Innovations

Integrated Model of PRMP and DFMEA for Identification & Mitigation of Technical Risks in a Hypervelocity Projectile Development

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Abstract: *This study involves application of integrated model of PRMP and DFMEA for identification and mitigation of technical risks in a hypervelocity projectile project. Literature review suggests that a new model/method is required to be developed for quick and accurate assimilation of technical risk while conduct of project risk management plan. This study therefore proposes a model for identification and mitigation of technical risks in a project by combining outputs from DFMEA into PRMP. This integrated model is applied in a hypervelocity projectile project that involves development of Penetration Cum Blast (PCB) warhead that has to achieve an impact velocity as high as 1500 m/s. As this project involves unproven and complex technology, identification of technical risks during preparation of PRMP was challenging. Conduct of DFMEA during the initial stage of the project by the same team which subsequently worked on PRMP helped in identifying technical risks promptly and accurately.*

Keywords: *DFMEA; Corrective Actions; Technical Risks; Project Risk Management Plan; Hypervelocity penetrator*

1.Introduction

Defence Research & Development (R&D) projects are prone to various types of risks during its lifecycle. This study incorporates Indian defence scenario in which three types of risks are considered to affect the outcome of five types of project. These three types of risks are technical risks, procurement risks and test & evaluation risks (MoD GoI, 2016) and five types of projects are Science & Technology (S&T), Technology Demonstration (TD), Mission Mode (MM), Infrastructure (IF) and Product Support (PS) projects (Bedi, 2018; CAG report 44, 2015; MoD GoI, 2016). Technical risks are the most crucial risks that can affect the success of the projects, if not mitigated. Technical risks occurs due to use of unproven or complex technology, changes in technology during project development, changes in design requirements, limitations of manufacturing processes and interaction between sub-assemblies/sub-systems (Segismundo& Miguel, 2008; MoD GoI, 2016). It is therefore important to identify technical risks by understanding reasons behind their occurrence, which often is a difficult and challenging task. This study involves application of integrated model of Project Risk Management Plan (PRMP) and Design Failure Mode and Effect Analysis (DFMEA) for identification and mitigation of technical risks in S&T project. A case study of hypervelocity projectile is considered for application of the proposed integrated model.

This study further incorporates detailed literature review to understand different types of risks associated with R&D projects with a special emphasis on definition of technical risk and impact of technical risks. Literature review is done to understand contemporary methods available for identification of technical risks. Literature is also reviewed to understand the relation between impact velocity and depth of penetration and effect of impact loads on the penetrator having specific strength. Need for identifying technical risks in a technically challenging hypervelocity projectile is iterated and an integrated model of DFMEA and PRMP is proposed to identify and mitigate technical risks. Since, PRMP is a mandatory requirement for such a complex project, apart from identifying technical risks, details such as probability of occurrence, detection methods and recommended actions required for completing PRMP are also supplanted from DFMEA.

2. Technical risk in defence R & D projects

Technical risk is one of the three risks identified in the Indian defence set-up, apart from procurement and test & evaluation risk. Before understanding definition of technical risk and methods utilized to identify technical risk, it is worth noting how risk in general is defined. As per IS_ISO-31000 (2009), risk is defined as an effect of uncertainty on objectives. These objectives can differ according to the industries in which these objectives are considered, however, in general these objectives are considered as cost, quality, schedule and resources. Project Management Body of Knowledge (PMBoK) has also defined risk as "an uncertain event or condition that, if occurs, has a positive or negative effect on at least one project objective, such as cost, time, scope and quality" (PMBoK, 2013). Another definition of risk is that it is a condition in which possible events of a decision is known or in other way risk actions can be predicted based on the chances and impact of occurrence (George, 2018).

Literature review for definition of technical risk fetched multiple results as per product functions as well as industry area in which risk is defined. Further review of the literature suggests that definition of technical risks with respect to R&D is mostly focused towards new product development or new product introduction and a specific reference to defence R&D projects is missing. As per one of the definition, technical risk is nothing but technological uncertainties in the project (Cramaet al., 2005). Australian government's department of defence has come up with a comprehensive handbook on technical risk assessment dedicated exclusively for management of technical risk. As per this handbook, technical risk is defined as "the risk that the project will not achieve its objectives due to risks which arise in the integration of critical technologies, and/or sub-systems dependent on them or to the integration of the system into the Defence Forces (DF)" (DSTO, 2010). The above definition is meant for the Australian Defence Forces (ADF), however, this definition can be generally applicable to all Defence Forces (DF) and hence ADF is replaced by DF in the above definition. One of the studies with respect to defining technical risks in defence projects has been done by Moon & Cook. According to them technical risks are those which are defining, interpreting and managing the operational requirements; system design, configuration and integration; interoperability and issues related to interoperability; undertaking of test and evaluations; addressing, operating and support issues; and further development and through-life upgrades (Moon & Cook, 2005).

Few other definitions of technical risk have been observed in the literature review. One of the definitions is by Sokri and Ghanmi, who have defined technical risk as the "probability of loss incurred through the execution of a technical process in which the outcome is uncertain, in which untested engineering, technological or manufacturing procedures entail some level of technical risk that can result in loss of time and resources" (Sokri&Ghanmi, 2017). Similarly, Klein & Cork have defined technical risk as the likelihood that a system embodied in a design will, when constructed, doesn't meets the performance requirements it is intended to meet (Klein & Cork, 1998). NASA risk management handbook has defined technical risk as "a risk associated with the evolution of the design and the production of the system of interest affecting the level of performance necessary to meet the stakeholder expectations and technical requirements" (NASA, 2011). Jaafri has defined technical risk as probability of project not performing to the required technical standard such as not meeting its license conditions or produce substandard products or have excess operating cost energy consumption (Jaafri, 2001). Technical risk is also defined as "probability of technical success in terms of meeting a specific set of goals (e.g. manufacturing feasibility, efficacy and safety expectations, reliability commitments) (Felli& Andersen, 2010).

Defence R&D projects are complex and untried projects and therefore these projects involve lots of uncertainties and higher technical risks. However, the impact created by technical risks in such projects is even higher. Impact of technical risk could results in component failure which can then propagates towards failure of the system (Hsiao et al., 2013) and therefore, it is important to understand what contemporary tools & techniques are available for identification of technical risks. Project Management Body of Knowledge (PMBoK) specifies standard tools and techniques for identification of technical risk and to that matter any risk. According to PMBoK, these standard tools and techniques are documentation review; information gathering techniques such as brainstorming, Delphi technique, interviewing, root cause identification and SWOT (Strength, Weakness, Opportunity and Threats) analysis; checklist analysis; assumption analysis; diagramming techniques such as cause & effect diagram, system or process flow chart, and influence diagrams (PMBoK, 2004). Since PMBoK is the most referred book of knowledge for project and risk management, these tools and techniques are considered as standard ones and being utilized across industries for identification of technical risks. A survey has been conducted by Raz and Michael to understand most preferred tools and techniques for identification of risks in project and their results corroborates PMBoK that checklist, brainstorming, risk documentation form and periodic risk reporting are the best methods for identification of risks (Raz & Michael, 2001).

3. Hypervelocity projectile with PCB warhead

Penetration of hypervelocity projectile into concrete is an extensively researched topic. It has been observed through these researches that at a speed of 1100 m/s to 1500 m/s, material removal from the nose of the projectile is evident along with phase changes of the projectile material and reduction in the length of projectile (Zhang et al., 2013). Changes in the projectile material are further corroborated by Walker et al. in their research, wherein they have mentioned that hypervelocity speed can induce severe deformation and erosion in the projectile material. This has exposed critical gaps in understanding the behavior of material under hypervelocity impact (Walker et al., 2024). If a projectile has to achieve impact velocity as high as 1500 m/s, the launching platform needs to be robust enough to propel the projectile at that velocity. Baker et al. has mentioned in their research that launching platform is a smooth bore 40mm powered gun for such application (Baker et al., 2016). However, in an Indian setup, this launching platform is a constraint along with other constraints as mentioned above in the hypervelocity projectile project. Development of test methodology for high velocity impact in concrete is another challenge in the project. Various such challenges related to hypervelocity impact testing have been spelled out by Piekutowski and Poorman (2023) in their research.

From the literature review it was evident that hypervelocity project having a PCB warhead would encounter various challenges including material selection for PCB which experiences high strain rates at impact. For selected combination of materials, there is a threshold at which maximum penetration can be achieved. One more challenge is how to launch a projectile at such a high velocity. Considering different challenges, the project obviously would have encountered risks, especially technical risk that needed to be captured in a risk management plan. Project risk management plan is a mandatory document in high risk projects, especially defence projects and is a framework to identify the procedures that should be adopted to manage risks and the approach being followed in the project. Since the hypervelocity project had multiple challenges and many technical areas were unknown, it was taken up as an S&T project in which identifying technical risks accurately was a challenge. S&T project is usually undertaken to prove a basic concept through simulations and experimentations, which ultimately is converted into prototypes. These prototypes are then trail evaluated to gain confidence and finalize the design. Another reason for taking up hypervelocity project as S&T project was the fact that many trials and experimentations were to be carried out to achieve desired results.

In his report on countering the hypersonic missile threat, Karako and Dalhgren (2022) have suggested multiple failure modes considering various technical challenges/risks in the hypervelocity domain. To overcome these challenges and to capture technical risks, an integrated model comprising of DFMEA and PRMP is utilized in this project. The integrated model is shown in figure 1.

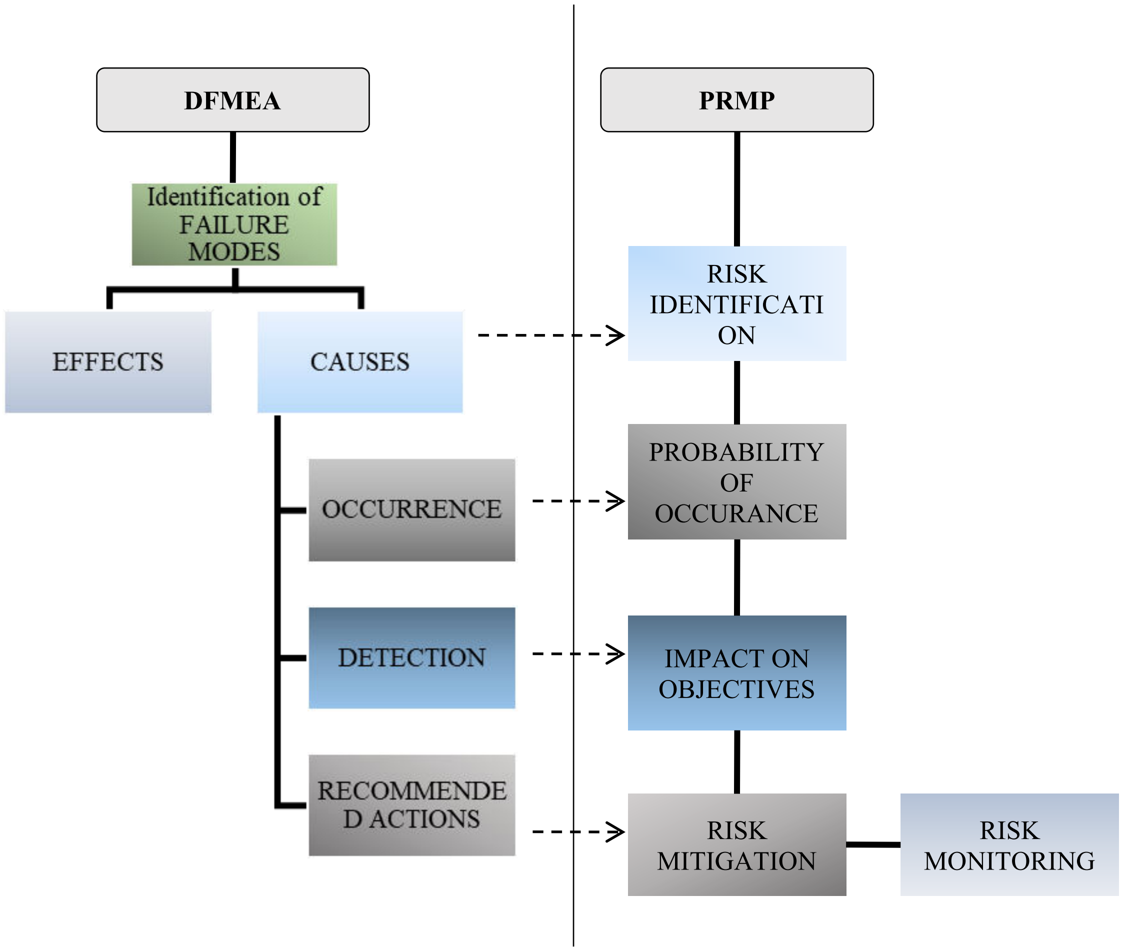

Figure 1. Integrated model of DFMEA & PRMP

4. Application of integrated model

A team of experts from design, manufacturing and quality engineering was assembled to understand technological challenges in the project if the projectile has to achieve the velocity as high as 1500 m/s and accordingly work on constructing the PRMP. This team anticipated various technical risks and the complexity of the project entailed the team to conduct DFMEA so that potential failure modes can be identified upfront. As the product was not realized, the team considered functional aspects of the product while working on DFMEA during conceptual stage of the project. While conduct of DFMEA, IS standard 15550:2005 was referred for suggested Severity (S), Occurrence (O) and Detection (D) evaluation criteria. Once the severity, occurrence and detection is suggested, Risk Priority Number (RPN) was calculated by the formula RPN = S*O*D.

The complete DFMEA is shown in Table 1. The team subsequently decided to consider recommending corrective actions for the causes having RPN of more than 100. These recommended actions are taken into considerations while considering mitigation plan for reduction of technical risks in PRMP.

Table 1. DFMEA for the hypervelocity projectile

Function	Failure	Effect	S	Cause	O	Control (Prevention)	Control (Detection)	D	RPN	Recommended Actions
To penetrate specified target at desired velocity	Did not hit specified target	Mission failure	8	Disturbance in the flight due to:						
				Mass properties not as per aerodynamic requirement	2	Solid modeling and CFD Simulation studies	Measurement of mass and CG	1	**16**	
				Dis-integration of projectile	2	Structural analysis to ensure Margin of safety for strength	Raw Material testing to be included in QAP	2	**32**	
				Excessive vibration	3	Design optimization of Sabot	Nil	7	**168**	Expert committee review. Root-Cause Analysis.
				Aerodynamic shape	3	CFD Analysis	Nil	5	**120**	Aerodynamic design to be reviewed after prototype testing.
				Sabot failure	6	CFD Analysis	Nil	5	**240**	Aerodynamic design to be reviewed after prototype testing.
				Projectile stuck in barrel due to: Excessive deformation	5	Structural analysis to ensure Margin of safety for strength	Raw Material testing to be included in QAP	2	**80**	
				Excessive dimensional deviations	2	Design review	Dimensional inspection to be included in QAP	1	**16**	
	Less penetration (less than 20%)	Degradation in primary function	7	Projectile disintegrated on impact	5	Material characterization	Raw Material testing to be included in QAP	2	**70**	
				Projectile design not adequate	2	Design review		2	**28**	
				Projectile impacting with high yaw	6	CFD Analysis for stability check		6	**252**	Aerodynamic design to be reviewed after prototype testing.
				Target strength overlooked during design	1	Design review		1	7	
				Higher Target strength	3		Compressive strength test to be included in QAP	2	**42**	
	Over-penetration (More than 20 %)	Degradation in primary function	7	Projectile design not adequate	5	Simulation studies & Design review	Penetration trials	3	**105**	Review after prototype testing.
				Low target strength	2		Compressive strength test to be included in QAP	2	**28**	
To achieve desired impact velocity	Lower than desired velocity at impact	Less penetration	7	Poor obturation	5	Design review	Driving band fitment trial to be included in QAP	2	**70**	
				Sabot did not separate	3	CFD & Design review		2	**42**	
				Poor aerodynamic design	2	CFD & Design review		2	**28**	
	Higher than desired velocity at impact	More penetration	7	Low projectile mass	2		Projectile mass check to be included in QAP	1	**14**	

After completing the DFMEA, all the identified potential causes were considered as technical risks in the risk management plan. Probability of occurrence of a cause identified in DFMEA is helpful in PRMP by providing more accurate values for probability of product failure at a given point in the product life cycle. Occurrence number in DFMEA has a relative meaning than an absolute value. In PRMP, this number has to be translated into probability of occurrence in terms of meaningful number. A comparative chart as per Table 2 was utilized for converting DFMEA occurrence number into probability of occurrence in PRMP. Detection number identified in DFMEA was used as reference for considering impact on various objectives. If the detection number is high it is certain that the failure mode is difficult to detect and hence its impact was considered as high.

Table 2. Occurrence comparative chart

Occurrence Ranking	**Possible Failure Rates per Million Items**		**Suggested Probability of Occurrence in PRMP**
	Per Million	**%**	
10	0.1	10	0.91 - 0.99
9	0.05	5	0.81 - 0.90
8	0.02	2	0.71 - 0.80
7	0.01	1	0.61 - 0.70
6	0.005	0.5	0.51 - 0.60
5	0.002	0.2	0.41 - 0.50
4	0.001	0.1	0.31 - 0.40
3	0.0005	0.05	0.21 - 0.30
2	0.0002	0.02	0.11 - 0.20
1	0.00001	0.001	0.01 - 0.1

Referring Table 1, occurrence ranking for high RPN (as shown in red color) causes in DFMEA was converted to probability of occurrence to be utilized in PRMP and is shown in Table 3. Project risk management plan for technical risks considering inputs from DFMEA is shown in Table 4. All the corrective actions from DFMEA were considered as risk mitigation plan and elaborated in the PRMP.

Table 3. Conversion of occurrence ranking into probability of occurrence

Causes in DFMEA Technical Risk in PRMP	Occurrence Ranking in DFMEA	Probability of Occurrence in PRMP
Disturbance in the flight due to Excessive vibration	3	0.3
Disturbance in the flight due to Aerodynamic shape	3	0.3
Disturbance in the flight due to Sabot failure	6	0.6
Projectile impacting with high yaw	6	0.6
Projectile design not adequate	5	0.5

Table 4. PRMP for technical risks in hypervelocity projectile project

Sr. No	Risk Description (Technical Risk)	Probability	Impact on Objectives-combined (Time, Cost & Performance)	Risk Priority Number	Risk Mitigation Strategy	Risk Mitigation Plan
1	Disturbance in the flight due to Excessive vibration	0.30	0.70	0.21	Control	Expert committee to review reasons for excessive vibrations. Root-Cause Analysis to be done by design team.
2	Disturbance in the flight due to Aerodynamic shape	0.30	0.50	0.15	Control	Aerodynamic design to be reviewed after prototype testing by design review committee and recommend corrective actions.
3	Disturbance in the flight due to Sabot failure	0.60	0.50	0.30	Control	Aerodynamic design to be reviewed after prototype testing by design review committee and recommend corrective actions.
4	Projectile impacting with high yaw	0.60	0.60	0.36	Control	Aerodynamic design to be reviewed after prototype testing by design review committee and

						recommend corrective actions.
5	Projectile design not adequate	0.50	0.30	0.36	Control	Review to be done after prototype testing to confirm design parameters.

Risk Mitigation Strategy	Accept	Accept the risk as it is
	Avoid	Recommend actions to avoid risk
	Control	Corrective actions to control risk
	Transfer	Transfer the risk to third party

5. Conclusion

Risk management for technical risk is important as technical risk contribute significantly towards success or failure of the project. Technical risks are generated when technological challenges are abound in the project and the systems/products which are getting realized through projects are more complex. Hypervelocity projectile project had multiple challenges and hence was prone to technical risks. These technical risks were captured in the risk management plan by considering outputs of DFMEA, which was conducted during the initial stage of the project. DFMEA allowed the project team to understand various failure modes and causes of those failure modes, which were nothing but technical risks in the project. Since DFMEA suggested corrective actions for these causes, same corrective actions were considered as mitigation plan for the technical risks in PRMP. One of the important actions considered as mitigation plan was conduct of aerodynamic studies and review of design after prototype testing to corroborate the results from testing as well as aerodynamic performance of the projectile. Both DFMEA and PRMP were complementary and since one team worked on both DFMEA and PRMP, the project team benefitted by completing the risk management plan accurately and quickly.

By considering causes for all the failure modes as technical risks into PRMP, considerable time saving was achieved simply by not reinventing the wheel of risks identification. Technical risks are considered as the most important risks having larger share compared to procurement and test & evaluation risks in S&T

projects. Significant time saving in PRMP was achieved by considering inputs from DFMEA in PRMP. As PRMP is a mandatory document for project manager, the process of PRMP is completed without delays.

Declarations

All authors declare that they have no conflicts of interest.

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