Modelling of risk factors for defence aircraft industry using interpretive structural modelling, interpretive ranking process and system dynamics

Selladurai Pitchaimuthu, Jitesh J. Thakkar and P.R.C. Gopal

Abstract

Purpose – *Risk management in defence aircraft industry has considerable interest among academics and practitioners. The purpose of this paper is to develop interactions among risk factors dimensions (RFDs) and inspect the importance relationship among the performance measures in Indian aircraft industry and, finally, understand the effect of involvements provided by the managerial team on risk reduction process.*

Design/methodology/approach – *An extensive literature review was carried out to identify 26 risk parameters and 13 performance measure indices relevant for an aircraft industry. Survey method was used to obtain the importance of these parameters and measures. Further, these factors are grouped into five risk dimensions based on the brain storming session by the project managers. Initially, Risk factors for defense aircraft industry (RFDs) analyzed by Interpretative structural model (ISM) to know the contextual relationship among the RFDs and then applied Interpretive ranking process (IRP) to inspect the pre-eminence relationship among them. Finally, SD is applied to understand the effect of involvements provided by the managerial team on risk reduction process.*

Findings – *Government policy and legal RFDs has emerged as the key driving RFDs. In IRP modelling, technology RFD has emerged as more influential RFD which is the more relevant factor with respect to performance measure indices and this result is supported by detailed sensitivity analysis of system dynamic model.*

Originality/value – *The outcomes of this research can help project management team to identify the high severity risk factors which need immediate risk reduction/mitigation action.*

Keywords *System dynamics, Interpretive structural modelling, MICMAC, Interpretive ranking process, Risk factor dimension*

Paper type *Research paper*

Selladurai Pitchaimuthu and Jitesh J. Thakkar are both based at Department of Industrial and Systems Engineering, Indian Institute of Technology Kharagpur, Kharagpur, India.
P.R.C. Gopal is based at School of Management, National Institute of Technology Warangal, Warangal, India

1. Introduction

India has noticed a sustained growth in defence aircraft industry (DAI) in the past decades. The DAI has seen a strong growth with large spending on research and development of indigenized aircrafts; transfer of technology project; and maintenance, repair and overhaul (MRO) of aircrafts. The Indian defence market is the seventh largest defence market across the globe with over US$40bn budget. The market is expected to witness a healthy growth rate till 2019, growing at a compound annual growth rate of 6.8 per cent. India is expected to spend more than US$250bn on defence equipment and services by 2022 and 40 per cent of the defence budget is dedicated to capital expenditure that focuses on capacity building for arms and related equipment (https://cdn.vibrantgujarat.com). The Government of India has set a target of meeting 70 per cent of defence needs internally by 2019. The

Received 22 May 2018
Revised 27 November 2018
8 May 2019
Accepted 12 May 2019

DOI 10.1108/MBE-05-2018-0028

government has launched its “Make in India” initiative and also has streamlined its Defence Production Policy. To boost indigenous manufacturing of defence equipment Indian government emphasizing on defence sector.

In the past decades, DAIs has been experiencing fast globalization and more technological changes mainly in the manufacturing and MRO sector. These changes leads to challenges to industries such as optimization of operation and maintenance function due to the continual evolving world of technologies, global competitiveness, environmental and safety requirements (Velmurugan and Dhingra, 2015). In such situations, organization encounter limited availability of resources such as manpower, manufacturing facility, equipment capacity, instruments/tools, availability of space and availability of spare parts (Safaei *et al.*, 2011). These are the major sources of risks associated with DAI, which may lead to problems such as poor serviceably of aircraft, long turnaround time, decreasing fleet availability for mission of the squadron, not able to meet customer delivery schedules and loss of customer goodwill. Risk is a multi-facet concept. In the context of DAIs, it could be the likelihood of the occurrence of a definite event/factor or combination of events/factors which occur during the whole process of manufacturing and MRO activities. It is a challenge to capture the multi-dimensional and inter-dependent behaviour of the risks in the process, product and business.

According to Aerospace Standard (AS 9001: 2009), an industry shall create, perform and continue a risk management process to the attainment of specific requirements, that includes as appropriate to the firm and its product. Risk is illustrates as discrete incidents with unfavourable or favourable events on the business. In spite of fluctuated definitions for the risk, all contain a singular idea. In the greater part of definitions for the risk, two perspectives “misfortune” and “instability” have been said (PMBOK, 2004). Risk is a multi-aspect idea. Distinguishing, dissecting and reacting to risk is project risk management process (PMI, 2008).

How well one can arrange, execute, and control the tasks and how well one can deal with the associations with every one of the partners required for the project constitutes the favourable outcome or not of the doing of a project (Sandhu and Gunasekaran, 2004). Project risk management is a normal component of project management. With respect to project risk, there are various risks when seeing alternate points of view of various stakeholders. In today’s exceptionally complex project condition, there is obvious requirement for better comprehension of how tasks are identified with each other and what the suggestions might be of their interrelations (Olsson, 2008). With regards to current industry, it is the probability of the event of a distinct occasion or mix of occasions which happen amid the entire procedure. It includes numerous factors, and it is frequently hard to decide circumstances and end results, reliance and connections. Thus, those risks assume a huge part in decision-making and may influence the execution of a project. In addition, it is frequently hard to decide circumstances and end results, reliance and relationships. It may influence the execution of a project (Scott, 2005). Success of the project depends on how well project managers managed performance dimensions. These dimensions are end goals where in every project is striving to achieve it. Understanding the pre-eminence relationship among the risk factors and performance measures are vital to address the risk effectively. For this, IRP is useful to attain the pre-eminence relationship between risk factor dimensions (RFDs) and performance measures dimensions. To the best of our knowledge, there is a gap to address the structure and pre-eminence relationship among risk factors in Indian defence sector.

The literature covers vast area of many ranking and decision-making tools, but there is absence of confirmation of applications of ISM and IRP, specifically for modelling risks for defence aircraft project. The strength of this technique lies in integrating analytical logic of the rational choice process and decision-making with intuitive process at the elemental level. This method has been developed to overcome the shortcomings of the existing ranking methods and tools (Haleem *et al.*, 2012). The ISM model may be applied to find out contextual relationship of identified RFDs and helped develop a hierarchical model. IRP may be applied to rank variables under study in the light of their reference variables or performance measure indices as against ISM, which limits itself to considering *interactions* among ranking variables only (Haleem *et al.*, 2012).

The rest of the paper is structured as follows. Section 2 provides a literature review on risk factors involved in DAI. Section 3 presents the three research methodologies used for modelling. Section 4 demonstrates an application of ISM in RFDs modelling in DAI. Section 5 illustrates an application of IRP technique in RFDs modelling. Section 6 presents a system dynamics model and discussion on SD simulation result. Section 7 discusses about managerial implication and results. Finally, Sections 8 and 9 conclude with summarizing the whole article and guiding the direction for further research in this industry.

2. Literature review

Risk is defined as a chance of loss, failure, danger, damage or any negative/undesired events. AS/NZS (2004) also illustrated a risk management programme that includes demonstrating the risk circumstances, risk identifying, risk analyzing, risk evaluating, risk treating, risk monitoring, and risk communicating processes. Regardless of the variations in specific risk management processes, they always include identification, analysis, and response of risks. Risk management process should be applied at each and every phases in project life cycle in a planned and complete way to get its overall benefit. It is also vital to select proper risk management instruments and methods for implementation of successful risk management process. Smith and Merritt (2002) describe risk in any project as the possibility that an undesired output, or the absence of a desired output, could affect a project. Risk management is the proactive process of identifying and controlling those undesired outputs.

2.1 Risk parameters

Tah *et al.* (1993) illustrated risks into external risks and internal risks. External risks are those that are prevalent in the external environment, such as those due to market inflation, fluctuation in currency exchange rate, design change due to technology, changes by client, political developments, natural disasters, and act of gods. External risks are continuously monitored because they are comparatively non-controllable and it has to be forecast according to the organization's strategy. Similar way, internal risks are comparatively well controllable and these risks are varying with type of projects. These internal risks are due to uncertainty in man, machine, material, resource, facility and subcontractor.

Wideman (1992) categorized project risks into human resource risk and failure, quality problems, scope deviations, project management integration failure, communications failure, contract and procurement failure, cost deviations and overspending, time deviation and schedule overrun, failure to effectively manage project risk and technical risk. (Skorupka and Kowacka, 2016) identified 14 risk factors namely faulty equipment, technical failures, errors of measurement data, failures of equipment, changes to the documentation, an observer's error, unpreparedness for measurement, lack of competence, damages to previously made stabilizing elements and markings, the execution incompatible with measurements, any delays occurred, weather changes, erroneous ground analysis and legislative developments.

Xu *et al.* (2015) identified 21 risk factors, namely, government intervention, nationalization/expropriation, public credit, legislation change, change in tax regulation, land acquisition, delay in project approvals and permits, lack of supporting infrastructure, inflation, public opposition, financing risk, completion risk, operation cost overrun, expense payment risk, change in market demand, price change, waste/labour non-availability, environment risk, residual risk, force majeure and organization and co-ordination risk. The various risk parameters referred by various authors used in various countries are given in Table I. Table I depicts that more external risk factors impacting more than internal factors.

2.2 Performance measures

Raju *et al.* (2012) illustrated the performance measurement variables are intended for use by aircraft industry supervisors for instituting process improvements for achieving best flight and maintenance safety records, improve operational availability of the aircraft and reduce costs:

Table I Research on risk factors

Sl.No	*Risk Factors*	*Description*	*Country*	*Author (s)*
R1	New technology implementation	*Changes due to technology implementation*	Malaysia	Cheng *et al.* (2013)
R2	Engineering and design change	*Constant changes due to technology implementation*	India	Renuka *et al.* (2014)
R3	Technical failures	*Failures due to technical issues*	Poland China	Skorupka and Kowacka (2016) Wang and Zhang (2017)
R4	Incomplete approval and other documents	*No proper approval as per the procedural process*	Australia The UK	Patrick *et al.* (2009) Sceral *et al.* (2018)
R5	Excessive approval procedures	*Cumbersome process authorization*	Australia	Patrick *et al.* (2009)
R6	Price inflation of equipment/ instruments	*Project equipment prices increased economy inflation*	China	Xu *et al.* (2015)
R7	Change of Scope of work by vendor	*Scope creep of the projects*	The USA	Wideman (1992)
R8	Low management competency of subcontractors	*Subcontractor's low competency*	Australia	Patrick and Zou (2009)
R9	Environmental Impacts	*Environmental uncertainties and it impact*	The USA	Lester and Tonder (2009)
R10	Financial risk due to government funding, imported materials expenses and Etc.,	*Lack of government subsidies on imported duties*	Iran	Sotoodeh Gohar *et al.* (2012)
R11	Safety accident occurrence	*Safety related issues during projects*	Australia	Patrick and Zou (2009)
R12	Quality Problem with in organization	*Quality issues in various levels of projects*	The USA	Max Wideman (1992)
R13	Incomplete or inaccurate cost estimate	*Poor estimation methods of projects*	Australia	Patrick and Zou (2009)
R14	Lack of coordination between project participants	*No proper communication among the project stakeholders*	India	Renuka *et al.* (2014), Paton and Barrie (2019)
R15	Unavailability of Certificate of competency (COC) holders & professionals	*No authorization certificates*	India	Renuka *et al.* (2014)
R16	Inadequate or insufficient information about production/ repair activities	*No proper information on maintains activates of project*	Australia	Patrick and Zou (2009)
R17	Natural disaster	*Unexpected natural calamities*	India	Dey (2002)
R18	Political unrest	*Stability of political situation*	Kuwait	Mustafa and Al-Bahar (1991)
R19	Terrorist attacks	*Threats from terrorist for defence projects*	India	Ali Diabat *et al.* (2012)
R20	Government regulation	*Regulations on various project activities*	China The USA	Xu *et al.*, (2015) Vaz *et al.* (2017)
R21	Labour strikes	*Unexpected labour strikes*	India	Diabat *et al.* (2012)
R22	Change in defence Procurement Procedures	*Sudden changes in procurement procedures*	India	Pandey (2010)
R23	Risk Changes in local law/Govt. policy	*Local laws and policy stability procedures*	India	Renuka *et al.* (2014)
R24	Cross- Border Contracting	*Inter level contracting procedures*	The USA	Reinsch (2005)
R25	Defence external stakeholders relationships	*Lack of proper relationships*	Australia	Gaidow and Boey (2005)
R26	Export/Import Restrictions	*Restrictions on procedural issues of export and import*	The USA	Reinsch (2005)

> In order to know if the company is reaching its organizational goals, performance metrics are used to trend and track performance. Every successful firm measures its maintenance performance in order to remain both competitive environment and cost effective (Taaffe *et al.*, 2014)

Performance measures are the parameters on which the comparison of other parameters is based upon Yu *et al.* (2007). The various key performance indicators related to aircraft industries referred by various authors given in Table II. These measures highlighted its importance in literature.

3. Research methodology

An extensive literature review carried out to identify 26 risk parameters and 13 performance measure indices relevant for an aircraft industry. Survey method was used to obtain the importance of these parameters and measures. By brainstorming, these risk factors and performance measure indices were grouped into five RFDs shown in Table III and five performance measure dimensions (PMDs) shown in Table IV respectively by experts. The industrial experts have at least seven years of working experience in managerial capacity in well-known Indian DAI. They were informed about the research objectives. In the brainstorming programs, core project managers were provided with a comprehensive list risk parameters and performance measure. The aims of this research article are to determine the correlations among various RFDs of DAIs and to rank risk factors with reference to different PMDs. Here, the ISM is applied to analyze the contextual relations between RFDs. IRP is used to rank the RFDs in connection to different performance PMDs. All the risk factors are grouped according to their similarity and listed in Tables III and IV.

3.1 Interpretive structural modelling

ISM method was succeeded by Warfield (1974) and Sage (1977) who were emeritus professor at George mason university, USA. It is an adaptation of paired-comparison technique and it is mainly useful for participants who work in a group in which structured debate can help them to gain a harmony view. It is generally software-aided and has the capability to handle group input. It helps in identify the inter-relations among variables under study. ISM is a pedagogical approach to an intuitive learning process, where arrangements of various dimensions under the study are organized into a complete deliberate model. The benefit of ISM technique lies in changing over the misty, ineffectively characterized mental models into well-defined hierarchical model for better comprehension of complex issues. ISM technique has five attributes. To start with, ISM is interpretive as the judgment of the gathering chooses whether and how the various components are connected. Second, it is basic on the

Table II Performance measures indices

Sl. no	*Factors*	*Country*	*Author*
P1	Serviceability index	India	Raju *et al.* (2012)
P2	Equipment uptime (Hours)		
P3	As good as new index		
P4	Index for breakdowns caused by poor preventive maintenance		
P5	Environmental condition index		
P6	Time index		
P7	Efficiency of fault diagnosis (%)		
P8	Work accomplishment index		
P9	Rework (No of times)	The USA	Taaffe *et al.* (2014)
P10	Corrective action request status (CAR)		
P11	Document rejected (No of times)		
P12	Defects at final inspection		
P13	Foreign object debris (FOD)		

Table III RFDs used for ISM

Dimension	*Risk factors*
X1.Technology Risk	New technology implementation (R1), Engineering and design change (R2), Technical failures (R3), Incomplete approval and other documents (R4), Excessive approval procedures (R5)
X2. External Risk	Price inflation of equipment/instruments(R6), Change of Scope of work by vendor(R7), Low management competency of subcontractors(R8), Environmental Impacts(R9), Financial risk due to government funding, imported materials expenses and Etc.,(R10)
X3. Internal Risk	Safety accident occurrence(R11), Quality Problem with in organization(R12) ,Incomplete or inaccurate cost estimate(R13) ,Lack of coordination between project participants(R14) ,Unavailability of Certificate of competency (COC) holders & professionals(R15), Inadequate or insufficient information about production/repair activities (R16)
X4.Macro level Risk	Natural disaster (R17), Political unrest (R18), Terrorist attacks (R19), Government regulation (R20), Labour strikes (R21)
X5.Goverment policy and legal Risk	Change in defence Procurement Procedures (R22), Risk Changes in local law/Govt. policy (R23), Cross - Border Contracting (R24), Defence external stakeholders relationships (R25), Export/Import Restrictions (R26)

Table IV PMDs used for IRP

Dimension	*Performance measures metrics*
Y1.Aircraft Availability	Serviceability index (P1), Equipment uptime (P2)
Y2.Reliability	As good as new index (P3), Index for breakdowns caused by poor preventive maintenance (P4)
Y3.Maintenance	Environmental condition index (P5), Time index (P6)
Y4.Operational availability	Efficiency of fault diagnosis (P7), Work accomplishment index (P8)
Y5.Non conformity (Process)	Rework (P9), Corrective action request status (CAR) (P10), Document rejects (P11), Defects at final inspection (P12), Foreign object debris (FOD) (P13)

premise of mutual relation; a general structure is extricated from the complex arrangement of components. Third, it is a modelling procedure; as the particular connections and general structure are depicted in a digraph demonstrate. Fourth, it assists to dictate direction and order on the complexity of relationships among different components of a framework (Sage, 1977). Fifth, it is basically planned as a gathering learning process; however people can utilize as per their like (Raj *et al.*, 2008). In literature, ISM is widely used in various fields (Govindan *et al.*, 2013; Luthra *et al.*, 2011; Mangla *et al.*, 2013; Gopal and Thakkar, 2016) of study. Various steps involved in ISM methodology are as follows:

- Step 1: project management team/literature review used to find out various variables (enablers), which are used to describe problems. The pairs of variables would be examined to establish contextual relationship among variables.
- Step 2: by using variables, structural self-interaction matrix (SSIM) is constructed. This SSIM shows the pair-wise relationship among variables under study. SSIM is checked for transitivity.
- Step 3: from the SSIM, final reachability matrix (RM) is constructed.
- Step 4: level partitioning matrix is constructed from final RM.
- Step 5: RM is converted into its conical form by binary variable one and zero.
- Step 6: from the above step, a diagraph is drawn to remove the transitivity.

- Step 7: this digraph is used to draw an ISM model by using nodes and arrows.
- Step 8: at the end, conceptual inconsistency is checked and final model is prepared.

3.2 Interpretive ranking process

IRP is an innovative ranking process that integrates the analytical logic of the rational choice method with the effectiveness of the instinctive procedure at the basic level. The technique robustness lies on paired comparison approach (Warfield, 1974, Saaty, 1977) which reduces the total amount of mental effort being used in this technique. The basic tool used in IRP is interpretive matrix and its paired comparison (Sushil, 2009). The traditional ANP methods like AHP's drawback that the interpretation of expert opinions remains opaque to the project implementation team is overcome in this technique as the team members here are supposed to find out the interpretive logic for dominance of one variable over the other variable for each time of comparison. IRP does not need the detail about the extent of dominance. IRP can be validated internally by vector logic of the dominance relationship. The procedure of IRP modelling (Sushil, 2009) is listed as follows:

- identification of performance measurement indices relevant to the issue;
- development of cross-interaction matrix based on existence or non-existence of relationship between RFDs and PMDs;
- construction of Interpretation of interaction for factor dimensions (RFDs) and PMDs;
- development dominating interaction matrix by comparing RFDs dimensions with respect to the reference variables (performances areas) as pair-wise;
- development of dominance matrix by summarizing dominating interactions; and
- construction of interpretive ranking model which is diagrammatically displays the final ranks of the ranking variables.

3.3 System dynamics

SD models are used to describe and analyze dynamic nature of systems. In SD model, simulation by computer used to understand dynamic behaviour of system. It was developed by Dr Forrester of MIT. He has published his work in "industrial dynamics" (Forrester, 1968) which was known as foundation of SD modelling. Meanwhile, SD models have been relatively grown up and used in multi disciplines. SD model core is to establishing a causal relation among the subjected variables. Interactions among the internal variables are analyzed by causal loop diagram (CLD) which may have single or multiple feedback loops. Causal chain can be formed by interrelated variables in system; meantime, causal chain polarity may get enhanced or weakened.

4. Interpretive structural model for risk factor dimensions of defence aircraft industry

In this portion, RFD model development by using ISM as follows.

4.1 Construction of structural self-interaction matrix

This method uses the expert opinion for construct SSIM. Experts from DAI were asked to find out the contextual relationship among the RFDs. Contextual relationship between RFDs is developed and is presented in Table V. The notations used for representing the type of relation between a pair of RFDs are.

- V denotes existence of relationship from direction i to direction j only;
- A denotes existence of relationship from direction j to direction i only;

Table V SSIM

RFD	X5	X4	X3	X2
X1	A	O	X	V
X2	A	A	A	
X3	X	V		
X4	0	A		

- X denotes existence of relationship in both directions;
- denotes non-existence of relationship in both directions.

4.2 Construction of final reachability matrix

The binary form of SSIM is known as RM. Binary number 0 and 1 used to replace X, V, A & O relationships (Lal and Haleem, 2009).Table VI show final RM with its driving and dependence power.

4.3 Construction of level partitioning matrix

Portioning of the risk dimensions into different rank is of great help in understanding the hierarchical relationships. It also assists in the construction of the ISM model. In this case, the RFDs along with their reachability set, antecedent set, intersection set and levels are shown in Table VII.

4.4 Construction of ISM model

The structural model is obtained from the final RM, by constructing graph using nodes and lines of edges. The relationship existence for risk dimensions i and j is shown by an arrow that points from i to j. The digraph is finally converted into ISM model. The ISM model developed for the risk dimensions involved in DAI project is shown in Figure 1.

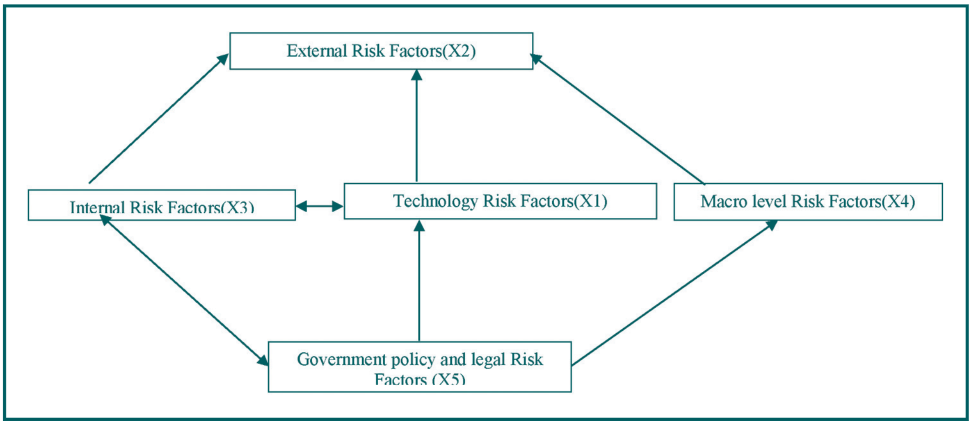
Table VI Final RM with driving power and dependence

RFD	X2	X3	X1	X4	X5	Driving Power
X2	1	0	0	0	0	1
X3	1	1	1	0	1	4
X1	1	1	1	0	0	3
X4	1	0	0	1	0	2
X5	1	1	1	1	1	5
Dependence5	3	3	2	2		

Table VII Summary of level portioning matrix

RFD	Reach ability Set	Antecedent Set	Intersection	Level
X2	2	1, 2,3,4,5	2	I
X3	1,2,3,5	1, 3, 5	1, 3, 5	II
X1	1, 2, 3	1, 3, 5	1, 3	II
X4	2, 4	4, 5	4	II
X5	1,2,4,5	3, 5	5	III

Figure 1 ISM-based model for RFDs

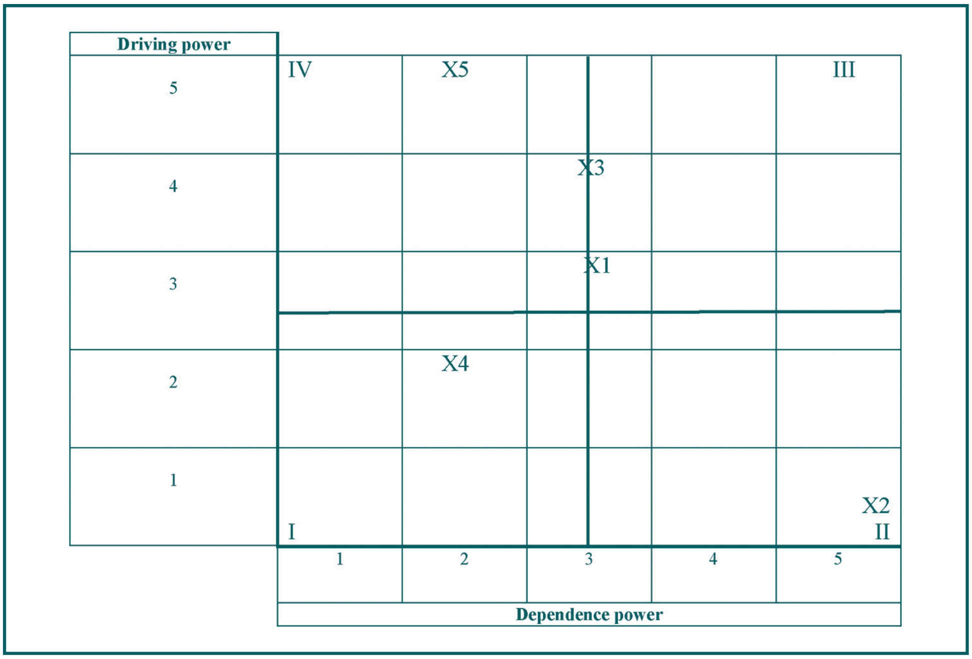


4.5 MICMAC analysis

MICMAC analysis is used to examine the driving and dependence power of variable involved in DAI. The variables are placed under four group's namely autonomous, dependent, linkages and independent (Mandal and Deshmukh, 1994) for MICMAC analysis.

Figure 2 shows macro level RFD fall under autonomous category and this is totally disengaged from the system. External RFD placed in dependent variable category which has the less driving power and the strongest dependency. Its high dependency indicates that all the criterions want to come together for efficient minimization of risks. Technology and internal RFDs are placed under linkage factor category as it has both strong driving and dependence power. These RFDs have less stability as any act on these RFDs will have a reaction on other RFDs and also a feedback on its own RFDs. Finally, government policy and legal RFD has strong driving power

Figure 2 Driving power and dependence power for RFDs



and least dependency. This RFD also play an important role in risk reduction and this risk dimensions minimization also play a main role in improving performance of DAI.

5. Interpretive ranking process for risk factor dimensions of defence aircraft industry

Two groups of variables used to develop IRP model namely ranking variables and reference variables. In this paper, based on the industrial expert's opinion, 13 such reference (performance measure) variables are identified and shown in Table II.

5.1 Construction of cross-interaction matrix

It is matrix in the form of cross interaction which shows the relationship existence or not between each set of variables. Number "1" used to show existence of relationship and "0" for vice-versa. Table VIII showing the cross-interaction matrix.

5.2 Interpretation of interaction

Interpreting all the interactions with entry "1" in terms of contextual relationships used to convert the cross-interaction matrix into a cross interaction interpretive matrix. For example, (X1, Y1) is interpreted as "technology has direct implication on aircraft availability" as shown in Table IX.

5.3 Dominating interaction matrix

The interpretive matrix is used to compare the RFDs with respect to the reference variables (PMDs) pair-wise, one by one. For example, the action X1 is compared with action *X*2 with respect to various performances Y1, Y2, . . ., and Y5, respectively. Here, the ranking variables which have to be ranked are not directly compared; rather their interaction with respect to reference variable(s) is compared. All the dominating interactions are tabulated in the dominating interaction matrix, as shown in Table X.

5.4 Construction of dominance matrix

The dominance matrix is summarized form of interaction matrix. Each cell in this matrix provides information about the number of times (performances), where one ranking variable dominates or is dominated by other ranking variables.

The net dominance for dimensions to be ranked is calculated as (R_C), where R is the total number of cases where ranking variable(s) dominates all other ranking variables and C the total number of cases in which a particular ranking variable is dominated by all other ranking variables. The ranking variable having the highest net positive dominance is ranked "1" followed by next lower and so on. The dominance matrix clearly indicating the ranking of all the factors is shown in Table XI.

Table VIII Cross interaction matrix

	Performance measurement dimensions				
	Aircraft Availability	*Reliability*	*Maintenance*	*Operational availability*	*Non conformity (Process)*
Risk dimensions					
Technology Risk	1	1	1	0	1
External Risk	1	0	1	0	1
Internal Risk	1	1	1	1	1
Macro level Risk	1	0	1	1	0
Government policy and legal Risk	1	1	0	0	0

Table IX Interpretation of cross interaction matrix

Risk ↓ Performance →	*Aircraft Availability*	*Reliability*	*Maintenance*	*Operational availability*	*Non conformity (Process)*
Technology Risk	Technology has direct implication on A/c Availability	Technology directly affect reliability	Technology plying vital role in maintenance	–	Technology directly related with process Nc's
External Risk	External risk factors reduction improve A/c Availability	Reliability also depends on external factors role	External risk reduction ply important role to increase maintenance	–	Nonconformity reduction also reduced by controlling external risks
Internal Risk	Internal risk like safety , quality directly related with A/c Availability	Repair activities, sufficient man power are key for reliability	Internal factors reduction helps to improve the maintenance	Operational availability mainly affected by Internal factors	Nc's are direct impact of internal factors
Macro level Risk	Macro level risks like natural disaster may affect A/c availability	–	Macro level risk ply invisible role in reduction of maintenance	Macro level risks directly affect operational availability	–
Government policy and legal Risk	Government policy and legal risk factor leads to affect A/c availability	Government policy and legal risk like product liability affects reliability	–	–	–

Table X Dominating interaction matrix

Dominating	*Technology risk*	*External risk*	*Internal risk*	*Macro level risk*	*Government policy and legal risk*
Technology risk	–	Y4,Y5	Y2,Y3,Y4,Y5	Y3,Y4,Y5	Y2,Y4
External risk	Y5	–	Y3,Y5	Y1,Y4,Y5	Y3,Y4,Y5
Internal risk	Y4	Y2,Y4	–	Y1,Y3,Y5	Y2
Macro level risk	Y2,Y5	Y2,Y5	Y1,Y4	–	Y1,Y3,Y4
Government policy and legal risk	Y1,Y3,Y5	Y3,Y5	Y3,Y4	Y1,Y4	–

5.5 Construction of IRP

The IRP model diagrammatically displays the final ranks of the RFD's. Figure 3 shows the ranks of various actions with respect to their roles in achieving different performance areas. The arrow indicates the reference variable(s) in the cases where a particular RFD variable is dominating the other RFD's.

6. System dynamics model for risk factor dimensions of defence aircraft industry

SD model namely risk factor dimension model (RFDM) is used to understand the effect of involvements provided by managerial team on risk reduction process. In this portion, RFD model development by using ISM as follows.

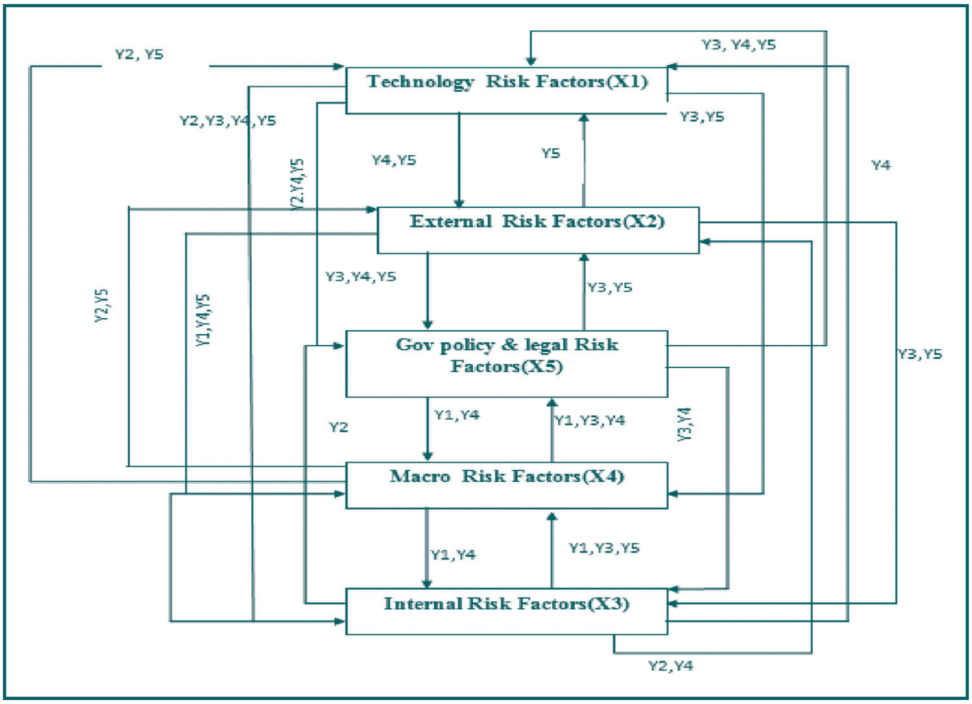
6.1 Causal loop diagram

The field of system science emphasizes on interconnectedness (Lane, 2008). Decision makers usually find it difficult to see the "whole picture" and hence cannot absorb all the interconnections or interrelations existing in a system (Morecroft, 1982). Therefore, it is always desired to have an overall picture of the system that can present all the interconnections and their impacts on the system. CLDs can aid in this purpose. CLD can have more than one number of loops; it may be either positive or negative type. A positive

Table XI Dominating matrix for ranking RFDs

	Technology risk	*External risk*	*Internal risk*	*Macro level risk*	*Government policy and legal risk*	*No of cases dominating (r)*	*Net dominating r-c*	*Rank dominating*
Technology Risk	– –	2	4	3	2	11	4	I
External Risk	1	– –	2	3	3	9	1	II
Internal Risk	1	2	– –	3	1	7	–3	V
Macro level Risk	2	2	2	– –	3	9	–2	IV
Government policy and legal Risk	3	2	2	2	– –	9	0	III
No of cases being dominated (C)	7	8	10	11	9			

Figure 3 IRP-based model for RFDs

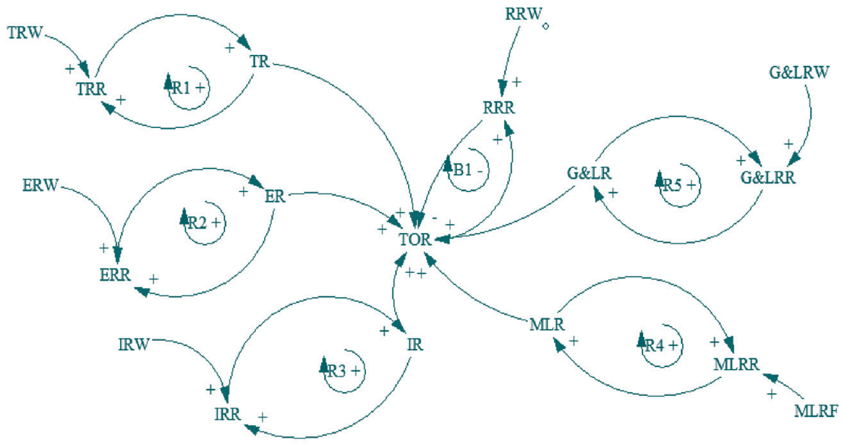


loop is known as reinforcing (R) loop and it tries to reinforce the behavior. A negative loop is known as balancing (B) and this balancing loop is used to keep the system to a desired state (Sterman, 2000). The CLD for RFDM is constructed to represent the various RFDs affecting successful completion of defence aircraft project. Figure 4 shows the CLD of the interdependency of system along with reinforcing and balancing loops.

6.2 Stock and flow diagram

The CLDs lack the ability to provide the level and flow of system (Sterman, 2000). Stocks indicate accumulations. They describe the condition of the state and produce the data whereupon decisions and activities are based. The RFD with the highest rank in IRP was taken weight equal to 1/15 since the rate of reduction of the factor was the least while the factor with the lowest rank was taken weight equal to 5/15 since the rate of reduction of the

Figure 4 CLD for RFDM



Notes: Legend: TR-Technology risk dimension, ER-External risk dimension, IR-Internal risk dimension, MLR-Macro level risk dimension, G&LR- Government policy and legal risk, TOR-Total organization risk, TRR-Technology risk dimension rate, ERR-External risk dimension rate, IRR-Internal risk dimension rate, MLRR-Macro level risk dimension rate, G&LRR- Government policy and legal risk rate, RRR-Risk reduction rate, TRW-Technology risk dimension weight, ERW-External risk dimension weight, IRW-Internal risk dimension weight, MLRW-Macro level risk dimension weight, G&LRW- Government policy and legal risk weight and RRW-Risk reduction weight

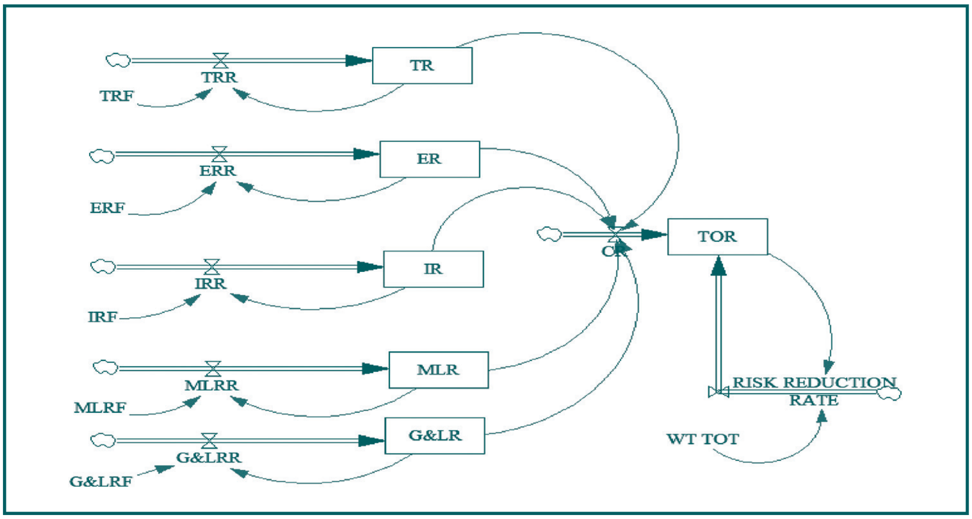
factor was the highest. The RFD with the highest rank i.e. “technology risk dimension” is assigned a weight of 1/15 and the RFD with the lowest rank i.e. “internal risk dimension” is assigned a weight of 5/15. The other RFDs such as external, macro level and government policy & legal are assigned the weights 2/15, 3/15and 4/15 respectively. The overall risk reduction weight assigned by core project management team during the project execution is 0.5. Initial stock was assigned by data obtained from number of risk event occurrence during the year 2005. A preliminary stock and flow diagram was generated first and trial simulation was run. Then the model was modified with the help of core project team member and an expert in the area of system dynamics. The detailed stock and flow diagram is shown in Figure 5.

6.3 Risk factor dimension model simulation run result discussion

The RFDM simulation carried out for the periods of 2005 to 2016 with time step of 0.0625 in VENSIM software. Initial stock was assigned by number of risk event occurrence during the year 2005 which is shown in Appendix along with relevant formulae. Initial RFDM is validated for boundary adequacy test, structure verification test, parameter verification test and dimensional consistency test.

In case of system dynamics simulation, trend of the simulation result is given more importance than the actual result but attempts are made that results should as much as possible close to the real ones. In a defence aircraft project, project risk mainly due to technology RFD as defined in IRP. Other factors like external, government policy and legal, macro level and internal risk factors have next level impact on successful completion of project activities. Simulation carried out for three scenario such as two extreme conditions

Figure 5 Stock and flow diagram for RFDM

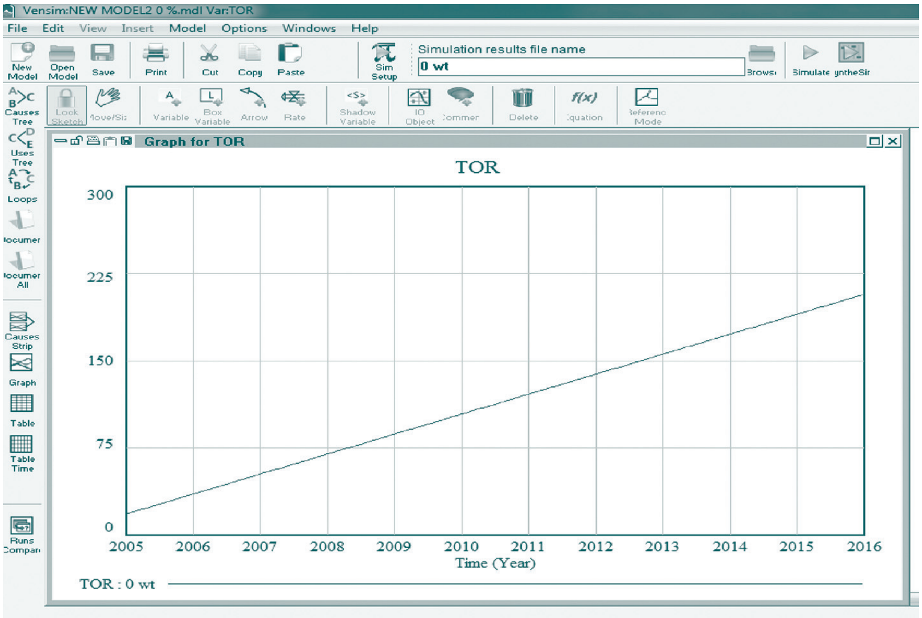


(risk reduction weight 0 and 1) and present overall risk reduction weight of 0.5 which is assigned by core project management team during the project execution.

Scenario 1: The management efficiency is 0 per cent i.e. risk reduction weight is zero when the management team fails to act completely then the number of risk occurrences goes on increasing at a tremendous faster rate (shown by increasing-trend line in Figure 6).

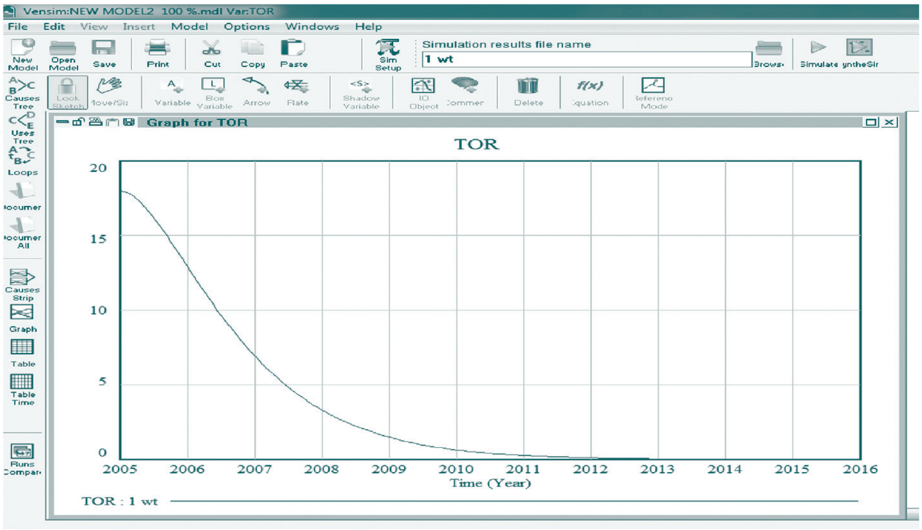
Scenario 2: The management efficiency is 100 per cent i.e. risk reduction weight is one when the team converts all risks into opportunities, the number of risk occurrences decrease at a much faster rate (shown by decreasing-trend line in Figure 7) and

Figure 6 Simulation result of TOR for scenario 1


Vensim:NEW MODEL2 0 %.mdl Var:TOR

Simulation results file name: 0 wt

Figure 7 Simulation result of TOR for scenario 2

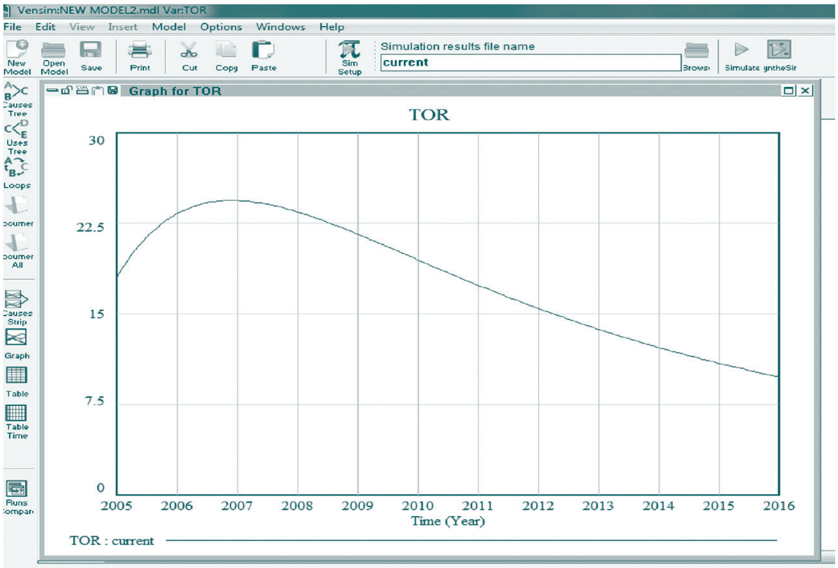


Simulation results file name: 1 wt

approaches 0 value concluding that the risks have been prevented from occurring at the initial stage itself.

Scenario 3: The present management efficiency is 50 per cent i.e. risk reduction weight is 0.5.Intially the number of occurrence of risk events increases and thereafter it start to decline (shown in Figure 8).This is verified from the fact that the amount of risk and the degree of uncertainty decreases over a period of time and as the project gets completed in any industry, the same being the highest in the initial stage. Furthermore,

Figure 8 Simulation result of TOR for scenario 3



Simulation results file name: current

the instantaneous risks i.e. the risks which appear as the project proceeds go on increasing from initial time to certain time period. This can be verified from the fact that constant changes occur due to design changes, new technology implementation, low management capabilities and other risks which are mentioned in the IRP model. However, as the management team recognizes that the risks have appeared, management efficiency comes into action and due to appropriate actions taken, the risk variables are reduced.

6.4 Sensitivity analysis of risk factor dimension model

Sensitivity analysis is used to see how “touchy” a model is to the adjustments in the estimations of the parameters (variables) of the model and to the adjustments in the structure of the model (Yuan, 2012). By utilizing Sensitivity analysis, we can additionally break down the impact of different elements thus their impact in whole system. Sensitivity analysis is completed to test for the heartiness of the SD model. The strength of the outcomes produced by the SD model is evaluated through the Sensitivity analysis of the model. Sensitivity analysis asks whether the conclusions change in courses vital to the reason when presumptions are differed over the conceivable scope of vulnerability (Barlas, 2007; Sterman, 2000). The sensitivity analysis was conducted by varying the weight of each RFDs for three different values (reduced to 30 per cent, original value & increased by 30 per cent) one at a time.

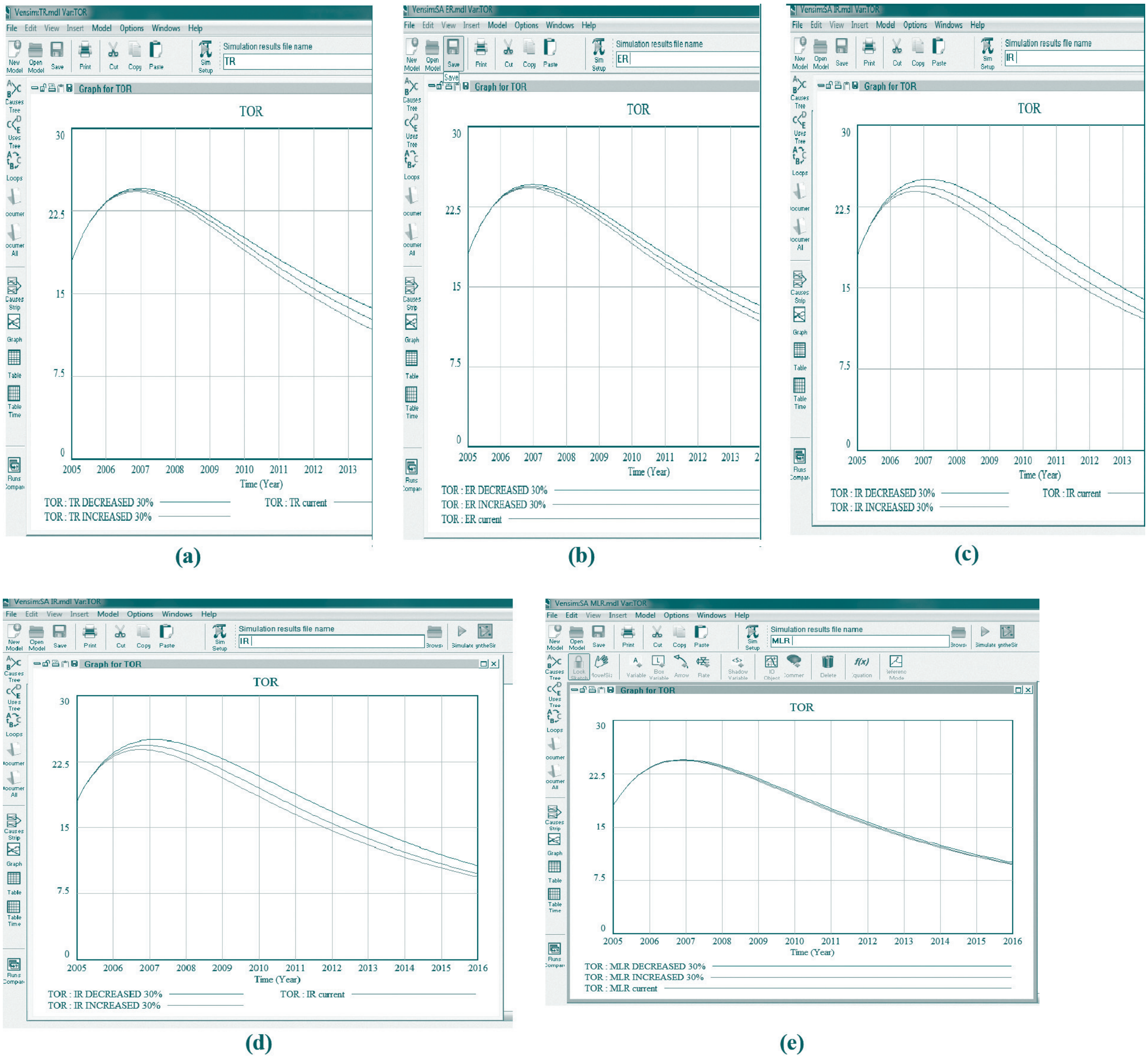
The sensitivity analysis results for RFDM suggest that technology risk factors such as new technology implementation, engineering and design change, technical failures, incomplete approval and other documents and excessive approval procedures are more influential compared to other factors which is in line with result obtained from IRP modelling. Sensitivity analysis shows a variation of 10.5 per cent to 23.1 per cent in total organization risk due to change in technology risk weight. External risk factors are next level influencing factors which shows a variation of 6.2 per cent to 15 per cent in total organization risk as compared to other risk dimensions. Other dimension like macro level and government policy and legal risk factors shows a less variation of 0.9 per cent to 2.8 per cent and 1.1 per cent to 3 per cent respectively. It is quite obvious that in such complex systems where interdependencies among parts are very high, any design change, etc., may be for performance improvement purpose or for better fitment purpose will have significant impact on the total organization risks thus have direct impact on performance of organization. When the performance of organization is improved, it reduces problem associated with organization to achieve successful completion of production and MRO projects. The results for key risk factors variations are shown in Figure 9.

7. Discussion on managerial implication and results

This experimental review on modelling risk factors for DAI using ISM, IRP and SD. Since this is a merely explored region, particularly with regards to India, the discoveries from this review are relied upon to be extremely helpful for both DAI managers and administration specialists. In this study, risk modelling and DAI problems are inherently intertwined. Their interactions boost a specific importance for the plethora of managerial problems faced while choosing which RFD reduction to be considered mainly for the successful completion on production and service targets in Indian DAI.

In IRP modelling, technology RFD has received the highest rank which is qualitatively yield better and more realistic results than ISM, if both are used for the same industry. IRP is used to rank RFDs with respect to their performance measure indices as against ISM which limits itself to considering those factors only. Technology risks threaten processes and products which are important to DAIs and it has straightforward effect

Figure 9 Sensitivity analysis graphs



Notes: (a) TR; (b) ER; (c) IR; (d) MLR; (e) G&LR

on DAI. New technology implementation, engineering and design change plays vital role to improve aircraft serviceably and to reduce TAT. Efficient fault diagnoses system, good work accomplishment index and proper quality procedures in the organization found to improve maintenance and reduce non conformity in process which finally has more impact in increasing fleet availability, meeting customer delivery schedules and to gain goodwill from customers. Project management team can be greatly benefited from the results of sensitivity analysis conducted on RFDM model. RFDM sensitivity analysis model shows technology risk factors greatly affect total organization risk which also received highest rank in IRP modelling. System dynamics captures the interplay among variables. Such complex systems involve a number of feedback loops where a change in one variable affects a set of variables dynamically. The SD model may not give the exact predictions but the trends suggested by the SD model simulation result will certainly help in making decisions.

DAI project managers need to focus on driving factors such as government policy and legal RFDs. In addition to this, technology RFD has emerged as more influential RFD which is the more relevant factor with respect to performance measure indices. Hence, project managers can also simulate and see the progress trend of the project and take corrective actions, if necessary. It is also seen that in case of small and simple project traditional project management tools give better result than SD model.

8. Conclusion and future scope of works

In this study, an attempt has been made to identify the major RFDs that affect DAI successful completion of production and MRO projects in India. The complex nature of defence aircraft environment projects typically working under government regulations has inevitable to risk generation. However, a detailed analysis on risk factors responsible for the problems in DAI environment is still not available. In order to address this challenge, the complex relationships among various risk factors and performance measures indices are systematically analyzed using an integrated ISM, IRP and SD modelling. The research findings presented in this project work are believed to help the stakeholders in defence aircraft environment projects. The study gives a comprehensive perspective regarding RFDs of DAI and can act as ready reference for the practitioners.

The aim with this project has been to analyze the interactions among risk factors and to develop a hierarchical structure using ISM. Secondly, IRP has been used to examine the dominance relationship among those factors. Finally, SD model has been used to understand the effect of involvements provided by managerial team on risk reduction process. In view of this, the research analyzes 26 risk factors and 13 performance measure indices used an integrated approach of ISM-IRP-SD modelling. These models were used to find out top most RFD which has more impact on successful completion of production and MRO targets in Indian defence aircraft environment. These results provided to the project management team for the effective reduction of risk and thus reduces problem encountered with organization. In ISM model, government policy and legal risks has emerged as the key driving factor. In case of IRP model, technology RFD has received the highest rank .This IRP result also supported by SD sensitivity analysis which shows a variation of 10.5 per cent to 23.1 per cent in total organization risk only by variation of technology risk weight.

The strengths of IRP modelling (Sushil, 2009) are:

1. IRP is used to compare the effect of involvements rather than the factors in abstract form.
2. IRP used to compare dominance of interaction over other variables without knowing extent of information.
3. IRP uses paired comparison with reference to the interacting variables.
4. IRP used to rank any combination of variables with respect to the interacting variables, e.g. supervisors and processes or circumstances and managers. In pair wise comparison process, the analysis can be done both ways, e.g. to rank circumstances w.r.t interaction with supervisors, or to rank supervisors w.r.t interaction with circumstance variables.
5. Several interest teams can participate which eliminate the bias during the analysis.

6. It does not require any software interference. Some of the drawbacks of IRP are as follows:
7. IRP may be more subjective because of interpretive and judgmental methods.
8. IRP provides equal importance to subjected criteria by paying no attention to the irrelative importance; this will be improved by assigning ordinal weights to different criteria and by sensitivity analysis.
9. Interpreting a matrix of 10 X 10 is very difficult due to exponential increment of paired comparisons and non-availability of software.

IRP is a novel ranking method and can be used to rank factors with reference to their performance measure indices as against ISM which limits itself to considering those factors only. If both ISM and IRP are used for the same industry, IRP calls for more information and provides qualitatively better and more realistic results than ISM. The result finding of integrated ISM-IRP-SD modelling concludes that technology risk factors such as new technology implementation, engineering and design change, technical failures, incomplete approval and other documents and excessive approval procedures are more influential compared to other factors in successful completion of projects. Technology risk factors reduction improves the organization performance, reduces organization problems. Further analysis and studies are thus recommended, for example, (1) The results of the risk factor rankings obtained can be verified by other methods like AHP/Fussy AHP, Fuzzy Multi criteria analysis (FMA). Comparison of the results between each other can give better insights in the application of each of the methods. (2) The study can be further extended and supported by various other simulation models including the cost and the schedule over run of the project.

9. Managerial implications

MRO project Managers need to understand the dynamic changes in technological aspects which will understand the management of risk in projects better way. In recent times, India has become sourcing and manufacturing destination for the many countries in defence sector. Indian MRO managers in defence sector need to carefully understand the Government policy and legal risks which are associated in the sector since these factors play key role in driving the projects. In addition, the following key suggestions are for the Indian MRO project managers:

- In order to successful achievement of MRO projects Indian project managers need to understand and analyze the technology related risks such as technical failures and technological changes in designs.
- Equipment up time mainly and serviceability index are important measurement dimensions.
- Indian MRO project managers should focus on New technology implementation, engineering and design change to improve aircraft serviceably and to reduce TAT.

10. Limitations

This study has few limitations. First, ISM model has its own limitations. For example, the model is highly dependent on the judgments of the experts. *Grouping of various factors into dimensions can be obtained through factor analysis*. So that, opinions of the experts may be biased. IRP will find its complexity level high when the number of factors is large.

References

Barlas, Y. (2007), “System dynamics: systemic feedback modeling for policy analysis”, *System*, Vol. 1 No. 59.

Cheng, S.G., Hamzah, Abdul-Rahman and Zulkiflee, Abdul Samad (2013), “Applying Risk Management workshop for a public construction project: Case Study”, *ASCE Journal of Construction Engineering and Management*, Vol. 139 No. 5, pp. 572-580.

Dey, P.K. (2002), “Project risk management: a combined analytic hierarchy process and decision tree approach”, *Cost Engineering*, Vol. 44 No. 3, pp. 13-26.

Diabat, A., Govindan, K. and Panicker, V.V. (2012), “Supply chain risk management and its mitigation in a food industry”, *International Journal of Production Research*, Vol. 50 No. 11, pp. 3039-3050.

Forrester, J.W. (1968), “Industrial dynamics – after the first decade”, *Management Science*, Vol. 14 No. 7, pp. 398-415.

Gaidow, S. and Boey, S. (2005), *Australian Defence Risk Management Framework: A Comparative Study*, DSTO Systems Sciences Laboratory, Edinburgh.

Gopal, P.R.C. and Thakkar, J. (2016), “Analysing critical success factors to implement sustainable supply chain practices in Indian automobile industry: a case study”, *Production Planning and Control*, Vol. 27 No. 12, pp. 1005-1018.

Haleem, A., Sushil, Qadri, M.A. and Kumar, S. (2012), “Analysis of critical success factors of World-Class manufacturing practices: an application of interpretative structural modelling and interpretative ranking process”, *Production Planning & Control*, Vol. 23 Nos 10/11, pp. 722-734.

Lal, R. and Haleem, A. (2009), “A structural modelling for e-governance service delivery in rural India”, *International Journal of Electronic Governance*, Vol. 2 No. 1, pp. 3-21.

Lester, O.P., Jr. and Tonder, B.C. (2009), “External strategic analysis of the aviation maintenance, repair and overhaul (MRO) industry and potential market opportunities for fleet readiness center southwest”, *The NPS Institutional Archive*.

Lane, D.C. (2008), “The emergence and use of diagramming in system dynamics: a critical account”, *Systems Research and Behavioral Science: The Official Journal of the International Federation for Systems Research*, Vol. 25 No. 1, pp. 3-23.

Luthra, S., Kumar, V., Kumar, S. and Haleem, A. (2011), “Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: an Indian perspective”, *Journal of Industrial Engineering and Management (JIEM)*, Vol. 4 No. 2, pp. 231-257.

Mandal, A. and Deshmukh, S.G. (1994), “Vendor selection using interpretive structural modelling (ISM)”, *International Journal of Operations & Production Management*, Vol. 14 No. 6, pp. 52-59.

Morecroft, J.D. (1982), “A critical review of diagramming tools for conceptualizing feedback system models”, *Dynamica*, Vol. 8 No. 1, pp. 20-29.

Mustafa, M.A. and Al-Bahar, J.F. (1991), “Project risk analytic assessment using the hierarchy process”, *IEEE Transactions on Engineering Management*, Vol. 38 No. 1, pp. 46-52.

Olsson, R. (2008), “Risk management in a multi-project environment”, *International Journal of Quality & Reliability Management*, Vol. 25 No. 1, pp. 60-71.

Pandey, S.C. (2010), “The challenges of contract/project implementation”, *Journal of Defence Studies*, Vol. 4 No. 1, pp. 68-75.

Paton, S. and Barrie, A. (2019), “The role of the project management office (PMO) in product lifecycle management: a case study in the defence industry”, *International Journal of Production Economics*, Vol. 208, pp. 43-52.

Patrick, X.W. and Zou, G.Z. (2009), “Managing risks in construction projects: Life cycle and stakeholder perspectives”, *International Journal of Construction Management*, Vol. 9 No. 1, pp. 61-77.

Raj, T., Shankar, R. and Suhaib, M. (2008), “An ISM approach for modelling the enablers of flexible manufacturing system: the case for India”, *International Journal of Production Research*, Vol. 46 No. 24, pp. 6883-6912.

Raju, V.R.S., Gandhi, O.P. and Deshmukh, S.G. (2012), “Maintenance, repair, and overhaul performance indicators for military aircraft”, *Defence Science Journal*, Vol. 62 No. 2, pp. 83-89.

Reinsch, R. (2005), “E-commerce: managing the legal risks”, *Managerial Law*, Vol. 47 Nos 1/2, pp. 168-196.

Renuka, S.M., Umarani, C. and Kamal, S. (2014), “A review on critical risk factors in the life cycle of construction projects”, *Journal of Civil Engineering Research*, Vol. 4, pp. 31-36.

Safaei, N., Banjevic, D. and Jardine, A.K.S. (2011), “Workforce-constrained maintenance scheduling for military aircraft fleet: a case study”, *Annals of Operations Research*, Vol. 186 No. 1, pp. 295-316.

Sage, A.P. (1977), *Interpretive Structural Modelling: methodology for Large-Scale Systems*, McGraw-Hill, New York, NY, pp. 91-164.

Saaty, T.L. (1977), “A scaling method for priorities in hierarchical structures”, *Journal of mathematical psychology*, Vol. 15 No. 3, pp. 234-281.

Sandhu, M.A. and Gunasekaran, A. (2004), “Business process development in project-based industry”, *Business Process Management Journal*, Vol. 10 No. 6, pp. 673-690.

Sceral, M., Erkoyuncu, J.A. and Shehab, E. (2018), “Identifying information asymmetry challenges in the defence sector”, *Procedia Manufacturing*, Vol. 19, pp. 127-134.

Scott, S. (2005), “Nature of the critical risk factors affecting project performance in Indonesian building contracts”, *21st Annual ARCOM Conference*, 1 September, pp. 7-9.

Skorupka, D. and Kowacka, M. (2016), “Identification of risk factor of development and operation of road in the light survey work”, *Archives of Civil Engineering*, Vol. 60 No. 2, pp. 183-190.

Sotoodeh Gohar, A., Khanzadi, M. and Farmani, M. (2012), “Identifying and evaluating risks of construction projects in fuzzy environment: a case study in Iranian construction industry”, *Indian Journal of Science and Technology*, Vol. 5 No. 11, pp. 3593-3602.

Sterman, J.D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*, McGraw-Hill, New York, NY.

Sushil (2009), “Interpretive ranking process”, *Global Journal of Flexible Systems Management*, Vol. 10 No. 4, pp. 1-10.

Taaffe, K.M., Allen, R.W. and Grigg, L. (2014), “Performance metrics analysis for aircraft maintenance process control”, *Journal of Quality in Maintenance Engineering*, Vol. 20 No. 2, pp. 122-134.

Tah, J.H.M., Thorpe, A. and McCaffer, R. (1993), “Contractor project risks contingency allocation using linguistic approximation”, *Computing Systems in Engineering*, Vol. 4 Nos 2/3, pp. 281-293.

Vaz, A.C., Fuccille, A. and Rezende, L.P. (2017), “UNASUR, Brazil, and the South American defence cooperation: a decade later”, *Revista Brasileira de Polıtica Internacional*, Vol. 60 No. 2.

Velmurugan, R.S. and Dhingra, T. (2015), “Maintenance strategy selection and its impact in maintenance function: a conceptual framework”, *International Journal of Operations & Production Management*, Vol. 35 No. 12, pp. 1622-1661.

Wang, L. and Zhang, X. (2017), “Critical risk factors in PPP waste-to-energy incineration projects”, *International Journal of Architecture, Engineering and Construction*, Vol. 6 No. 2, pp. 55-69.

Warfield, J.N. (1974), “Developing interconnection matrices in structural modeling”, *IEEE Transactions on Systems, Man, and Cybernetics*, No. 1, pp. 81-87.

Wideman, M.R. (1992), *Project and Program Risk Management: A Guide to Managing Project Risks and Opportunities*, Project Management Institute, Newtown Square, PA.

Xu, Y., Chan, A.P., Xia, B., Qian, Q.K., Liu, Y. and Peng, Y. (2015), “Critical risk factors affecting the implementation of PPP waste-to-energy projects in China”, *Applied Energy*, Vol. 158, pp. 403-411.

Yu, I., Kim, K., Jung, Y. and Chin, S. (2007), “For construction companies”, *Journal of Management in Engineering*, Vol. 23 No. 3, pp. 131-139.

Yuan, H. (2012), “A model for evaluating the social performance of constructi on waste management”, Vol. 32 No. 3, pp. 1218-1228.

Further reading

ANSI/PMI 99-001-2004 (2019), “A guide to the project management body of knowledge: PMBOK® guide”, *Project Management Institute*.

AS/NZS ISO 31000 (2009), *Risk management – Principles and Guidelines*, Standards New Zealand, Wellington.

AS9100C (2009), "Quality management systems – requirements for aviation, space and defense organizations", SAE, Warrendale, PA.

Goh, C.S., Abdul-Rahman, H. and Abdul Samad, Z. (2013), "Applying risk management workshop for a public construction project: case study", *Journal of Construction Engineering and Management*, Vol. 139 No. 5, pp. 572-580.

Hekimoglu, M. and Barlas, Y. (2010), "Sensitivity analysis of system dynamics models by behavior pattern measures", *Proceedings of the 28th International Conference of the System Dynamics Society, Seoul*, pp. 1-31.

PMI (2004), *A Guide to the Project Management Body of Knowledge: PMBOK Guide*, Project Management Institute, Newtown Square, PA.

Zou, P.X.W. and Zhang, G. (2009), "Managing risks in construction projects: life cycle and stakeholder perspectives", *International Journal of Construction Management*, Vol. 9 No. 1, pp. 61-77.

Appendix

Table AI Mathematical model for RFDM

Sl. no.	*system variables*	*Equations*
1	TRR	TR*TRW
2	ERR	ER*ERW
3	IRR	IR*IRW
4	MLRR	MLR*MLRW
5	G&LRR	G&LR*G&LRW
6	RRR	TOR*RRW
7	TOR	(ER+G&LR+IR+MLR+TR)/5+(RRR)
8	TRW	Constant(1/15 ,Rating as per IRP)
9	ERW	Constant(2/15 ,Rating as per IRP)
10	IRW	Constant(5/15 ,Rating as per IRP)
11	MLRW	Constant(4/15 ,Rating as per IRP)
12	G&LRW	Constant(3/15 ,Rating as per IRP)
13	TR	29(Input for the year 2005)
14	ER	17(Input for the year 2005)
15	IR	31(Input for the year 2005)
16	MLR	5(Input for the year 2005)
17	G&LR	4(Input for the year 2005)

About the authors

Selladurai Pitchaimuthu is a Post Graduate student in the Department of Industrial and Systems Engineering at IIT Kharagpur. He obtained his Bachelor of Engineering degree in Mechanical Engineering with First class distinction from Bharathidasan University, Tiruchirappalli, Tamil Nadu, in 2004. Presently, he is working as a Manager in Hindustan Aeronautics Limited, Bangalore, India. He has 13 years of industrial experience in various quality planning/inspection activities such as fabrication and erection of piping work, welding, NDT, electro-plating, painting and spectrometric oil analysis programme. His areas of interest include quality control, lean management, Six Sigma, TQM and system dynamics.

Jitesh J. Thakkar is an Associate Professor at the Department of Industrial and Systems Engineering, Indian Institute of Technology (IIT) Kharagpur, India. He has published research in the areas of lean & sustainable manufacturing, supply chain management, quality management, small- and medium-sized enterprises and performance measurement. The publications have appeared in the leading journals –*Journal of Cleaner Production, Production Planning and Control, Computers & Industrial Engineering, International Journal of Advanced Manufacturing Technology, Journal of Manufacturing Technology Management, and International Journal of Productivity* and *Performance Measurement.* He is an Editorial Board member and Guest Editor for *International Journal of Lean Six Sigma*, Emerald. He is a Guest Editor for *Electronics Commerce Research and Applications*, Elsevier. He extends his services as a reviewer to the reputed international journals in the area of Operations Management.

P.R.C. Gopal is an Assistant Professor at the School of Management, National Institute of Technology Warangal. He earned his PhD from Department of Industrial and Systems Engineering, IIT Kharagpur. He did his MBA from National Institute of Technology (NIT) Warangal in 2008 and Bachelors in Mechanical Engineering in 2005 from Bapatla Engineering College, Acharya Nagarjuna University, Andhra Pradesh. His publications have appeared in peer-reviewed international journals such as *Production Planning and Control, International Journal of Productivity and Performance Management and International Journal of Sustainable Engineering.* P.R.C. Gopal is the corresponding author and can be contacted at: prcgopal@nitw.ac.in