Innovations

Comprehensive Analysis of Risk Management Plan for Technical Risks in Defence R&D Projects

[1] Prem Y Borse, [2] Nilesh Ware

[1] Technology Management group, Armament Research & Development Establishment (ARDE), Pune-411 021, India

[2] Defence Institute of Advanced Technology, Pune- 411 024, India

Corresponding Author: **Prem Y Borse**

Abstract: *Defence Research and Development (R & D) projects are riskier and costlier because of their interdisciplinary nature as well as complexities involved with these projects. A review of literature suggests that various risks are associated with defence R & D projects, however, in all the risks, technical risk is considered as crucial due to the way this risk impacts the final outcome of defence R & D project. It is therefore important to understand what makes technical risk so important than other risks in defence R & D projects. This study involves comprehensive analysis of literature to understand different types of risks associated with defence R & D projects, definition of technical risks, risk management plan for technical risks with a special emphasis on identification and mitigation of these risks. This study also explores the literature for possible understanding about importance of technical risks compared to other risks and tools and techniques utilized for identification of technical risks, with a special focus on Design Failure Mode and Effect Analysis (DFMEA) methodology. Indian defence scenario is considered to understand different types of projects and risks while conducting comprehensive analysis of technical risk.*

Keywords: *Technical risk; Defence R & D projects; S&T projects, Risk Management Plan*

1. Introduction

Defence R & D projects are undertaken to realize various products required for military and paramilitary forces of the country. Defence R & D projects are crucial for the growth of country and to make country self-reliant in defence area. Every developed and developing country allocate substantial amount of its budget for defence R & D, however, these projects run through obstacles and not necessarily fructify all the times, causing loss to country's exchequer. These obstacles are in the form of risks emanating during the progress of the projects. Since defence R & D projects are of various types, each type of projects is prone to different types of risks. In this study, Indian defence scenario is considered for delimitation of projects as well as risks, as illustrated in figure 1. Accordingly, defence R & D

projects are categorized into five types namely, Science & Technology (S & T), Technology Demonstration (TD), Mission Mode (MM), Infrastructure (IF) and Product Support (PS) projects (Bedi, 2018; CAG report 44, 2015; MoDGoI, 2016) and risks are categorized into three types namely, technical, procurement and test & evaluation risks (MoD GoI, 2016).

Technology Readiness Level (TRL) is used to measure the technologicaloutcome of the above mentioned five projects, which are the most common measure for systematically comunicating the readiness of new technologies or new application of existing or legacy technologies. TRL level of 1 to 10 signifies different stages of the product/system with 1 being the abinitio research done for the system to 10 signifying product/system available off-the-shelve. Science and Technology project is undertaken as a basic R & D project with an aim that a technology or a system can achieve TRL of 2 or 3 after completion of the project. Multiple experimentations, simulations and trial and evaluations are carried out in S & T project to convert a basic idea or scientific concept into technology or a system. TRL level of the project at the beginning could be 1 and when the project is completed, TRL level of 2 or 3 can be achieved. S & T projects are very crucial for any defence R & D organizationdue to the fact that S & T projects provide detailed understanding of the system/technology and can give confidence to the scientific community to explore the technology further and pave path for TD & MM projects. Technology demonstration projects are next level projects to S & T projects in which technology is further explored, sub-systems are developed and integrated into system and this integrated system or prototype is test evaluated in simulated working conditions. TD projects can achieve TRL of 6 to 7 at maturation. Mission mode projects are undertaken to fulfill users requirements which are time bound and are taken up to further enhance the TRL of the system. At the completion of the MM project, a system can achieve TRL of 9.

This study comprehensively reviews different types of risks associated with R & D projects emphasising more on definition, impact and risk management plan for technical risk in S & T type of project. Importance of technical risks compared to procurement and trial & evaluation risks and tools and techniques utilized for identification of technical risks with a special focus on Design Failure Mode and Effect Analysis (DFMEA) methodology is also elucidated in this study.

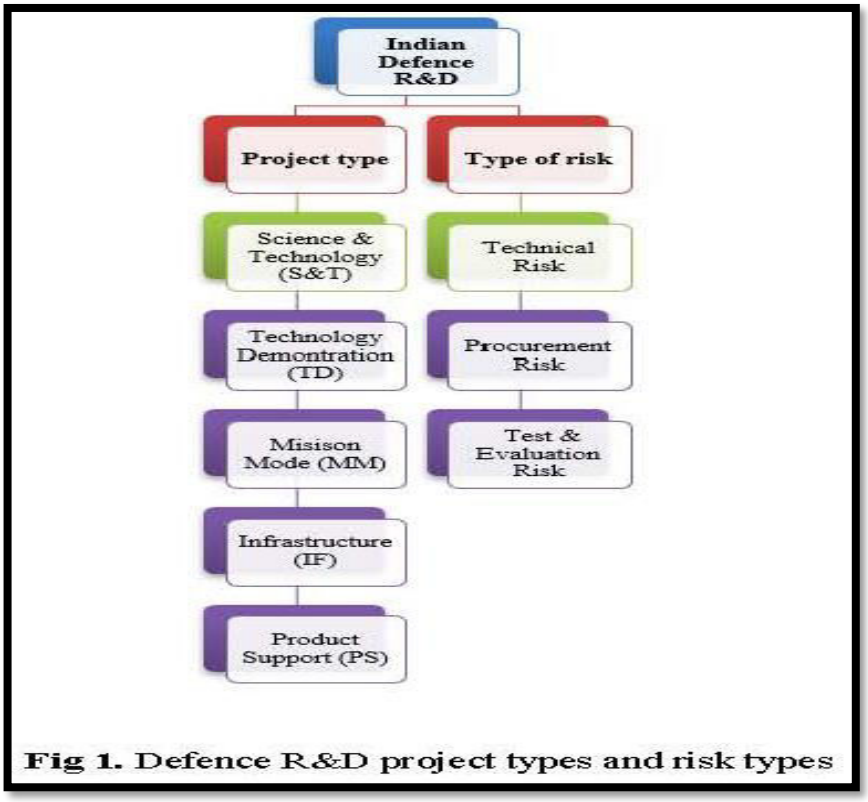


Fig 1. Defence R&D project types and risk types

2. Risks in R & D projects

2.1 Definition and types of risks in R & D projects

Risk 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). IS_ISO and PMBoK are the two frequently referred references for understanding the definition of risk and is well illustrated in figure 2. As per IS_ISO-31000(2009) risk is defined as an effect of uncertainty on objectives. These objectives can be different in different industries but mostly considered as cost, quality and schedule. Project Management Body of Knowledge (PMBoK) defines risks 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).

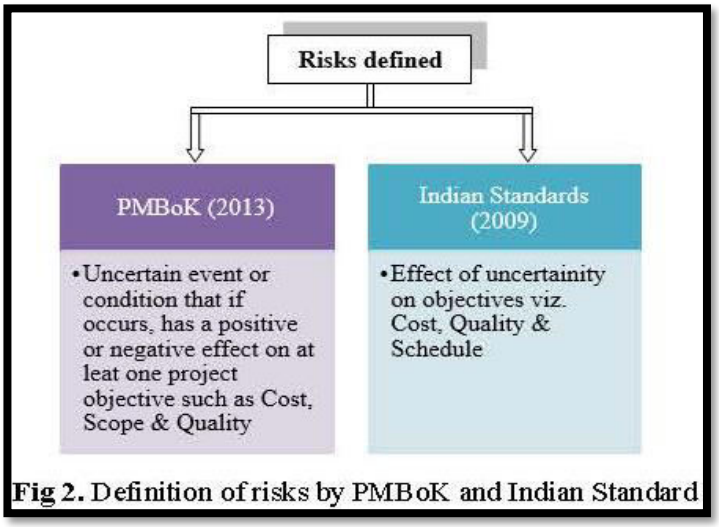


Fig 2. Definition of risks by PMBoK and Indian Standard

Apart from the technical, procurement and trial & evaluation risks as discussed in the introduction section, various authors have classified risks based on multiple factors. Nicholas & Steyn have classified risk in projects as Internal and External Risk wherein market risk, assumption risk and technical risk are part of internal risk and multiple external factors influencing the project are part of external risk (Nicholas & Steyn, 2008). Similarly, Kerzner has classified risk as Technology, Development, Financial and Marketing Risks (Kerzner, 2009). Literature is in excess with definitions of risk and types of risks in projects, however, in this study, types of risks associated with R&D projects including defence R & D projects are only considered. Correct identification of risks is crucial for all projects but it is more important to identify risks in R&D types of projects as R & D projects are more complex, interdisciplinary and have lots of unknowns (Cakmak & Gokpinar, 2007). Hillson has classified risks in R&D projects as technical, project management, organizational and external risks (Hillson, 2001). Kasapet al. have categorized risks in R&D projects into four major types such as Market, Technology, Environmental and Organization related risks (Kasapet al., 2007).

In their research Chenaraniet al. have proposed four types of risks and risk characterization according to effects of risks on project constraints such as time, cost, scope and quality (Chenaraniet al., 2017), especially in R&D projects.

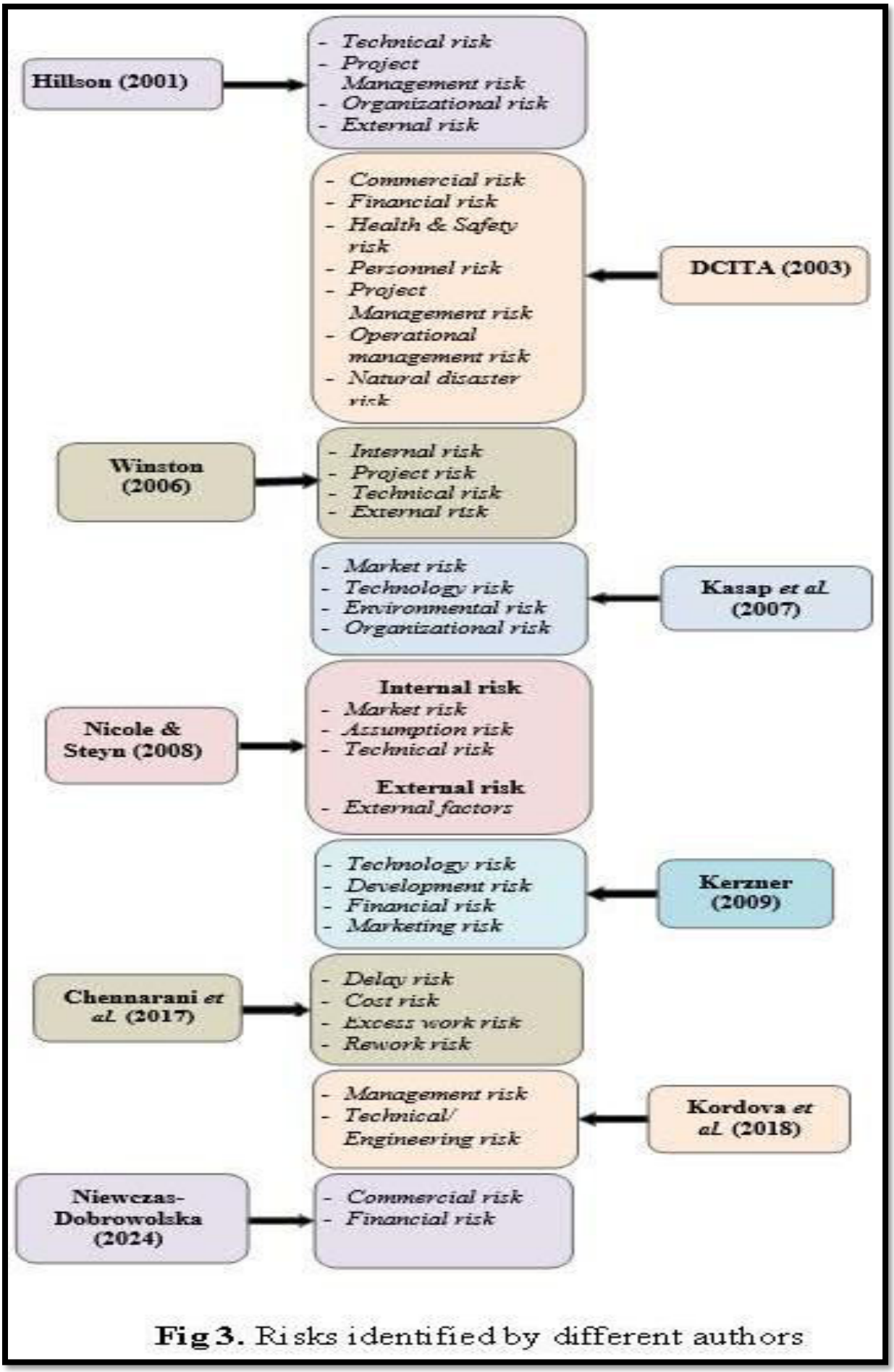


Fig 3. Risks identified by different authors

These four types of risks are Delay Risk that affects the activity duration, Cost Risk that affects the activity cost, Excess Work risk that causes additional work for the same activity and Rework Risk causing repeat of some or all parts of group of activities. According to Kordovaet al. risk in defence projects are mainly categorized as Management Related Risks such as cost and organizational expenses and Technical/Engineering Risks such as specifications, performance demands and premature technology (Kordovaet al., 2018).Department of Communication, Information Technology and Arts (DCITA) of Australian government has defined risks in R&D projects as commercial, financial, health & safety, personnel, project management, operational management and natural disaster risks (DCITA, 2003). Winston has also categorized risks in R&D projects as internal, project, technical and external risk (Winston, 2006). Categorization of risks in R&D projects are also done by Dobrowolska and accordingly these risks are commercial and financial, research achievability and integrity, research method and process, research team, external stakeholders, ethics and infrastructure (Niewczas-Dobrowolska, 2024). Most studies have identified technical risk as one of the risks emanating in R&D projects. The above-mentioned different types of risks defined by various authors is illustrated in the form of chart in Figure 3.

2.2 Technical Risk in R & D Projects

Assessment of literature reveals that definition of technical risk varies depending upon the product functions as well as industry segment in which risk is defined. This assessment also suggests that technical risks concerning to R&D is mostly concentrated towards new product development or new product introduction and a specific reference to R&D projects or to that matter defence R&D projects is missing. Cramaet al. (2005) have defined technical risk as technological uncertainties in the project. Technical risk assessment handbook of the Australian government department of defence is a comprehensive and book dedicated exclusively for management of technical risk. According to 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, it could be generally applicable to all Defence Forces (DF) and hence ADF is replaced by DF in the above definition. Moon & Cook have defined technical risks as those risks 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).

According to NASA hand book, technical risk is ‘‘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''. The design, test, and production processes (process risk) influence the technical risk and the nature of the product as depicted in the various levels of the Product Breakdown Structure (product risk)(NASA, 2011). 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). Technical risk management chapter in handbook of research on technology project management, planning and operations has defined technical risk as ''any occurrence that could negatively impact the result of a program which could be mitigated by application of technical skills resulting in an improved design of a component, system or process, thereby reducing the potential impact on the program'' (Hylton, 2009).

Sokri & Ghanmihas defined technical risk as ''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). Klein & Cork has 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). Jaafri has summarized various types of risks encountered in a project including R&D project and also 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). Table 1 illustrate definition of technical risks as defined by various authors.

Table 1. Technical risk defined

Technical risk defined	
Author	**Definition**
Klein & Cork (1998)	The likelihood that a system embodied in a design will, when constructed, doesn't meets the performance requirements it is intended to meet
Jaafri (2001)	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
Moon & Cook (2005)	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
Crama *et al.* (2005)	Technological uncertainties in the project
Hylton (2009)	Any occurrence that could negatively impact the result of a program which could be mitigated by application of technical skills resulting in an improved design of a component, system or process, thereby reducing the potential impact on the program
DSTO (2010)	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
Felli & Andersen (2010)	Probability of technical success in terms of meeting a specific set of goals
NASA (2011)	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
Sokri & Ghanmi (2017)	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

2.3. Sources and impact of technical risk in defence R & D projects

The sources of technical risks are varied but could be technical requirements, performance demands and premature technology (Kordovaet al., 2018). Segismundo & Miguel have considered technical risks as crucial and stated that the sources of technical risks are from the use of unproven or complex technology and from changes in technology during project development (Segismundo & Miguel, 2008). In addition to these two sources, Procedure for Project Formulation and Management, PPFM-2016proposestwo additional sources from where technical risks can originate in R&D project; i) changes in design requirements, ii) limitations of manufacturing processes (MoD GOI, 2016). PPFM-2006was a structured guidelines on procedures to be adopted for project formulation and management which was later revised in 2016 (MoD GoI, 2016; Mohindra & Srivastava, 2019).Based on these authors experience, interaction between sub-assemblies/sub-systemsis another source from where technical risks can originate. Dey in his research has defined sources of technical risk as scope change, technology selection, implementation methodology selection, equipment and material risk and engineering & design change (Dey, 2002). These sources of technical risks arising from various reasons are illustrated in figure 4.

S & T projects would inherently exhibit technological uncertainties in the form of technical risks, which may result in S&T project failure (Cramaet al., 2005). These

authors in their earlier research have substantiated that technical risks are high in S&T project compared to TD & MM projects (Borse& Ware, 2024) and therefore these authors believe to review the literature to understand studies concerned with impact of technical risks in S&T projects. As literature review was carried out for understanding the impact of technical risk in S&T project, it was noticed that research in regards to impact of technical risk in S&T project is missing. Specific mention of technical risk and S&T projects was absent in various studies identified during the literature review, however, literature is in excess with studies generalizing the impact of risk on projects of which few studies are highlighted here.

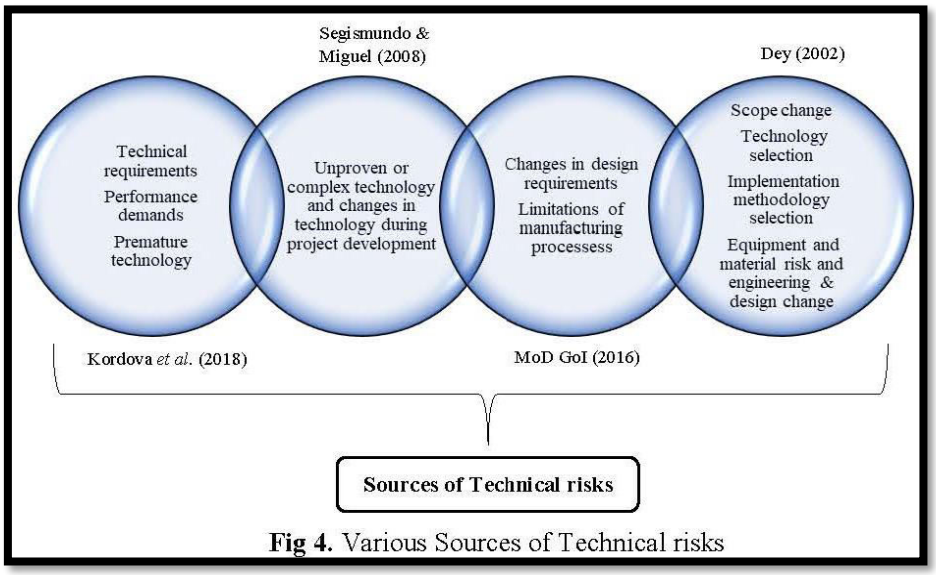


Fig 4. Various Sources of Technical risks

Thamhain has studied the impact of risks in complex projects and has divide drisks into four categories with respect to risk impact on project. All the four categories of risk impact on project considered for complex project holds true for all the projects including defence R&D projects (Thamhain, 2013). Browning et al. discusses about impact of risks in terms of project failing to meet the requirements in which some requirements are absolute thresholds below which the entire system is unacceptable. Other requirements represent customer preferences, where more is better but less might be acceptable (Browning et al., 2002). In a complex project like defence R&D project, Kordova & Fridkin have defined two types of risks, one that can be predicted in advance and the other which can't be predicted in advance (Kordova & Fridkin, 2021). It is the second type which could have major impact on the outcome of the project. Technical risks, as per its definition would be generated during integration of major technologies and hence technical risks would be difficult to predict in advance and therefore would have major impact on project objectives.

Since defence R&D projects are complex and untried, impact created by technical risks are higher in defence R&D projects and are mostly on four primary objectives of the projects i.e. scope, quality, cost and schedule. However, Turner & Hunsucker in their research states that risks could have impact of several types and

can threaten several organizational activities. They suggest assessing the impact of these risks in such a way that all organizational goals are accurately and fully represented, regardless of their origin(Turner & Hunsucker, 1999). The impact of technical risk could result in component failure which can then propagates towards failure of the system (Hsiao et al., 2013) and therefore, it is important to recognize importance of technical risks and methods of identification of technical risk.

3. Identification of technical risks in defence R&D/S&T projects

3.1 Importance of technical risk in defence S&T project

Importance of risks has been stated by many authors in their studies and they demonstrated that risks in R&D project could hamper the success of the projects and can significantly contribute towards lowering the success rate of the projects (Van Zylet al., 2007; Sicotte & Bourgault, 2008; Jolonen, 2011). Importance of technical risk can be substantiated from the fact that technical risk can propagate system failure, meaning failure of the project itself. Technical risks can also put projects behind schedule, over budget, and compromise safety and security. Technical risk is highly important in defence project so much so that the defence system analysis division of defence science and technology organization of Australian Defence has published a technical report on technical risk assessment. This report has enumerated importance, identification, assessment and possible mitigation plan for technical risk specifically in the S&T scenario (O'Neill et al., 2007).

According to the procedure for project formulation and management published in 2016, one of the reasons for origination of technical risk is due to changes in design requirements (MoD GoI, 2016). Since S&T projects are undertaken as basic R&D projects with an aim to explore and convert every facet of basic scientific conceptin to technology or system, design requirements do change during this phase and hence, S&T projects are bound to have technical risks inherited in it. Final design in S&T project is arrested only after multiple experimentations and trial and evaluations. Evolution of technology from a TRL level of 1 to further TRL level happens only after S&T project is completed and for this, it is imperative that technical risk is identified, assessed and mitigated during S&T project. A successful S&T project paves way for TD and MM project. It is therefore important for project managers to understand how to properly identify, assess, manage, and mitigate technical risk in order to ensure that their projects get done on time, within budget, and without any unpleasant surprises. Mitigation of technical risk would be possible when these risks are identified.

3.2 Tools and techniques for identification of technical risk with focus on FMEA

Since the product/system is not yet fully realized in S&T project, designers tend to understand the failure modes by considering functional aspects of the product/system and therefore conduct of DFMEA during conceptual stage of the design is helpful. DFMEA is an opportunity for designers to understand various

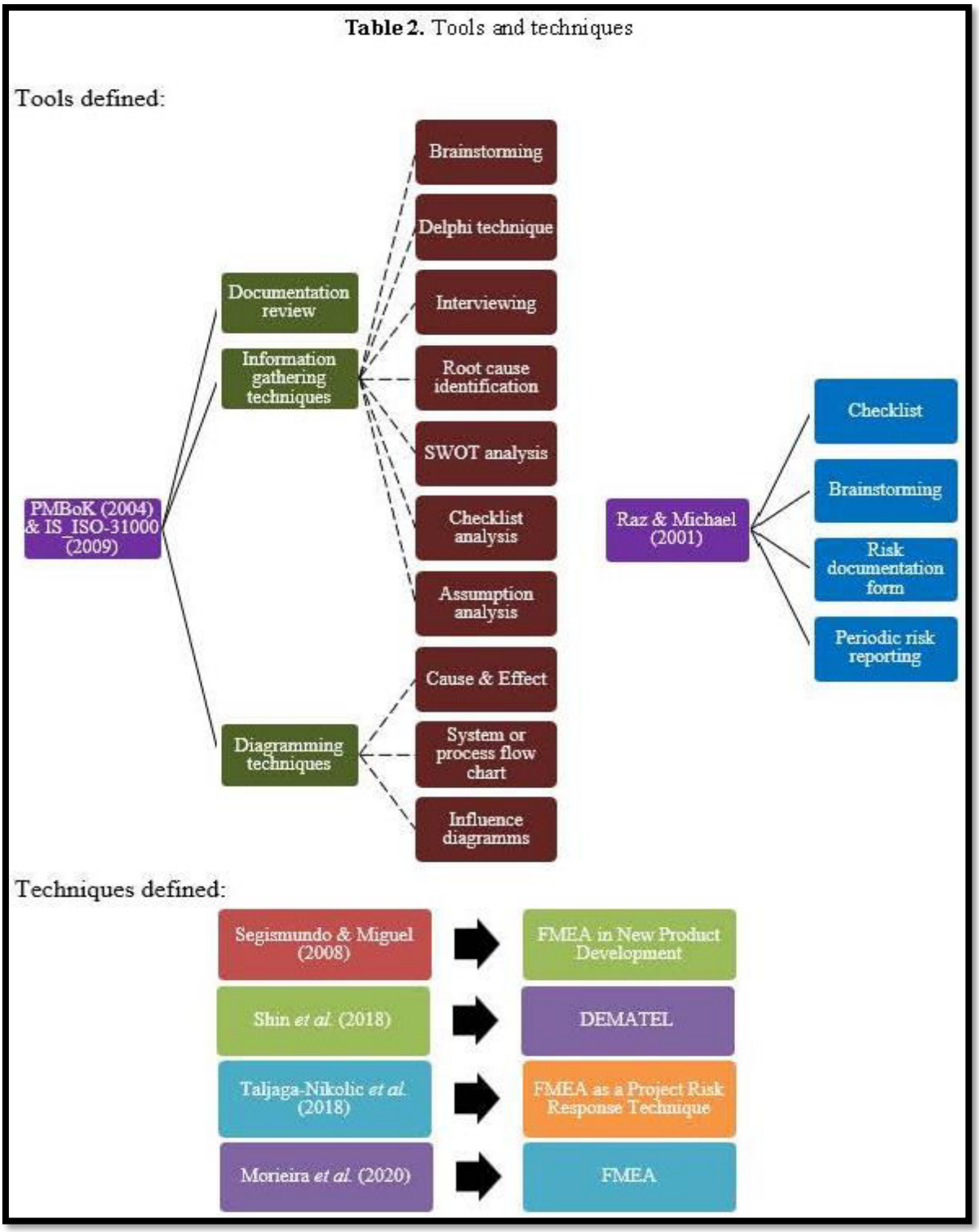
risks in the design and hence many authors have incorporated FMEA in risk management studies. Literature is reviewed to understand different types of tools and techniques enumerated for identification of technical risks and also to understand if FMEA has been utilized for identification of technical risk in projects or to that matter R&D projects.

The Project Management Body of Knowledge (PMBoK) guide is the most referred document among project managers to get general overview of the best contemporary project management practices including risk management. According to PMBoK, standard tools and techniques that are utilized for identification of any risk including technical risk 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). Many authors have quoted and referred PMBoK for citing similar tools and techniques for identification of risks inprojects, including R&D projects. Few such research studies are quoted here on sample basis and they are by Wageman (2004), Kasapet al. (2007), George (2018), Kordova & Fridkin (2021), Mashiriet al. (2022) and Enobakhare (2024). Similarly, IS_ISO-31000(2009) also provides similar tools and techniques mentioned in PMBoK for identification of technical risk and to that matter any risk. Raz & Michael have conducted a survey to understand the most preferred tool and technique for identification of risks in project. They have found that checklist, brainstorming, risk documentation form and periodic risk reporting are the best methods for identification of risks (Raz& Michael, 2001).Ghaeli has also conducted a survey to identify different tools which are implemented during different phases of project risk management (Ghaeli, 2018).

Review of literature is conducted to understand if FMEA is used as a technique for identification of risks in projects, especially in R&D projects. It is observed that various authors have incorporated FMEA as a risk assessment tool in which failure modes itself are considered as potential risks in the system/product. Some of these studies are: Morieiraet al. have explored the applicability of FMEA as an effective tool for decreasing failure risk in early phase of New Product Development (NPD) (Morieiraet al., 2020). Similarly, Shin et al. have proposed a systematic approach of performing R&D failures and risk management in R&D process. They have modified FMEA to meet the specific requirements of R&D process with a stage-gate model for identifying failure modes in each stage of R&D process. Further they have suggested use of Decision Making Trial and Evaluation Laboratory (DEMATEL) for prioritizing the risks of R&D failure (Shin et al., 2018). Segismundo & Miguel have analysed the role of FMEA in the process of risk management and have recommended systemization and utilization of technical risks through the use of FMEA technique to optimize the decision making process in NPD (Segismundo & Miguel, 2008). Toljaga-Nikolic et al. have utilized FMEA technique for identification

of risks in project. They propose to use FMEA as project risk response technique to reduce time and resources in the project (Toljaga-Nikolic et al., 2018).It is pertinent to note that various studies reviewed with respect to risk identification with various tools and techniques in R&D projectsare in general applicable to all kinds of risks including technical risks. Once identification process of technical risks is over, it is also noteworthy to ascertain studies related to mitigation of these risks in R&D/S&T projects. These tools and techniques for identification of technical risks is further explained in detailed in Table 2.

Table 2. Tools and techniques



4. Risk management plan for technical risks in defence R&D/S&T projects

As technical risk impact is assessed, a process of mitigating these risks is crucial so that the impact is minimized or nullified. Risk management process of technical risk encompasses the overall process from identification to mitigation of technical risk. Ineffective management of risks invariably results in poor performance of project and hence risks need to be managed effectively (Luppinoet al., 2014). In other words, it has been proved that adopting best risk management practices results in improvement in the project performance (Junior et al., 2013). The purpose of risk management is to reduce the impact of uncertaintieson project outcome. Development of methodologies to mitigate risks has been reiterated by many practitioners (Shin et al., 2018; Jiang & Chai, 2015).Plethora of studies are available in literature regarding risk management plan however, this study is focused towards management plan for R&D projects. It was also observed that many authors have integrated multiple tools and techniques and methods to better streamline the risk management process itself but the focus of this study is not to review these tools & techniques but focus on the risk management plan in R&D projects.

For defence R&D projects, JSP 892, (risk management part 1: directives) details out complete risk management process (UK MoD JSP 892, 2015). Kasapet al. defines risk management in R&D process as a four-step process of identifying, quantifying, planning and monitoring & managing risks (Kasapet al., 2007). Alshehhiet al. have studied the management of risk in delivering complex R&D projects in UAE armed forces (Alshehhiet al., 2018). Wageman has examined R&D risk using sequential and reiterative process of planning, identifying, categorizing, analysing, prioritizing, response development and monitoring and controlling, which is a standard process of risk management (Wageman, 2004). Taherdoost has specifically explored the R&D specific risk management strategies for the R&D projects. Specific chapter is dedicated to elucidate unique challenges faced by R&D projects in a book titled "Innovation through Research and Development", wherein this chapter presents a structured approach to identify, assess and mitigate risks in R&D projects (Taherdoost, 2024). O'Neill et al. have also enumerated risk management plan for risks in R&D projects (O'Neill et al., 2007).

Literature is explored in regards to risk management plan for technical risk in R&D project. Project risk management plan for R&D projects are preparatory measures for project risks and to deal with occurrence of unexpected and undesired events and also to take advantages of opportunities (Cooper et al., 2005; Razet al., 2002). In the realm of project management, risk management is an important factor and has been elaborated in the PMBOK. Third edition of PMBoK has defined processes for project risk management in five stages (PMBOK, 2004) and are applicable to all projects. Similar to five stages of project risk management mentioned in PMBOK, Naaman (2016) has defined five stages exclusively for defence projects, which is applicable for identified technical risks in S&T projects. Naaman's risk management process for defence projects is given in Table 3.

Table 3. Naaman's risk management process for defence projects

Steps	Risk Management process for defence projects (Naaman, 2016)
Step 1	Risk Identification through Brainstorming
Step 2	Risk Analyzing including assessments of severity, probability and risk level
Step 3	Risk Factor Analysis and defining responses, including contingency plan
Step 4	Risk Presentation for authorization purpose
Step 5	Monitoring and re-measuring risk

As per Naaman's process of risk management for defence project as given in Table 3, identification of risk is considered in Indian defence scenario as technical, procurement and test & evaluation risk. Importance, sources, impact and tools and techniques for technical risk are already explained. Namman's risk management plan suggests assigning severity and probability of occurrence as the second step in risk management process. Estimation of risk includes a judgment of the likelihood of the risky event that is going to take place and its probable impact (Sharma & Bhat, 2014). Naaman's next step is technical risk factor analysis and defining risk response followed by developing a contingency plan. Technical risk mitigation strategy can involve avoiding the risk all together, controlling the risk, transferring the risk or accepting the risk.

Monitoring and re-measuring risk is the last step in Naaman's risk management process after risk authorization plan is approved. Risk monitoring and control is applicable throughout the project life cycle which involves risk tracking, monitoring residual and new risks that can be prevented after an action and execution of the action plan and evaluation of its effectiveness (Santos & Cabral, 2008). Other studies similar to Naaman's study in regards to risk management plan is by Razet al. who have studied the risk management practices with respect to project types (Razet al., 2002). Similarly, Rodageet al. have developed a risk analysis model specifically focusing on the risk identification and risk mitigation phase during the initial phase of the project for technological risks (Rodageet al., 2014). Advancement in general risk management is systematically captured by Aven in his study wherein he mentions that emerging risk and its management has emerged in recent years and societal risk decision making and its management is another area where more focus needs to be given (Aven, 2016).

5. Conclusion

Risk management for technical risk is important as technical risk contribute significantly towards success or failure of the project. This study comprehensively review literature to understand definition of technical risk as well as various aspects of technical risk including importance, impact and tools and techniques involved in identifying technical risk. Technical risks are generated when technological challenges are in excess in the project and the systems/products

which are getting realized through projects are more complex. This study is an elaborative effort to analyze literature in terms of risk management process for technical risk in S&T project.

Risk management process is in place since project management principles evolved and studied thoroughly for long time but there are advancements in the way mitigation process is defined for various risks. More risks have been evolved and identified as the systems get complicated however, major risks remain same. In the series of major risks, technical risks are more complex and under researched as has been noticed during the literature review. This study comprehensively analyze svarious studies related to technical risks in defence R&D projects so that it can serve as a baseline for further exploration in the area of technical risk in defence R&D projects. This study can also serve as a baseline template for future researchers in the area of technical risks in R&D projects.

***References**:*

- *A Guide to the Project Management Body of Knowledge (PMBoK Guide). (2004). Newton Square, PA 19073-3299, USA, 2004.*
- *Alshehhi, B., Thorpe, D., Goh, S. and Alkaabi, S (2018). Management of Risk in Delivering Complex Research and Development Projects: a Case of Research & Development Centre of the United Aram Emirates Armed Forces. Archives of Business Research, 6(11): 48-154.*
- *Aven, T (2003).Foundation of Risk Analysis. John Wiley & Sons, Ltd, West Sussex PO19 8SQ, England.*
- *Bedi, R (2018). India's MoD Advancing 'Mission Mode Projects'. Jane's Defence Weekly. March, 2018. Jane's by IHS Markit.*
- *Borse, P and Ware, N. (2024).Control of Technical Risks in Defence Science & Technology Projects [Manuscript submitted for publication]. Technology Management Group, Armament Research & Development Establishment, India.*
- *Browning, T. R., Deyst, J. J., Eppinger, S. D., and Whitney, D. E (2002).Adding Value in Product Development by Creating Information and Reducing Risk. IEEE Transactions on Engineering Management, 49(4): 443-458.*
- *Cakmak, M.A. and Gokpinar, E.S (2007).Research & Development Project Selection Model and Process Approach in Defence Industry Related Programs: First Phase – Concept Approval Decision. PICMET, 2007 Proceedings, 2225-2235.*
- *Chenarani, A., Druzhinin, E. A.and Kritskiy, D. N (2017).Simulating the Impact of Activity Uncertainties and Risk Combination in R&D Projects. Journal of Engineering Science and Technology Review, 10(4): 1-9.*
- *Cooper, D., Grey, S., Raymond, G. and Walker, P (2005). Project Risk Management Guidelines – Managing Risk in Large Projects and Complex Procurements. John Wiley& Sons, Ltd.*

- *Crama, P., Reyck, B. D., Degraeve, Z. and Leus, R (2005). Managing Technological Risk in R&D Project Planning: optimal Timing and Parallelization of R&D Activities. SSRN Electronic Journal.*
- *Defence Research and Development Organization(2016).Procedure for Project Formulation and Management, PPFM-2016.MoD, GoI-2016*
- *Dey, P (2002). Project Risk Management: A Combined Analytic Hierarchy Process and Decision Tree Approach. Cost Engineering, 44(3): 13-26.*
- *Enobakhare, Benjamin (2024). Risk Analysis in Project Management.*
- *Felli, J. C. and Andersen, J. S (2010).R&D Risk Management. Wiley Encyclopaedia of Operations Research and Management Science, edited by James J. Cochran, John Wiley & Sons, Inc.*
- *Ghaeli, M (2018). The Advantages of Project Risk Management Tools. Journal of Project Management, 3(2): 121-124.*
- *George, C (2018). The Essence of Risk Identification in Project Risk Management: An Overview. International Journal of Science and Research, 9(2): 973-978.*
- *Hsiao, C., Malak, R., Tumer, I. and Doolen, T (2013).Empirical Findings about Risk and Risk Mitigating Actions from a Legacy Archive of a Large Design Organization. Procedia Computer Science, 16: 844-852.*
- *Hillson, D (2001). Extending the Risk Process to Manage Opportunities. PMI, Europe, Berlin.*
- *Hylton, P (2009).Technical Risk Management. Source in Handbook of Research on Technology*
- *Indian Standard (2009).Risk Management- Principles and guidance (IS_ISO 31000:2009), Bureau of Indian Standards, New Delhi.*
- *Jaafri, A (2001). Management of Risks, Uncertainties and Opportunities on Projects: Time for a Fundamental Shift. International Journal of Project Management, 19(2): 89-101.*
- *Jiang, W. and Chai, H (2015).A Risk Management Methodology for R&D Project Risk Basedon AHP and Fuzzy Comprehensive Evaluation Method. Proceedings of the 2015 IEEE,IEEM,320-324.*
- *Jolonen, H (2011). The Uncertainty of Innovation: a Systematic Review of Literature. Journal of Management Research,4(1).*
- *Junior, R. and Carvalho, M (2013). Understanding the Impact of Project Risk Management on Project Performance: an Empirical Study. Journal of Technology Management & Innovation, 8: 64-78.*
- *Kasap, D., Asyah, I. andElci, K (2007). Risk Management in R&D Projects. PICMET, 2007 Proceedings,2287-2290.*
- *Kerzner, H (2009). Project Management – A Systems Approach to Planning, Scheduling, and Controlling and, Inc, Hoboken, New Jersey.*
- *Klein, J. H. and Cork, R. B (1998).An Approach to Technical Risk Assessment. International Journal of Project Management, 16(6): 345 – 351.*

- *Kordova, K., Katz, E. and Frank, M (2018). Managing development projects-The partnership between project managers and system engineers. System Engineering, 22(3): 227-242.*
- *Kordova, S. and Fridkin, S (2021). Risk Management for Defence SoS in a Complex Dynamic Environment. Sustainability, 13(4): 1789.*
- *Luppino, R., Hosseini, M. R., and Rameezdeen, R (2014).Risk Management in Research and Development (R&D) Projects: The Case Study of South Australia. Asian Academy of Management Journal, 19(2): 67-84.*
- *Mashiri, G., Mwange, A., Chiseyeng, J., Matoka, W., Manda, R., Mutambo, N. and Bwalya, J (2022). Critical Analysis of Risk Management: A Narrative Literature Review, Public Policy and Administration Research,12(5).*
- *Ministry of Defence (UK)(2015).JSP 892: Risk Management, Part 1: Directives.*
- *Mohindra, T. and Srivastava, M (2019). Comparative Analysis of Project Management Frameworks and Proposition for Project Driven Organizations.PM World Journal, 8(8):1-15.*
- *Moon, Tasmia and Smith, J.and Cook Stephan (2005). Technology Readiness and Technical Risk Assessment for the Australian Defence Organization. In SETE 2005: A Decade of Growth and Beyond. Systems Engineering/Test and Evaluation Conference: Conference Proceedings. (ICE Australia, 2005).*
- *Moreira, A.C., Ferreira L.M.D.F. and Silva, P (2020). A Case study on FMEA-based improvement for managing new product development risk.International Journal of Quality & Reliability Management.*
- *NASA Risk Management Handbook (2011).NASA/SP-2011-3422, Version 1.0.NASAHeadquarters, Washington, D.C. 20546.*
- *Naaman, A (2016). Establishment of the Armed Force-Research Development in Air Force, Between the Poles, Part 3. IDF: Jerusalem, Israel, 85-99.*
- *Nicholas, J. and Steyn, H (2008).Project Management for Business, Engineering, and Technology – Principles and Practice. Butterworth-Heinemann, Burlington, MA, USA.*
- *Niewczas-Dobrowolska, M (2024). Risk Management in R&D Projects. Proceedings of the 12th National and 4th International Conference on Quality Management "Quality of the future – the future of quality",134-147.*
- *O'Neill, J., Thakur, N. and Duus, A (2007). Technical Risk Assessment: a Practitioner's Guide. Defence System Analysis Division, Defence Science and Technology Organization, DSTO-GD-0493.*
- *Raz, T. and Michael, E (2001).Use and Benefits of Tools for Project Management. International Journal of Project Management,19(1):9-17.*
- *Raz, T., Shenhar, A. J. and Dvir, D (2002). Risk Management, project success, and technological uncertainty. R&D Management, 32(2): 101-109.*
- *Rodage, H., Lei, H. and Ganjeizadeh, F (2014). Risk Management for Research and Development Projects. International Journal of Engineering Research & Technology, 3(10): 824-831.*

- *Santos, F. R. S. and Cabral, S (2008). FMEA and PMBOK Applied to Project Risk Management, Journal of Information systems and Technology Management, 5(2): 1347-364.*
- *Segismundo, A. and Miguel, P. A. C (2008). Failure Mode and Effect Analysis (FMEA) in the Context of Risk Management in New Product Development: A case study in an automotive company. International Journal of Quality and Reliability Management, 25(9): 899-912.*
- *Sharma, S. K. and Bhat, A (2014). Supply Chain Risk Assessment Tools and Techniques in the Automobile Industry: a Survey. The IUP Journal of Supply Chain Management, 11(1): 67-76.*
- *Sicotte, H. and Bourgault, M (2008).Dimension of Uncertainty and their Moderating Effect on New Product Development Project Performance. R&D Management,38(5): 468-479.*
- *Shin, J., Lee, S. and Yoon, B (2018). Identification and Prioritisation of Risk Factors in R&D Projects Based on an R&D Process Model. Sustainability, 10(972): 1-18.*
- *Sokri, A. and Ghanmi, A (2017).Risk Analysis of Defence Acquisition Projects.DRDC-Centre for Operations Research and Analysis. Defence Research and Development Canada, Ottawa, Canada.*
- *Taherdoost, H (2024). Risk Management in R&D Projects. In: Innovation through Research and Development. Signals and Communication Technology. Springer, Cham.*
- *Thamhain, H (2013). Managing Risks in Complex Projects. Project Management Journal, 44(2): 20-35.*
- *Toljaga-Nikolic, D., Todorovic, M. and Bjelica, D (2018).Application of FMEA Technique in Project Risk Analysis. European Project Management Journal, 8(2): 36-42.*
- *Turner, J. V. and Hunsucker, J. L (1999). Effective risk management: A goalbased approach. International Journal of Technology Management,17(4): 438-458.*
- *Union Government (Defence Services) Army (2015). Ordnance Factories and Defence Public Sector Undertakings, Report No. 44; Report of the Comptroller and Auditor General of India. Chapter VI: Defence Research and Development Organisation, 2015.*
- *Wageman, S (2004). Risk Management on Research and Development Projects. In AACE International Transactions, Morgantown, RI71-RI76.*
- *Winston, R (2006). Risk Management for R&D Projects? Why bother? PM World Today,8(10).*
- *Zyl, V., Du Preez, N. and Schutte, C (2007).Utilizing Formal Innovation Models to Support and Guide Industry Innovation Projects. South African Journal of Industrial Engineering, 18(2): 203-219.*