	Key words: High
		3-5 events per week	Probability of 0.014 to 0.029761905
8	7.14%	Many (>10) per week. 10 to 12 events per week	Key words: High
			Probability of 0.0298 to 0.071428571
9	50.00%	Many (>10) per day	Key words: Very High
		Happens every two hours	Probability of 0.072 to 0.5
10	100.00%	Many (>10) per shift. Event happens every hour.	Key words: Extremely High
			Probability of 0.51 to 1.0

2.5.4. Process Control Mechanisms

Process control mechanisms are the controls that are currently in place to either detect the failure mode should it occur, or prevent it from occurring. The two common types of process controls to consider are: prevention and detection systems. The first prevents the cause while the second detects the cause of the potential failure mode (Bolanos 2007). The ranks used in the FMEA were developed based on the time-to-detect probability or

expected through put time (TPT), that the product may have during the process. Table 4 shows the ranks used in the research.

Table 4. Detection and containment ranks. (Source: FMEA Ranks' reference criteria tables, rev04a. Internal Publication. Bolaños, E. J. CR AT. 2006.)

Rank	Control detection	Criteria [Extension or magnitude of the issue on downstream operations]	Comments (could vary depending on the process)
1	Internal [beginning of the process]	Extremely High probability of detecting within the same lot [thus preventing excursions on downstream, modules]	100% of units accounted @op0
			Time to Detect: 1-3 hrs
2	Internal	Very High probability of detecting the issue within two lots [will detect at the start of the second/next lot]	50% of units accounted @op0
			50% of units accounted @op0+1
			Time to Detect: 3-6 hrs
3	Internal	High probability of detecting the issue within a few lots. [No more than 3 lots affected]	50% of units accounted @op0+1 and @op0+2
			Key Words: Few [3-5]
			Time to Detect: 6-9 hrs
4	Internal	High probability of detecting the issue within a few lots. [No more than 5 lots affected]	50% of units accounted @op0+2
			50% of units accounted @op0+3
			Key Words: Few [3-5]
			Time to Detect: 1 day
5	Internal	Moderate risk / probability of not detecting until several lots are affected.	50% of units accounted @op0+3
			50% of units accounted @BI^
			Key Words: Several [5-10]
			Time to Detect: 1-2 days
6	Internal	Considerable risk / medium probability of not detecting until many lots are processed. Can detect at the test/BI operation [in the case of an assembly issue]	100% of units accounted @BI
			Key Words: Many [>10]
			Time to Detect: 2-3 days
7	Internal	Detection point is at our test operations. High Risk. [Post test issues that may be detected by downstream modules like final visual]	50% of units accounted @BI
			50% of units accounted @Test
			Time to Detect: 3-4 days
8	Internal	Very low probability (but still some) of detecting at the test operations. Will be detected at the final visual inspections.	50% of units accounted @Test
	[End of process]		50% of units accounted @FVI
			Time to Detect: 4-5 days
9	External	Extremely low probability of detecting within the factory, will have DPM impact	100% of units accounted @End°
			+ Cost of addressing customer issue
			Time to Detect: 5-7 days
10	External	No probability of detecting within the factory, will have considerable DPM impact	100% of units accounted @End°
			+ Cost of addressing customer issue
			Time to Detect: >7 days

2.5.5. Risk Priority Number

Part of the FMEA analysis is the calculation of the Risk Priority Number (RPN). This is a simple parameter that is the result of the product of the three ranks assigned to each of the failure modes. The three ranks are the severity (SEV), the occurrence (OCC), and the detection (DET). The RPN formula is noted in equation (1).

$$SEV \times OCC \times DET = RPN \qquad (1)$$

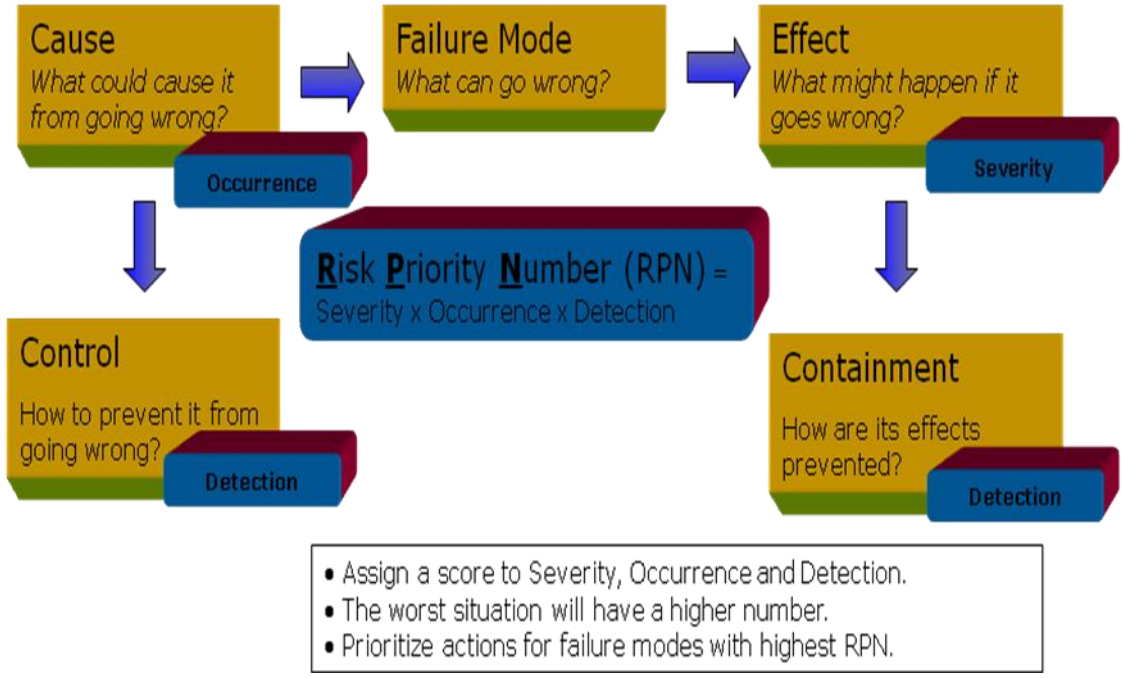
RPN is a simple criticality index number. The use of RPN is an extremely effective way to determine the risk priorities in an FMEA. Those with the highest values have the highest risks (Bolanos, 2007).

RPN computation may also be adjusted by weighting the three parameters depending on the concern of the analysis. Additional weight constants may be used for the areas that need more focus on.

2.6. FMEA Model

In Figure 2 is the FMEA model showing its components. Understanding all potential failure modes and exploring the methods to detect and prevent problems before they occur are key ingredients to a good FMEA (Bolanos, 2007). Devising and recommending possible action plans, which would reduce high risk failure modes, should not be the end of the method. It is important to monitor the process or system after the implementation of the recommended actions to verify their effectiveness.

Figure 2. FMEA model. (Source: Failure Modes and Effects Analysis Training. FMEA – IQT008191 Rev. 6.0. Oct. 2001.)



In summary, the review showed that TQM effort involves everyone in the organization. Everyone is expected to contribute to attain total quality. The review also showed that having a quality culture does not mean zero error. It implies the importance of having control mechanisms to detect errors and problems. Corrections must be made at the root cause. Different sources of errors include equipment, process and people. For this research, focus was on human errors, specifically on management errors. HF PFMEA methodology was used to analyze errors in engineering processes and tasks, which were later tied with management tasks and errors.

Chapter 3 – Research Method

In this chapter is the discussion of the method used in the research. The first section describes the data collection procedure and the second section describes the application of the HF PFMEA method in the analysis and evaluation of management errors.

3.1. Data Collection

The research was conducted in one of the factories of one of the leading semiconductor companies in the country. The research work was conducted while the author was a Graduate Technical Intern at the company.

Initial data collected consisted of production test issues that occurred over a period of three years, 2006 to 2008. Data was extracted from the company's issues database using a Quality and Reliability tool. The issues collected were first categorized based on the sources of the errors. The categories assigned for the problem sources are human-error, machine-error and non-Product Engineering (non-PE) issues.

The categorization of the issues was done by the author with the help of the company's Product Engineers, who owned and were also involved in the issues in question. Individual meetings were called in order to collect the information necessary for the categorization. The analyses done were focused on the problems that were owned by the Product Engineering Department and were human-error related.

The excursion data collected was used as the starting point to identify the processes that need to be analyzed. The necessary information was collected from the Product

Engineers, who were involved on the issues, through individual interviews and e-mail exchanges. Other senior Product Engineers, who are also experts on the processes in question, were asked for inputs on the analyses of the issues. They all have owned more than three products and they were responsible for the implementation of the processes and controls on the processes identified.

The FMEA template was presented to the Engineers as a guide for them to provide the information and data needed for the research. The template contained sets of questions for each column that need to be filled-up with information. They served as a guide for the Engineers, not only for them to correctly follow the FMEA method, but also to keep them focused on the human factors concern of the research.

In addition to the actual documented issues that occurred, the author also asked the engineers to include all other undocumented problems they encountered or could also possibly encounter on their processes. The undocumented issues refer to the errors that the engineers committed in their tasks but did not have any effect on the product, due to early detection. Such errors do not get documented as they do not produce any impact on the product. As such, they are not considered as valid issues. The intention here was to use the data for comparison and correlation purposes, to check for recurrences of those errors.

3.2. HF PFMEA and Data Analysis

The engineering processes identified in the research were determined based on the list of the human-error related issues collected. The processes were then broken down into tasks in order to determine all other possible issues and potential failure modes for each task.

Each failure mode was carefully and thoroughly analyzed to determine all the possible effects and root causes. Root causes were identified after asking and answering "why" several times and until all possible factors were considered.

The risks were evaluated and identified according to the FMEA's evaluation criteria, which were discussed in the FMEA components section in Chapter 2 (Literature Review) of this report.

Severity was used as the measurement factor for the effect of each failure mode on the product. This is the rank associated with the most serious effect for a given failure mode. Rank range is from one to ten, which is equivalent to its criteria range from no or negligible product fallout to 100% fallout or complete loss of materials.

In this research, the impacts of the errors were measured with respect to the impact of the effect on the product. If the errors committed resulted to zero fallout, the severity (SEV) of that effect is zero. This means there was no impact on the product yield and quality. Errors that fall in this case are usually the errors that get detected early in the production flow. The detection control mechanism for such failure modes and errors are good and effective.

The other end of the rank suggests that either products failed at test, thereby affecting the product output, or products passed, and would only later fail once used by the customers. The later suggests worst-case scenario because of the impact to product quality. It also means no working detection control mechanism was in place.

Each root cause was assigned with occurrence rank numbers, OCC, ranging from one to ten. OCC is the measure of the frequency of occurrence in an objective parameter called the probability of occurrence. This parameter was defined as a function of a complete calendar year against the amount of working shifts that the factories have in a year. For this research, the table was readily available from the factory. One is equivalent to once per year while 10 is equivalent to an occurrence of more than 10 times per shift, which is also equivalent to the event happening or occurring every hour.

Detection (DET) values were also assigned to each cause and effect. FMEA detection rank was developed based on the time to detect probability or expected through put time (TPT) that the products may have during the process. For the research, the rank table for this parameter was also readily available in the factory. Controls in place determine or affect the value of the detection. A rank value of one is equivalent to one to three hours of time-to-detect. A rank of 10 is equivalent to a time-to-detect value of more that seven days.

Also part of the FMEA analysis done is the calculation of the RPN. RPN is the result of the product of the three ranks assigned to each failure mode, which are the severity (SEV), the occurrence (OCC) and the detection (DET). As given in equation (1) in Chapter 2 of this report, RPN = SEV x OCC X DET. This value is a criticality index that dictates the

priority of the risks. With this value, the team or organization knows where to place the necessary resources to implement actions to reduce the risk level of an error or an issue.

Chapter 4 – Results

Discussed in this chapter are the data collected in the research and the results of the analysis done. The important error definitions to understand the results of this research are presented in the first section. Section 2 presents the issues that were used in the FMEA analysis. Sections 3 and 4 contain the management errors identified, as well as the results from the analysis and evaluation of those errors. In the last section of this chapter is the summary and conclusion made from the research data and its analysis.

4.1. Definitions and Considerations

In order to avoid confusion, the different errors used in the research and results discussion are defined below:

1. Engineer errors refer to errors committed by the engineers while performing their tasks, i.e. test program integration, test program implementation, and fuse file release.

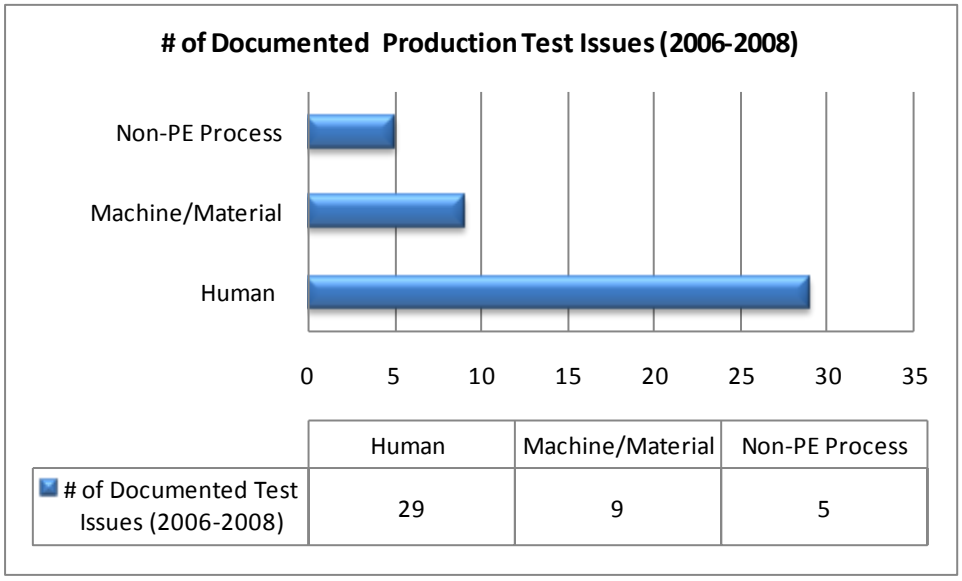
2. Manager errors refer to errors committed by the managers while performing their management tasks and responsibilities, i.e. project planning, resource development and management, and daily tasks and workload planning and allocation.

3. Engineer errors were used as the link between the product functional problem and the manager errors.

4.2. Issues

Figure 3 shows the summary of the number of documented excursions or production test issues collected. There were a total of 43 documented production test issues found. Twenty-nine of the issues were human-error related. The nine machine-error problems were not used in this research. The remaining five issues, which were classified as to have come from non-Product Engineer (non-PE) process issues were also not used in the research. They require investigation of issues coming from different departments other than the Product Engineering Department, and they are not within the scope of this research.

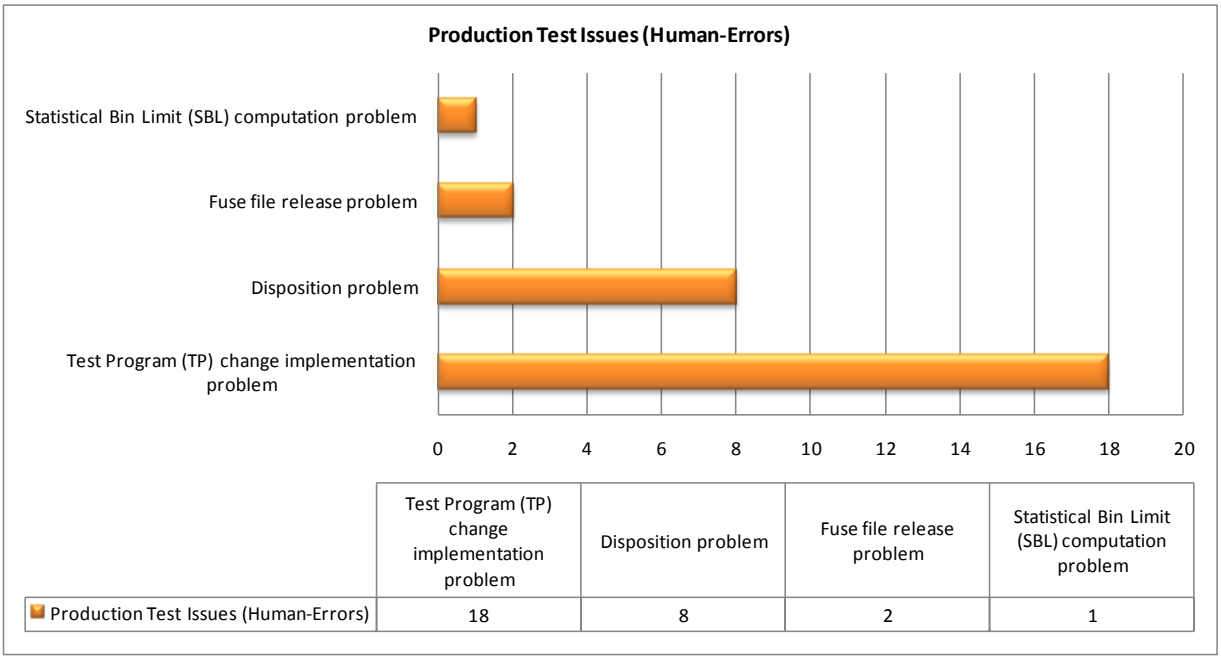
Figure 3. Number of documented production test issues from 2006 to 2008 and the sources of the problems.



The human-error related issues were further classified based on the processes from where the problems occurred. Figure 4 shows that 18 out of the 29 PE issues came from

problems on the test program implementation process. Eight issues came from disposition process problems, two from fuse file implementation process issues and one from the Statistical Bin Limit (SBL) computation problem.

Figure 4. Number of documented production test issues from 2006 to 2008.



The problem on the SBL computation was found to be a simple honest mistake committed by the engineer. The problem or cause prevention was implemented by adding automated improvements on the process. No management-related issue was attached to the root cause of this failure mode.

The eight disposition problems were also found to be free of management errors. The errors were committed due to several reasons, including negligence to documented instructions, outdated response flow documents and un-documented response flow

updates. Additional automation and reviews were identified as the corrective and preventive measures for these issues.

Both the fuse file release and test program implementation processes contain issues with root causes that came from management errors. Table 5 lists the problems from both processes. Eighteen issues came from the test program implementation process and two from the fuse file release process, totaling to 20 issues.

Table 5. Problems encountered on the test program implementation and fuse file release processes.

Process	Problem	Number of occurrence
Test program implementation	Wrong test program code implementation	10
Test program implementation	Wrong down-binning rule implementation	4
Test program implementation	Wrong test program release setup	4
Fuse file release	Problem in fuse file release	2

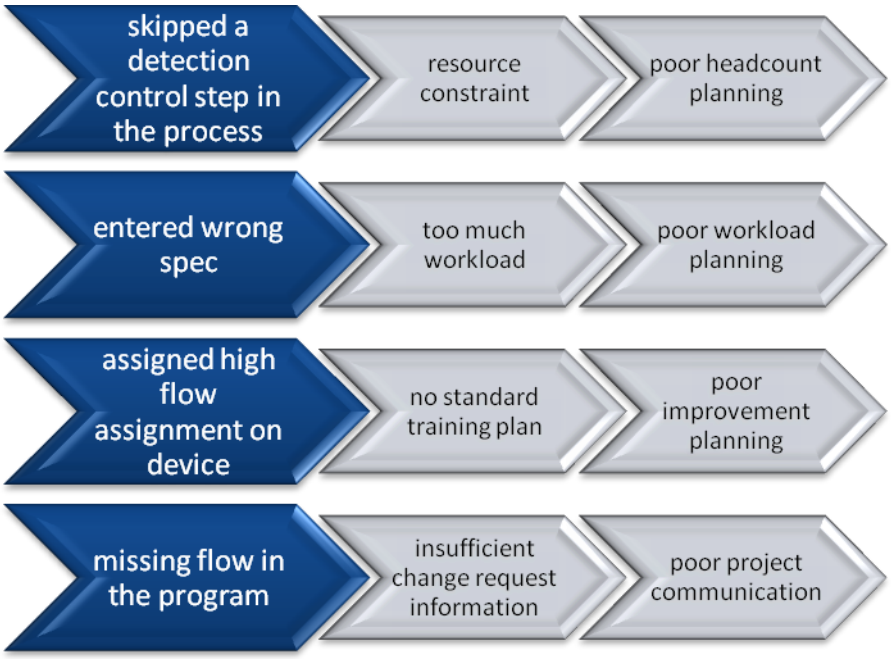
The 20 issues listed came from four different errors on two processes, test program implementation and fuse file release. After further investigation and analysis, it was found out the five out of the 20 documented issues were related to manager's errors.

The author also tried to collect a list of undocumented errors committed by the engineers to compare it with the documented issues. There was, however, no useful data collected, and thus was not included in the research data.

4.3. Management Errors

Figure 5 shows the list of manager errors identified as the root cause of the human errors committed by the engineers that led to functional product issues.

Figure 5. Result of the root-cause tracking done in the research. (Appendix A contains the complete root-cause tracking data for the research.)



Based on the interview results regarding the issue of a skipped detection control step, poor headcount planning problem was identified to be the best-fitting error committed by the manager. At the time the error was committed, there were only two engineers working on all test program activities for that particular product. Tasks included test program integration, test program correlation, pilot run, production release, and initial production data monitoring. On average, a test program release happened every other week. With only two engineers working on all those tasks, time is limited to perform and

finish all tasks in time. Due to that limitation, engineers skipped a validation process that later resulted to product failures. Full validation on the test program was not done before the production release. According to a senior Group Leader who was asked about the issue, a better forecast could have been made on the headcount requirements for that product, had the manager considered product complexity and demand forecast in his plan.

From the interview results, the issue on a wrong spec input was related by the owner to poor workload planning. The engineer, who was responsible for the mistake, recounted that there was an imbalance in the work assignments among members of the team at that time. His work-load was way much heavier than most members of the team. The engineer admitted to having accidentally committed the error out of exhaustion. Although the author believes that the engineer could have raised his work-load issue, it still remains that the manager has the responsibility of looking at his workforce and making sure everyone is given the proper amount of task to perform for the success of their product or project.

The issue on the wrongly assigned flow in the program resulted from a training problem. The engineer did not get the necessary training in order to successfully accomplish her tasks in the program integration. She was trained, but the training was incomplete. According to the problem owner, there was no training plan available for test program integrators at that time. Resource development planning is one of the tasks the manager was expected to take care of. As it turned out, the manager failed to make sure his engineers get the appropriate training for them to perform their tasks.

As for the remaining issues, according to data and information from product owners, two of the product issues resulted from poor communication of project requirements. Not all the required test program and fuse file changes were presented in the appropriate meetings. Change communications were done off-line and the communicated changes were incomplete. The insufficient change information requests that were done resulted to an incomplete work that caused functional problems on the product. The engineers tried to address this specific issue by creating a Test Program Change Committee that approves all test program change requests. The committee was also made responsible for the change request distribution.

Appendix A contains the completed HF PFMEA table containing all the root-cause tracking done on all the issues covered. The root cause column shows the series of answers from the series of why's asked regarding the root cause of the problems. Information on the table came from the Product Engineers who owned and were involved in the issues.

4.3.1. Risk Priority Numbers

Table 6 summarizes the RPN range for each management error for each possible effect on the product. The RPN values were calculated based on the SEV values assigned for each effect, OCC values assigned for each cause and DET values assigned for each cause and effect. The formula given by equation 1 in Chapter 2 of the report (RPN = SEV * OCC * DET) was used in the computations.

Based on the data that was gathered, RPN is higher on issues the led to under-testing of products and lower on those that caused delay in the process. Similar errors may have different RPN values depending on the severity of the effects, the probability of occurrence, and the probability of the time-to-detect. Data showed that SEV is the factor that defined most of the differences in the RPN values for each error. There were no significant differences among management errors in terms of OCC and DET. Appendix A contains the table with all the numbers assigned per cause and effect, which led to the RPN values summarized in Table 7.

Under-testing proved to be the most severe effect that came out of the human errors committed. They need to be in the top priority in terms of implementing prevention and detection mechanisms.

Table 7. RPN values of management errors on different effects.

	Under-testing	Lower bin split/yield	Test device may not operate at the spec frequency	Over-killing	Testing will be halted	Lots will be put on-hold
Workload planning RPN Range	240 - 300	60 – 75	30 – 60	15	3	3
Headcount planning RPN Range	160 - 200	40 – 50	20 -40	10	2	2
Resources development planning RPN Range		40 – 50	20 -40			2
Project management and communication RPN Range	400			20	4	

4.4. Management Errors in Risk Analysis

The management errors identified did not come from new management tasks. They came from exactly the same tasks all managers are expected to do. According to the research data, resources development and management, and project planning and communication are the tasks from which the mangers of the group concerned have a problem on. This data is helpful for the managers in terms of determining which to prioritize in their action plans for their process improvement plans.

The problem areas identified in this research, the inadequate human resources development and management and the lack of planning and communication problems are all barriers to TQM. The reason why most problems re-occur is that not all root-causes get prevented. Remedies are being done only on the symptoms. In order to eliminate problems, the organization must systematically address each and every cause of the problem. For this case, management errors must also be addressed.

This research showed that HF PFMEA is one methodology that may be used by organizations to evaluate human risks, including those coming from the management. The benefits this method provides include problem prevention and continuous improvement. Accomplishing both will help in the achievement of total quality.

It must be remembered that achieving total quality involves the participation of every single member of the organization. If everyone is a contributor to the success of quality improvement, it also follows that everyone may also contribute to the opposite. This only implies that everyone's process must be checked.

4.5. Summary and Conclusion

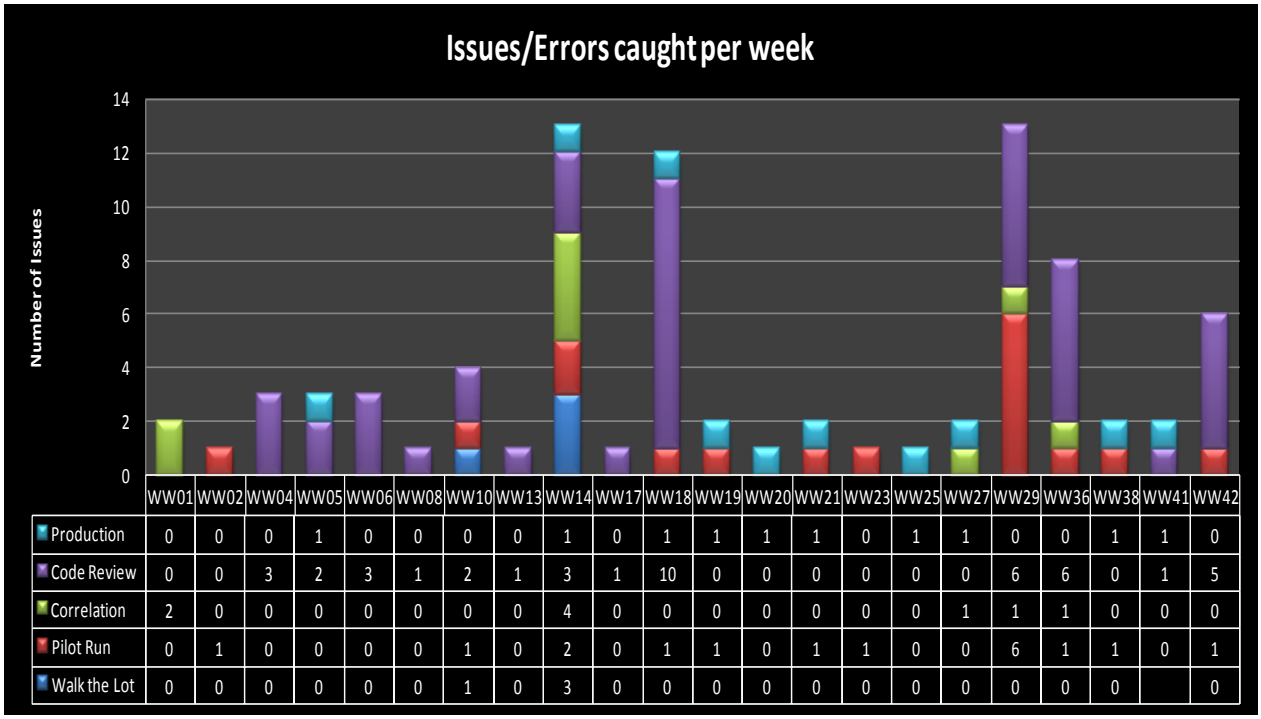
HF PFMEA was utilized in the analysis of product functional problems encountered in a semiconductor company. The methodology was used to determine the manager errors that led to the engineer errors that caused the product issues. The engineer errors were used as the link between product functional issues and management errors.

The FMEA methodology was also used to evaluate those management errors or risks in terms of RPN values. Issues with the highest RPN values are the issues that need to be prioritized in terms of improvement action plans.

Results led to the conclusion that the managers of the engineers, who were responsible for the product functional problems under study, had problems on resource development and management, and project planning and communication. These are the areas that the managers need to improve on. The highest RPN values were found to have come from management's project communication problem. This is the area where the improvement efforts need to start at.

The author believes that if these problem areas will be addressed, issue recurrences will be minimized, if not totally eliminated. The author collected issue-recurrences data in order to show the possible improvement impact this research's data has, if used properly. Figure 6 shows issues that recurred even with the addition of more automation and process changes. The author believes that if the manager errors will be addressed, those recurrences would be minimized, if not totally avoided.

Figure 6. Issues caught per week showing problem recurrences. (Data collected by author to check for issue recurrences.)



	WW01	WW02	WW04	WW05	WW06	WW08	WW10	WW13	WW14	WW17	WW18	WW19	WW20	WW21	WW23	WW25	WW27	WW29	WW36	WW38	WW41	WW42
Production	0	0	0	1	0	0	0	0	1	0	1	1	1	1	0	1	1	0	0	1	1	0
Code Review	0	0	3	2	3	1	2	1	3	1	10	0	0	0	0	0	0	6	6	0	1	5
Correlation	2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	1	1	0	0	0
Pilot Run	0	1	0	0	0	0	1	0	2	0	1	1	0	1	1	0	0	6	1	1	0	1
Walk the Lot	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0		0

In conclusion, the author was able to show the data that management errors contribute to product functional problems. Those management error risks were also evaluated and assessed using the HF PFMEA method. From the research data, improvement plans may be devised and implemented. Addressing the management problems on resource development and management, and project planning and communication are contributory to TQM effort.

This work suggests that managers also contribute to issues that lead to product functional problems. These issues need to be addressed and the results from which are beneficial in the achievement of total quality.

Chapter 5 – Suggestions for Additional Work

This research focused on the severity of the effect with respect to product functionality. The author suggests that the same research method could be employed, to analyze issues and processes, with focus on the severity of the effect with respect to schedule. Such research method will generate data that could be helpful in process optimizations to save time.

Another suggestion is to apply the HF PFMEA methodology in the analysis and evaluation of other engineering processes. Doing so could reveal more data that could be useful for the organization's problem prevention and process and quality improvement efforts. The implementation of HF PFMEA methodology on a variety of human processes could also reveal useful data for the development of a model that could be useful for management risk analysis.

Another possible path of study on the subject could be the research and implementation of other systematic tools for the human-error analysis. Different problem-solving methods apply to different organizations, depending on their business type of operations and cultures. Implementing a systematic methodology that applies to the type of business and culture could reward the organization with a great and untapped reservoir of improvements.

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Appendix A – HF PFMEA Research Data

Potential Failure Modes	Potential Effect(s) of Failure	SEV	OCC	DET	RPN	Potential Cause / Mechanism of Failure
Test Program (TP) integrator put lower than spec device frequency	Tested device may not operate at the spec frequency	10	1	1	10	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		10	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		20	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		30	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		40	TP integrator didn't double check his./her work -> TP integrator is over-confident
			2		20	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		20	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is biased or over-confident
TP integrator put higher than spec device frequency	Lower binsplit or yield for the device	5	1	4	20	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		20	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		40	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning

			3		60	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		80	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
			2		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		80	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is biased or over-confident
TP integrator wrongly assigned a lower bin/flow for a given device speed	Lower binsplit or yield for the device	5	1	5	25	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		25	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		50	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		75	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		100	TP integrator didn't double check his./her work -> TP integrator is bias that he/she didn't commit an integration mistake
			2		50	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		50	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		100	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is bias that he/she didn't commit an integration mistake

TP integrator wrongly assigned a higher bin/flow for a given device speed	Tested device may not operate at the spec frequency	10	1	1	10	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		10	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		20	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		30	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		40	TP integrator didn't double check his./her work -> TP integrator is bias that he/she didn't commit an integration mistake
			2		20	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		20	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is bias that he/she didn't commit an integration mistake
TP integrator wrongly assigned a non-existent bin/flow for a non-existent device speed	Lots may get held due to mismatch in binning between TP and planning set-up	1	1	1	1	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		1	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		2	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		3	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		4	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident

			2		2	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		2	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		4	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is bias that he/she didn't commit an integration mistake
TP integrator wrongly assigned an existing bin/flow for a non-existent device speed that is higher than what should be assigned	Lower binsplit or yield for the device	5	1	5	25	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
			1		25	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		50	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		75	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		100	TP integrator didn't double check his./her work -> TP integrator is bias that he/she didn't commit an integration mistake
			2		50	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		50	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		100	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is bias that he/she didn't commit an integration mistake
TP integrator wrongly assigned an	Tested device may not operate at	10	1	2	20	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo

existing bin/flow for a non-existent device speed that is lower than what should be assigned	the spec frequency		1		20	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
			2		40	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		60	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		80	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
			2		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> No one available to train him/her -> resource constraint -> poor headcount planning
			2		40	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator didn't know -> TP integrator didn't receive training -> no standard training plan for TP integrators --> poor resource development planning
			4		80	TP integrator didn't do necessary preventive and detection controls in place -> TP integrator is biased or over-confident
TP integrator fails to encode all device names needed by production or NPI	No testing will happen	1	6	1	6	TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator was not copied in the memo
						TP integrator is using an older bin matrix file -> TP integrator is not aware of a newer bin matrix file -> TP integrator was not able to read bin matrix release memo -> TP integrator accidentally deleted the memo
TP integrator fails to connect a test segment in the flow	Testing will be halted	1	2	1	2	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		3	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		4	TP integrator didn't double check his/her work -> TP integrator is biased or over-confident
			4		4	TP integrator didn't know he/she needs to connect the test segment -> TP integrator received insufficient information about this requirement -> TP integrator received incomplete requirement during the TP changes input collection meeting -> poor project management and communication

			1		1	TP integrator didn't know he/she needs to connect the test segment -> TP integrator didn't fully understand that he/she needs to connect the test segment -> TP integrator lacks necessary training to understand the requirement
TP integrator makes an infinite loop in the flow	Testing will be halted	1	2	1	2	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		3	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		4	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
TP integrator didn't put a required kill segment in the flow	Under-testing	10	4	10	400	TP integrator didn't know he/she needs to put the test segment -> TP integrator received insufficient information about this requirement -> TP integrator received incomplete requirement during the TP changes input collection meeting -> poor project management and communication
			1		100	TP integrator didn't know he/she needs to put the test segment -> TP integrator didn't fully understand that he/she needs to connect the test segment -> TP integrator lacks necessary training to understand the requirement
TP integrator wrongly makes a recovery flow to a fail flow without any fail bin assigned	Under-testing	10	2	8	160	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		240	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		320	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
TP integrator accidentally bypasses recovery flow to always passing units	Under-testing	10	2	10	200	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		300	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		400	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
TP integrator bypasses some kill test segments by mistake	Under-testing	10	2	10	200	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		300	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		400	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident

TP integrator implements a new flow not as planned	Under-testing	10	2	10	200	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		300	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		400	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
			4		400	TP integrator didn't fully understand the requirements of the new flow -> TP integrator received insufficient information about the new flow --> poor project management and communication
			1		100	TP integrator didn't fully understand the requirements of the new flow -> TP integrator lacks the necessary competencies or knowledge about the new flow -> TP integrator didn't receive training regarding new flow
TP integrator implements a new flow not as planned	Over-kill	5	2	1	10	TP integrator committed a typographical error -> fatigue -> too much workload -> resource constraint -> poor headcount planning
			3		15	TP integrator committed a typographical error -> fatigue -> too much workload -> poor workload planning
			4		20	TP integrator didn't double check his./her work -> TP integrator is biased or over-confident
			4		20	TP integrator didn't fully understand the requirements of the new flow -> TP integrator received insufficient information about the new flow --> poor project management and communication
			1		5	TP integrator didn't fully understand the requirements of the new flow -> TP integrator lacks the necessary competencies or knowledge about the new flow -> TP integrator didn't receive training regarding new flow

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