COMPARISON AND CONTRAST OF PROJECT RISK ANALYSIS TOOLS: A TOPIC ANALYSIS MEASURING EFFECTIVENESS OF RFMEA OVER FMEA

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Abstract- The dilemma whether risk management tools provides control measures, detect variations and offer competencies to make differences for projects is questionable and relevant to both practitioners and research communities from a long-time. In this paper a review of previous literatures addressing latest development and key findings focusing on project risk analysis tools is presented. In addition, a qualitative analysis of case studies is carried out to describe how FMEA and RFMEA works and how they serve purpose. The results states the effectiveness of using RFMEA during project life cycle generating accurate mitigation measures. The findings recommend to increase exponential curve of awareness of risk tools by gauging actual evaluation and differences. Lastly, new research directions indicate limitations and suggestions for tools in practice and theory to overcome created gap in their applicability.

Keywords- FMEA, RFMEA, Project Risk Management (PRM), Risk analysis, Risk mitigation

I. INTRODUCTION

Project Risk Management is one of the significant and prominent areas of project management context. Integrated and latest research on issues related to project management practical tools and techniques is need of an hour, which can bridge the gap between theory and practice, equip essential skills and enhance analytical capability. This paper provides an introduction to practical project management techniques applicable to business projects in the private and public sectors. Also, it discovers risks and issues management strategies prior and at the time of projects execution. This involves framework building, risk analysis influencing project decisions, and assessment risk management processes during the entire project life. The tools illustrated represent fundamental guidelines in new product development and decision-making. Risk regulation is the intrinsic and primary part of project management to escalate project performance and bring out risk mediation.
Theoretical principles and approaches discussed in the paper will help to estimate the appropriateness and gauge the limitations of previous methods used within organisations. This paper intend to work on topic analysis of project risk management tools and articulate specific sub-topic of risk analysis techniques. For this reason, FMEA and RFMEA are the tools selected for the interpretation and demonstration of analysis and assessment of risk. To examine the implementation of both techniques a qualitative research in the form of case studies is presented in further section of methodology. FMEA is focusing primarily on Engineering disciple cases of the photovoltaic components and sub-components system whereas RFMEA deals with the Electronic Industry Integrated Circuits (IC's) development and analysis of critical threats in the form of risks (Altabbakh, 2013).
Both tools fulfil the similar objective of estimating, examining and abating failure events and risk events by recognizing them in project integrated development environment. Termed and serving as risk priority tools for planning out major, complicated and risky projects in Engineering, R&D and technology; RFMEA is receiving more attention for project success and performance. In either cases, mentioned tools evaluate "Risk Priority Number (RPN) " factor referring three different terms elaborated further. Carbone and Tippett (2004) stated that RFMEA can be used along with FMEA for product design, process development and service deployment. RFMEA has extended evolution of standard FMEA. As a qualitative techniques, FMEA prefer 1-10 numerical scale for assigning values of RPN calculation, however, RFMEA use scales from 1-5. Standard ratings are decided in accordance with guidelines for both tools interpreted later on.
Tools and techniques applied to project activities define effective project management to meet stakeholders needs and expectations from a project. The latest development of project risks tools is reflected by focusing on research publications and articles key findings in last 9 years. It consists of A*, A, C and not- ranked journal. It suggests that project vulnerabilities known as "exposure" and "capacity" can be used with risk analysis which considers organizational factors and their influence on PRM process beside risk events. Moreover, they explain limitations and contemporary issues of a risk management tools and techniques. After that, in methodology two tools FMEA and RFMEA are described in detail by conducting and writing a case study on both to justify their working, purpose and difference between them. Comprehensive guidelines and terminologies are stated and procedure is manifested to know the effectiveness of RFMEA over FMEA. In addition, it exemplify risk's nature and its

effect on project environment. In reality, this help compute project risks tools quality. Results of these case studies showed competence of applying a particular risk management tool set. It exhibited efficiency of RFMEA in terms of all-inclusive risk assessment till end which defines linkages and interrelationship of strategic deployment and managing of project risks from a strategic perspective.

Comparison of FMEA and RFMEA is interpreted through findings on the basis of criteria and their definitions developed. It elucidate key differences for terms such as process, RPN, Risk score, detection measure etc. Lastly, practical and theoretical implications refer difficulties in applying two tools and under-studied nature suggesting improvements and future research to improve applicability.

II. LITERATURE REVIEW

A review of project risk management literature in general covers publications of research articles in last 9 years from 2011- 2019. The developments that took place in relation to risk management tools is demonstrated below in Table 1 mentioning main research focuses and findings in particular years by different authors. Almost A*and A ranked primary journals are shortlisted and chosen from Australian Research Council (ARC), FT50 Journals, Australian Business deans council (ABDC) Journals list to exhibit finest and latest findings. One C and Not-ranked journal is considered. There are two journal named as Geraldi et al. (2010) and Kutsch & Hall (2010), which extended review back 1 year till 2010. In other words, as per generic review of frameworks of risk management tools, out of total cited 92 research articles, 49 articles were chosen for the specific time period of 2010- 2019. Eventually, 11 articles dedicated exclusively for project risk analysis tools were selected. As a result, it is clearly evident that collaborative study and research is prerequisite to little extent in risk management coordinating techniques in all industrial fields.

Table 1. Literature review of various authors publications discussing key findings in Project Risk Management area

Sr. No	Author Name and Year	Journal Name	Journal Rank	Industry	Methodological Choice	Research focus	Key findings
1.	Abdel-Basset et al. (2019)	Future Generation Computer Systems	A	Supply chain	Case Study	To revamp and upgrade decisions making process in supply chain by abating risks, controlling and analyzing them. To deal effectively with uncertain, vague and subjective information to manage supply chain risks by referring qualitative analysis	Proposed method of AHP[1] and TOPSIS[2] technique using neutrosophic scale helps to quantify risks and its evaluation Determinants of quantitative analysis failed to generate accurate results, giving rise to inconsistency impacting risks decisions whereas multi-criteria techniques assess supply chain risks effectively
2.	Bevilacqua & Ciarapica (2018)	Reliability Engineering & System Safety	A	Process and oil refinery	Conceptual model	Risk management and human factor integration in risk management system to identify high risk events in relation to human practices	Better understanding of human error factors and consequences is possible using identification models Human factor risk management methodology can result into well managed corporate culture increasing human factor contribution to organization activities, mitigating human error risks
3.	Hugo et al. (2018)	South African Journal of Industrial Engineering	C	Generic	Questionnaire and hypotheses	Analysis of risk factors in terms of resources available, organizational risk framework, risk models, risk data and risk management skills	More focus is significant for improving risk management competence and maturity levels in risk management processes within organizations Availability of resources in form of human and software to perform risk management Efforts and study on the quantitative aspect of risk analysis models and risk management to make it misconception free in practice
4.	Kokangul et al. (2017)	Safety Science	A	Manufacturing	AHP approach	To determine risk hazards in large manufacturing companies and measure risk classes using Fine & Kinney[3] method	Importance levels and hazards risk classes are able to determine in combination using AHP method
5.	Marcella & Rowley (2016)	International Journal of	A	Fashion	Qualitative analysis	Investigating effective application and uncovering challenges of risk management tools and techniques in creative industry	Identifying key barriers and difficulties to adapt needs of fashion industry Stakeholders relations are to be improved for successful delivery of project

[1] AHP is Analytic Hierarchy Process used to analyze real world risks in supply chain and these risks can be quantified using fuzzy logic
[2] TOPSIS is a Technique for Order of Preference by Similarity to Ideal Solution and used to carry out multi-criteria mathematical optimization and analysis. It is assessing and measuring e-commerce risks
[3] Fine & Kinney method is a assessment for determining risk parameters and risk exposure in project planning

Sr. No	Author Name and Year	Journal Name	Journal Rank	Industry	Methodological Choice	Research focus	Key findings
		project management					Openness to change and flexibility is critical
6.	Hazir (2015)	International Journal of project Management	A	Software	Analytical models	Focuses on mathematical optimization tools and Earned value analysis (EVA), to help control and plan in an uncertain project environment	To monitor and control the progress of project Decision Support System (DSS) design, EVA metrics and statistical control can help to predict project performance beforehand. Uncertainty of future events can be mitigated using project management software and future study is essential on modeling analysis and approximate algorithms
7.	Marcelino-sadaba et al. (2014)	International Journal of project Management	A	Small enterprise	Literature review	1. Provides guidance to managers of small enterprises who are not project risk management expertise and professionals 2. Investigate phases of small businesses in project risks practices so that they can focus on proposed methodologies for working on development of new product or implementation of new system projects	Utilization of proposed methodologies of investigation offers following benefits for small firms: 1. It rectify shortcomings in the project objectives and definitions. It eliminate strategic formulation and implementation risks 2. Minimum time is required for collection of risk information and its documentation of resources 3. The risk templates developed for risk documentation are simple and useful
8.	Pereira et al. (2013)	Procedia Technology	Not Ranked	Small and Medium enterprises	Literature review	Presents an application for SME to encourage use of risk management practices utilizing current online sources	SME lack in empirical models, tools and metrics to overcome and manage project risks Framework to ameliorate potential biases and risk attitudes is manifested and conditions are drawn to offer concise model to evaluate project risks
9.	Zwikael & Ahn (2011)	Risk analysis	A	Business	Survey	1.Analyze and examine effectiveness of risk management in diverse nations and their risk management practices to reduce project risks in International businesses 2. Recommends to focus on project planning phase as most of the project risks practices are performed during this phase which can assist further in	1. Higher level of risk management planning reduces risk probability and has insignificant effect on project success. 2. Risk planning tools encounter number of faults such as: Restricted tools, lack of quality, intricate procedure and difficultly to grasp, little command of project manager and are ranked lesser in value 3. For low risky projects, risk management planning is ineffective wherein it is opposite for medium and high risk projects
Sr. No	Author Name and Year	Journal Name	Journal Rank	Industry	Methodological Choice	Research focus	Key findings
						reducing uncertainty	
10.	Geraldi et al. (2010)	International Journal of project Management	A	Management	Review of literatures	Suggests successful response criteria of unanticipated and unknown events for project managers with respect to three basic conditions: 1. Appropriate functional organizational structure 2. Good interpersonal and people skills within team 3. Being technically sound and competent in one's profession	States three key attributes for mentioned conditions to manage response towards unexpected events: 1. Granting more freedom and space to build up capability to implement and render quick and proper decisions within organizational context 2. Stakeholder engagement and negotiation to encourage transparent communication of available information 3. Team development and leadership skills enhancing emotional intelligence and self-awareness to develop organizational competencies
11.	Kutsch & Hall (2010)	International Journal of project Management	A	Information System	Pilot study	Evaluate irrelevance of information related to project risks and its consequences on PRM process throughout project life-cycle	Elements responsible for ignorance and irrelevance are: "Off -the- track" or "beyond scope " information termed as untopicality Doubtful and Undecidability, Unclear and incomplete material termed as inconvenient and uncertain for having useless risks which leads to ignored and irrelevant information coined ineffective on outcomes

Overall findings in relation to risk management practices clarify the convoluted analysis, limitations and restrictions of risks in terms of building scope, quality and efficacy of its management process in all enterprises.

III. METHODOLOGY

A qualitative analysis of FMEA and RFMEA is carried out using case study assessment in order to know their efficacy.

1. FMEA

FMEA is a procedural tool that examine possible failure modes during design of products and processes. It critically analyze failure modes to control risks.

Objective, function and use

FMEA approach support and recognize potential errors before the occurrence of catastrophe to reduce risk possibility. Even it measures risk and equivalent effects affecting designs through detailed analysis of failure modes (Krasich, 2007).

FMEA definitions (Terminologies)

FMEA includes qualitative reliability and technique of risk analysis, to investigate faults present at the sub-component level of product. FMEA manifest risk assessment by examining causes resulting into effects for each failure mode. Figure 1 presents cause and effect model of FMEA.

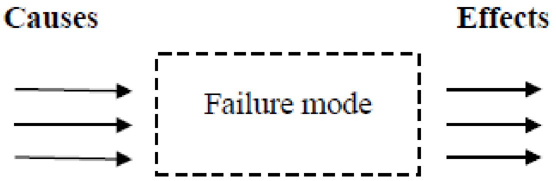

Figure 1. FMEA model

Table 2 describes terminologies of FMEA in detail.

Table 2. FMEA terminologies

Sr. No	Terminology	Definition
1.	Occurrence (O)	Probability of estimation of happening a specific cause and occurence of failure mode during project life-cycle and product use. Rated using numeric scale from 1-10 (Paul, 2016).
2.	Severity (S)	Measures seriousness of a failure mode cause and possible effects. Evaluation is done using numerical scale from 1-10 (Paul, 2016).
3.	Detection (D)	Assess probability of control devices to detect cause of a particular mode of failure, to avoid its occurence and reach customers. Alike previous terms detection is scaled from 1-10 (Paul, 2016).
4.	Risk Priority Number (RPN)	Mathematical multiplication of ratings of Occurence (O), Severity (S) and Detection (D) Equation 1 below indicates formula of RPN: *RPN = Occurrence (O) x Severity (S) x Detection (D) ----- Equation 1* (Paul, 2016) In general standard scale of RPN ranges from 1-1000, but can be variable as per product or system design of a every unique project's requirements and functionality Use to assign failure modes priority for planning out further actions in terms of quality improvement. Team needs to assign values and rate O, S and D between 1-10 for each failure mode to estimate RPN. Failure modes are prioritize using RPN for corrective actions. High RPN indicates critical modification need. Thus, lower RPN value is preferred.

(Source: Colli,2015)

FMEA steps and flowchart

The following Figures 2 and 3 covers detailed steps and flowchart of FMEA to understand its working and application in industry on different projects. Both figures constitute start-to-end process and methodology in general to describe systematic analysis.

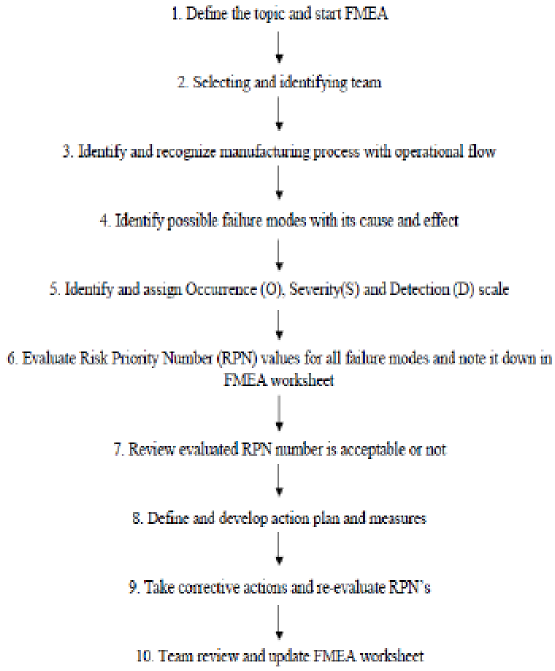

Figure 2. FMEA steps (Source: Riplova,2007)

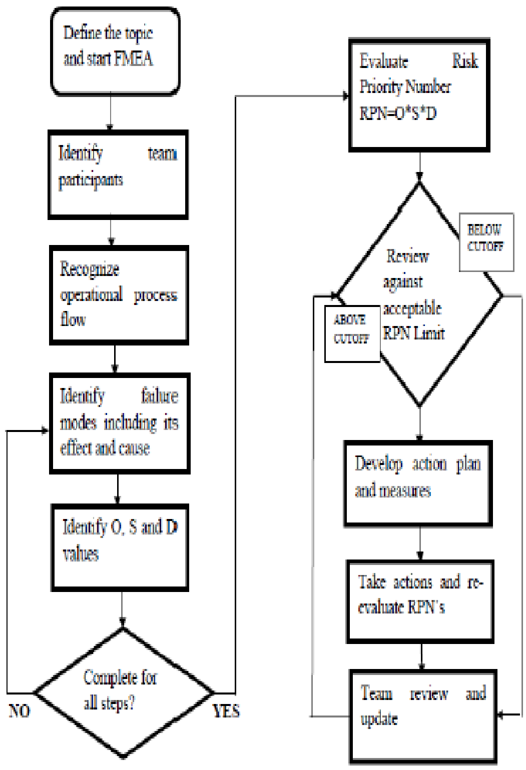

Figure 3. FMEA flowchart (Source: Riplova,2007)

Case Study

This case study aims at identifying potential modes of failure taking its causes and effects into consideration for a grid-connected Photovoltaic System (PV) parts.

At first, PV system is surveyed at sub-components and components level in relation to needs, practical descriptions, diagrammatic figures and models. Following this process, selection of team is done consisting of expertise and users of Photovoltaic System etc. Referring comprehensive analysis, stakeholders discover failures and their causes and effects for all components exhibited in Table 3. Failure rate for each component and its parallel sub-component is mentioned in Table 3.

The whole sub-system constitutes of intensive failure modes list but few samples are demonstrated further to understand thorough concepts of low, medium and high RPN values.

Table 3. Components, subcomponents and Failure rates of PV sub-system

Components Unit	Subcomponents Unit	Rate of failure (per unit hour)
0. PV Module Unit	0.1 Transistor	1.39[1]
	0.2 Zener diode/P-N junction diode	6.81[7]
1. Rack structure	1.1Ground protection	1.70[2]
2. Cabling	2.1 Aerial wires	1.10[8]
3. Power conditioning	3.1 AC to DC Inverters	1.80[8]

(Source: Colli, 2015)

Ratings of the Occurrence (O), Severity (S) and Detection (D) are rated using subjective standard scales.

Probability of Occurrence (O), Effect of severity (S) and detection (D) are scaled below in relation to PV Subsystem and guidelines in Table 4 below.

Table 4. Scaling of O, S and D of a PV system

Scale	Occurrence probability	Definition for PV Sub-system	Severity Impact	Definition for PV Sub-system	Evaluation of Detection	Definition for PV Sub-system
10	Almost always	In a day frequent occurrence of failure	Failure	A complete breakdown of whole system without warning	Almost impossible	Detection failure mechanism is unknown
9	Very High	Occurrence of failure every 3-4 days	Serious	Major interruption may be caused in the system without any warning	Very remote	Thorough inspection is necessary for the detection of failure which is not performed readily
8	High	Occurrence of failure every 8-10 days	Very High	Failure may be stop operations in a system	Remote	Manual inspection may detect error but undefined process is there and detection won't be planned
7	Moderately high	Fortnight occurrence of failure i.e. every 14 days	High	Major re-work and repairs may lead to failure of system	Very low	Manual inspection is possible to very lesser degree and therefore few possibility of process happening
6	Moderate	Occurrence of failure once in a month	Moderate	Minor problems may be caused to a system with few modifications	Low	Manual inspection is possible to lesser degree and therefore very few possibility of process happening
5	Moderately low	Occurrence of failure once in a one and half month	low	Minimal problems may be caused to a system with very few modifications	Moderate	Automated detection is not possible but error detection through inspection is possible
4	low	Occurrence of failure approximate every 3 months	Very low	Very minor modifications may be caused due to failure	Moderately high	Automated detection is not possible but error detection through inspection is highly possible
3	Slight	Occurrence of failure approximate once every six months	Slight	Little effect will be caused on the system due to failure	High	Inspections and review is conducted of the process but not automated
2	Remote	Occurrence of failure approximate once in a year	Very slight	Very little effect will be caused on the system performance due to failure	Very high	Process inspection and analysis is conducted and even it is automated
1	Almost never	No Occurrence of failure	None	No effect of failure on the system	Almost always	Automatic mechanism and to block failure, constraints are offered

(Source: Silva et al., 2014)

In effect, failure mode probability of occurrence, impact of severity and evaluation of detection are scaled numerically for PV system based on guidelines.

Risk priority number ratings are calculated using the combination of defined ratings for equation 1which indicates risk measure for every failure mode shown below in the Table 5.

High value RPN indicates critical and urgency of failure mode, requiring corrective and immediate action for an identified and specific modes of failure. RPN values are scaled from 1 to 127 for this case study (Colli, 2015). As per previous discussion, smaller value of RPN are better than higher values (Colli, 2015).

At last, these RPN values are reviewed and if higher and exceeding desired limit of failure modes, corrective actions are to be taken and recommended. Finally, RPN scores are revised using re-evaluated values of O,S,D.

Table 5. Failure modes details of FMEA

Mode of failure ID	Subassembly	Modes of failure	Reason of occurring or Cause	Impact	Score of Occurrence	Score of Severity	Score of Detection	Score of RPN
0.1	Transistor	Loss of electric current	Low parallel resistance	Less output energy	8	2	8	128
0.2	Zener diode/ P-N junction diode	Short in either voltage contacts	Unprotected shield of insulator	Unsafe	4	8	2	64
1.1	Ground protection	No flow of current and open	Impairment to metal	No energy at output	9	4	8	288
2.1	Aerial wires	Wear and tear of cables	Poor material quality and degradation	Little efficiency gain	6	2	8	96
3.1	AC to DC Inverter	Fluctuation in output	Dysfunctioning of measurement devices	Incorrect output	8	6	4	192

(Source: Colli, 2015)

With reference to Table 5, failure modes with ID 0.1, 1.1 and 3.1 of subcomponents are greater than 127 and more than acceptable RPN limit value. Consequently, action plan is requisite for these modes of failure. As mentioned previously, score of occurrence, impact and detection are revised, re-calculated and updated. In effect, risk occurrence and severity is reduced and mitigated.

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[7] Value extrapolated from Oelian A. PV system reliability: an operator's perspective. IEEE J Photovolt 2013; 3(1):416–21.
[8] Value from Power systems reliability subcommittee of the power systems engineering committee, IEEE industry applications society. IEEE Std. 493-2007 recommended practice for the design of reliable industrial and commercial power systems. IEEE-SA standards board, New York, NY. IEEE 493-2007.

[1] FMEA stands for Failure Mode and Effect Analysis
[2] RFMEA stands for Project Risk Failure Mode and Risk Analysis
[3] FT50 journals is a list of 50 journals used by the financial times in compiling the Business School Research rank. It is widely used by the business schools in US to assess research quality.

Therefore, FMEA technique application interpreted above for PV assembly can improvise conditioning of PV parts and sub-parts by knowing failures and its associated risks, following available numerical values useful evaluation.

2. RFMEA

A procedural and extended approach of FMEA for controlling project risks.

Objective, function and use

Quantification and elimination of risk events especially in project context is carried out by RFMEA. Helps in managing project and improves performance by reducing the potential unexpected events. It examines risks throughout project life-cycle. It's a risk tool to capture program and project risk events which can score them and respond to highest priority risks in overall risk management process.

RFMEA definitions (Terminologies)

RFMEA is a intuitive tool and extension of RFMEA with few modifications for risk priority planning. It assist in increasing accuracy of identified risk events, overlooked in generic risk log of FMEA.

Table 6 describes terminologies of RFMEA in detail.

Table 6. RFMEA terminologies

Sr. No	Terminology	Definition
1.	**Likelihood (L)**	Probability of evaluating likelihood of happening a specific cause and occurrence of risk event during project life-cycle. Rated using numeric scale from 1-10.
2.	**Impact (I)**	Assess risk event potential effects on the performance of project. Numeric scaling is preferred from 1-10.
3.	**Detection (D)**	Capacity of risk event detection in order to develop contingency plan beforehand. Detection is scaled similarly from scale 1-10.
4.	**Risk Score (RS)**	Likelihood and Impact scale product of a each risk event. It's formula is written as: *Risk Score (RS) = Likelihood (L) x Impact (I) -------- Equation 2 (Luppino et al., 2014)*
5.	**Risk Priority Number (RPN)**	Mathematical multiplication of three terms Likelihood (O), Impact (S) and Detection (D) ratings In mathematical terms it is expressed as: *RPN = Likelihood (L) x Impact (I) x Detection (D) -------Equation 3 (Carbone & Tippett, 2004)* Equation 3 in other way can be expressed as: *RPN = Risk Score (RS) x Detection (D)------- Equation 4 (Luppino et al., 2014)* Unlike FMEA, RFMEA has no standard scale or limit as an acceptable value of RPN. Its critical value is considered as RPN acceptable limit, determined using computing parameters of Pareto charts. RPN values greater than its critical value indicates need of a risk response plan. Therefore, RPN lesser value is better than its critical value.

RFMEA steps and flowchart

The following Figures 4 and 5 covers detailed steps and flowchart of RFMEA to understand its working and application in industry on different projects. Both figures constitute of start-to-end process and methodology in general to describe effective analysis of RFMEA.

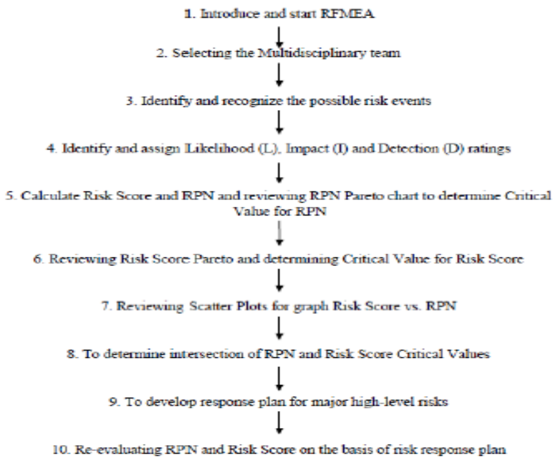

Figure 4. RFMEA steps (Source: Hazir, 2015)

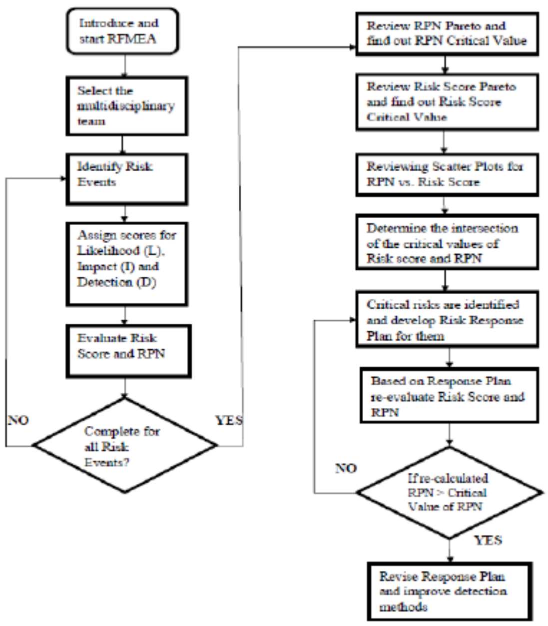

Figure 5. RFMEA flowchart

Case Study

RFMEA is studied in relation to the Electronic Integrated Circuit (IC) manufacturing project in package distribution and system engineering. Case study key intention is utilizing RFMEA as a effort of developmental unit during planning process with a timeline of one year. RFMEA was initiated and introduced in project planning phase. Initiation of RFMEA takes place during phase of project planning. After that, participants from different fields such as engineers, experts are chosen as project team. Preferring brainstorming in total 45 risks are identified in a whole project. Team members add symptoms of the identified risks and on the basis of standard guidelines the likelihood, impact and detection are assigned scores.

The Likelihood, Impact and detection standard qualitative scales scored and assigned by team are written below in Table 7.

Table 7. Scaling of L, I and D of a Electronic Integrated Circuit (IC) Project

Scale	Likelihood	Definition for IC manufacturing	Severity of Impact	Definition for IC manufacturing	Evaluation of Detection	Definition for IC manufacturing
9or 10	Very certain	Occuring often and more than 1000 repeatedly	Very critical	Timeline- >20% increase to critical milestone and duration path Budget- >30% of increase in project cost Practical- Scope creep leads to uncontrollable changes in project outputs	Almost impossible	No procedure available and no chance for risk detection
7 or 8	High	Occuring daily but within specific cycles	Critical	Timeline-10-20% increase to critical milestone and duration path Budget- 30%-40% increase in project cost Practical-Scope creep turn out project outputs meaningless	Very low	Very little possibility of detecting risk using control devices and testing equipments, termed as unproven
5 or 6	Moderate	Occuring once in a month or a week or even not	Major	Timeline-15%-20% impact on critical milestone and duration path Budget- 10%-20% increase in cost Practical-Scope creep changes require assurance of customers	Moderate	Average probability of detecting risk events using control devices and testing equipments
3 or 4	low	Occuring once in a five years	Minor	Timeline- < 15% impact on critical milestone and duration path Budget- < 15% increase in project cost Practical - Minor scope creep but requires internal and client's approval	Moderately high	Above average probability of detecting risk events using control devices and testing equipments
1 or 2	Very unlikely	No chances of occurence	Very minor	Timeline- Negligible impact Budget- No cost increase Practical- No scope creep	Very high	Control devices will detect risks using testing equipments

(Source: Carbone & Tippett, 2004)

Thus, Table 7 interpret scales in the form of numeric score values of Risk Event for IC development exhibiting probability of likelihood, impact reflecting duration, changes in technical specifications and budget that belongs to project. Even it shows score for detection using software equipments to detect and analyze flaws in IC development and manufacturing. By detecting symptoms it is possible to score detection and recognize risks.

For each Risk Identifier (ID), Equation 2 & 3 of Table 6 helps to evaluate RPN and Risk score referring previous Table 7. For instance, from the list of risks identified, M and N risk are chosen for showcasing the process of RFMEA.

Table 8. Risk event details of RFMEA

Risk or WBS ID	Risk Triggers (IF....Then... Statement)	Detection Symptom	Likelihood possibility	Impact value	Risk Scoring	Detection	RPN Value
M	If built up hardware is defective, then redesign IC extending timeline of 10 weeks and budget of $150K	At the time of unit and performance testing of hardware	5	8	40	6	240
N	If a prototype is not satisfying customer then operational validation is postpone for a period of 60 days and $40k budget overrun takes place	At the time of implementation	6	7	30	8	336

Moreover, Pareto graphs are extracted using Risks ID. As mentioned earlier, only few risks are selected for the purpose of demonstration from the actual project manifested in Figure 6 & 7 below.

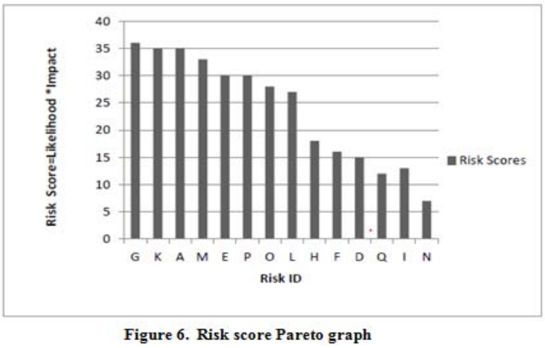

Figure 6. Risk score Pareto graph

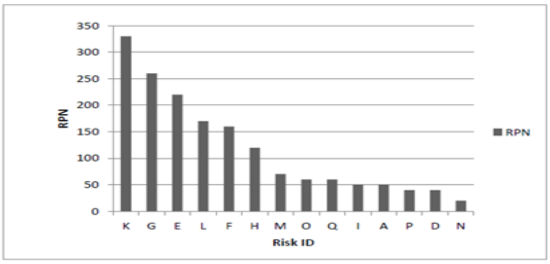

Figure 7. RPN values Pareto graph

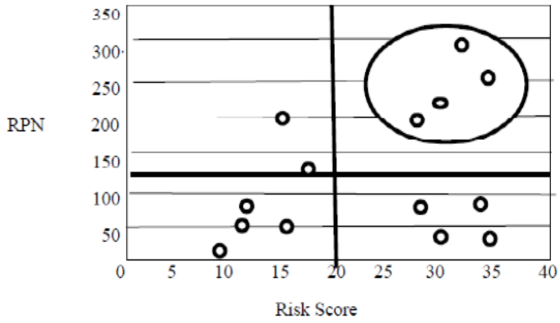

Figure 8. Risk score and RPN values scatter diagram

Critical values of RPN and Risk scoring intersection points were identified. Besides, in the upper half of first right quadrant, four significant and critical risks are located and encircled in Figure 8 which needs risk response planning at earliest. Based on the contingency response planning, project team quickly starts re-evaluating the risk score and RPN values. Figure 8 above represents critical risks from the list of partial risks considered for the whole project as put forth earlier.

Out of total 45 identified risks, 20 critical risks were found through risk assessment, but after applying RFMEA procedure only four significant risks were remaining exceeding critical values for further risk control and response.

Updated risk response pattern is exhibited for critical risks M and N in Table 9 by revising risk scoring of all terms and corresponding RPN values.

Table 9. RFMEA risk control and response

WBS ID of work packages	Updated likelihood	Updated Impact	Updated Risk Scoring	Updated detection	Updated RPN value
M	2	4	8	2	16
N	4	4	16	6	96

Hence, risk database is provided by RFMEA referred to project documentation and knowledge management of risks. This database can serve as historical record for future projects and their planning by framing contingency plan and revising results.

IV. RESULTS

Case study of Photovoltaic subsystem helped to search and study key modes of failure for which requisite response plan has to be written and documented. In other words, Table 5 doesn't have columns of actions recommended, actions implemented and revised values of O, S and D considered as a work for future scope for FMEA. These columns are added in Table 10 of Risk log of Appendix A of Appendices. It is noticeable from Pareto graphs of Risk scores and RPN values that score values distribution of work packages with greater risk scoring won't be equal for Risk ID's with high RPN values. For example, Table 9 risk control plan for risk M is to construct generic testing which can shorten revision work within less time. The detection for work package M was six in the earlier case, but because of generic boards, detection of risk was possible before and thus its revised detection reduced to two. Finally, reduction of RPN took place. Revised RPN value for risk ID M is below 25 (RPN's critical value) and there is no requirement of revising response plan. And, for Risk Id N revised RPN is greater than critical value of RPN where response and contingency planning need to be re-estimated.

V. FINDINGS AND DISCUSSION

The key focus of FMEA is to reduce crisis and impact of failure modes to increase productivity and reliability in the development whereas RFMEA deals with risk events severity to mitigate project failures by escalating risk control measures. In terms of function, FMEA recognize potential modes of failure taking causes and effects into consideration giving rise to risks. RFMEA find out potential risk events considering symptom or threat resulting into project risks. FMEA can be used to design and develop the system, product and process. Alternatively, RFMEA can be used during project planning stage or for high-risks projects. FMEA is defined as the analytical and qualitative tool for identifying occurrence probability and severity scales to reduce failure events. Conversely, RFMEA is evaluating and determines likelihood probability and impact scales to mitigate events of risks. For FMEA, RPN is the multiplication of Occurrence probability (O), Severity (S) and Detection (D) values i.e. RPN = O x S x D. On the other hand, RPN in RFMEA is the product of Likelihood probability (L), Impact (I) and Detection (D) scales i.e. RPN = L x I x D. The steps followed in FMEA recognize possible faults (failure modes) aligning causes and effects where RPN values are scaled within the acceptable limit values from 1 to 1000 as per product requirements. Effective measures are suggested and implemented for unacceptable values. The process of RFMEA reveals possible risk events and symptoms of it. There is no standard scale defined as acceptable limit but its critical value identified using Pareto chart of RPN. For risks trigger greater than a RPN critical value, risk control plan is built. Although Risk scoring is calculated as the multiplication of L x I in RFMEA, it doesn't exists in FMEA. In FMEA, by gauging the possibility of control devices to detect failure events, detection is rated. Its purpose is to recommend actions and avoid events of failures reaching customers. Alternatively, for RFMEA detection scale viability of detecting risk triggers is checked so that enough time can be allotted to develop risk control measures. It's main motto is treatment of risks in the form of risk abatement strategies. Prioritization of risk in FMEA is based on RPN values unlike RFMEA which prioritize risks using critical values of RPN. In FMEA, course of actions are recommended and implemented, also RPN is re-estimated. RFMEA frames control plan for risks, implement them and re-evaluate RPN. FMEA worksheet and register of Appendix A consists of the columns namely Failure ID, Modes of Failure, Occurrence (O), Severity (S), Detection (D), Actions suggested and Actions implemented. RFMEA worksheet columns consists of ID of a Risk, Risk triggers, Likelihood scale (L), Impact scale (I), Risk scoring, control measures of risk. RPN score and detection scale columns are same for both the techniques. FMEA deals with negative events and uncertainties, however, RFMEA involves risks and opportunities in the form of positive and negative uncertainties.

VI. PRACTICAL IMPLICATIONS AND SUGGESTIONS

FMEA is not able to recognize failure modes for the whole systems which includes multiple modes of failure and can quantify one consequence at a time. Both carries subjectivity while estimating and allocating O, S and D values for FMEA and L, I and D values of RFMEA. This in turn decreases precision and accuracy of evaluated scores. Despite of being termed as efficient tool, FMEA face complexities while implementing procedure to multiple sub-systems comprising of components and sub-components (Kutsch, 2010). Rather it works smooth for only a part of sub-system which is only limited to part of grid connected PV system in mentioned case study. It is impossible for the whole PV system. FMEA another negative aspect is its detailed process of being too long, expensive and time consuming process to build because of its comprehensive nature of utilizing more resources and time frames. FMEA does not consider human potential errors or failure modes of uncertain environment at the time of assessment. It consider only those potential failure hazards excluding normal operations (Bevilacqua, 2018). The another negative outcome of FMEA is that O, S and D parameters generate different combinations and similar RPN for various risk strength, because of this events of high-risk goes missing. Numerical scales from 1-10 used while risk evaluation can create uncertainty in decision making process or it would be impractical to apply them precisely in the real world. Cross functional teams have different backgrounds people to make decisions (Pereira, 2013). Their judgements might be based on past preferences and experiences which makes complex to understand and maintain single consensus opinion within groups of both tools (Marcelino-Sádaba, 2014).

As scoring scales and models cannot be reliable and subjective, few measures could be adopted to minimize subjectivity by including large set of people in place of small groups. Average of these people's opinion could be taken while making decisions and biasing could be avoided. Involving human resources on large scale can reduce subjectivity by increasing preciseness to some extent. Defining proper strategic alliance can avoid differences within opinion and reduce subjectivity, helping to scale values more skillfully avoiding errors. Organizational records and historical databases can help in collecting information in relation to failure modes and risk triggers instead of giving importance to human opinions. Sensitivity analysis can forecast the effects of decision in future at the time of referring past information. Developing four point scale can reduce variation instead of 10 point scale. Whole product probabilistic or fuzzy theory approach can be applied for multiple failure modes of FMEA.

VII. THEORETICAL IMPLICATIONS AND SUGGESTIONS

Limited research and study is observed in R&D projects of PRM where results and discussions are restricted to fewer case studies implementation of specific industries and their organizations. Furthermore, organizational cultural influence and environment would create issues leading to conflicts and disagreement while deciding risk score and RPN critical values which is been neglected. For the above indicated issues, rigorous research is required on case studies belonging to different industry and organizations worldwide. Construction industry underutilize risk management practices at planning level, however, manufacturing industry use it widely. Thus, extended study involves integration and mapping of FMEA and Last Planner System (LPS) framework used for control and planning in construction (Geraldi, 2010). This could be further promoted by initiating new methods and procedures in the proposed model by making improvements and amendments in the existing theories. Comprehensive research is required in construction industry to develop risk logs using scenario panning and RFMEA so as to eliminate uncertainty of detection factor. Reducing detection will be more effective than framing contingency plan. In effect, RFMEA-Scenario planning conjunction is considered as innovative risk management initiative (Kokangül, 2017).

Survey and scoring criteria tools can be used for the experts from construction field, corroborating an initiative of encouraging its use in construction firms. Study of managing risk events and proactive identification of them in project context referring project risk indicators is limited to only selective divisions of engineering organizations. Procedural method of gathering data and applying qualitative data analysis of handling risks constitutes to restricted range of information labelled as minimal and insufficient research. Methodology of qualitative data analysis is to be practiced in other disciplines and divisions of industrial firms and organizations other than engineering which is possible through improved procedures. High complexity and less knowledge of risk analysis has revealed inefficiency of risk management process among construction professionals and practitioners while coming across the review of Project Risk Management and its 16 risk analysis tools in construction industry. Current techniques can be revised and new sophisticated techniques could be build, increasing knowledge management for being usable to managers (Abdel-Basset, 2019).Very little and insignificant research is been observed to confirm the effects of ignorance and irrelevance on PRM process. This is carried out particularly within IT industry and even it' s study is questionable in chemical, construction and engineering firms in future. Wide scope of projects (High, Medium & Low scale) are to be considered in various disciplines for evaluating, measuring and studying the effects of irrelevance and ignorance of project risks.

Due to large availability of Risk management and analysis tools, detailed research and study is necessary to know appropriateness of tool in a specific situation and project environment (Hugo, 2018). Adoption of understandable and less complex structure of risk tools is essential as many businesses are making it daily part of their business operations. Uncertainties issues can be addressed by developing simple and different tools to enhance accurate and critical thinking analysis of project risks. Literature review articles shortlisted in relation to risk management practices and project performance are most concentrated to construction and IT projects. This signify future work and research for testing the applicability of risk frameworks in multiple sectors. Literature review research gap can be reduced by refining and making changes in the risk frameworks to reduce publications inadequacy within specific industries.

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APPENDICES

Appendix A
FMEA log

Table 10. FMEA Register

Failure ID	Potential Failure mode	Potential causes	Potential effects	Occurrence rating	Severity rating	Detection rating	Risk Priority Number
1.							

Recommended Actions	Actions taken	Person assigned	Target date	Revised Occurrence rating	Revised Severity rating	Revised Detection rating	Revised Risk Priority Number

Appendix B
RFMEA log

Table 11. RFMEA Register

Risk ID or WBS #	Risk Event (If...then...)	Symptom	Likelihood	Impact	Risk Score	Detection	RPN
1.							

Risk Response Plan (Or Work Package #)	Revised Likelihood	Revised Impact	Revised Risk Score	Revised Detection	Revised RPN

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