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An Improved Methodology for Cost Estimation of Defence Research and Development Projects in India with Special Emphasis on Risk Analysis

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Abstract:- Defence R&D of critical technologies has played a vital impact on the economy of the developing country. As the development of critical technologies is a major challenge for the developing nation and acquiring through foreign collaboration puts a major impact on the nation's economy and restricts independent exploitation for further R&D. Therefore, Cost estimation becomes vital in the decision-making process in defence research projects and it is critical to have the estimation as accurate as possible. The main objective of this study is to propose a cost estimation model with special emphasis on the cost-risk estimation that complies with the research projects undertaken by DRDO, India. Thus, cost estimation of the critical technology at the early design stage in defence research projects has always been a difficult task as there is little knowledge about the existing resources, development and operational features. For decades researchers have been focusing on developing efficient cost estimation methods. Yet their scarce access to cost information and real-time development scenario becomes a challenge for cost-risk estimation. The methodology was developed after studying the cost estimation methodology of defence research projects of India and other foreign nations. The article intends to provide an efficient manner of cost-risk estimation concerning R&D in India.

Keywords:- *Cost Estimation, Cost-Risk Estimation, Defence R&D Projects*

I. INTRODUCTION

Cost Estimation of research projects has been a focal point in sanctioning of any R&D Project and a key agenda for managerial policies and business decisions. Cost estimation has a direct bearing on the time, budget and performance of the organization. Various methods for various kinds of projects have been undertaken at DRDO for cost estimation. Each research project is unique and every project requires the development of new technologies, resources, and services. A project consists of numerous activities and each activity consuming resources that incur the cost. The efforts of in-house development of defence equipment, for which cost estimation for development must be the part of the proposal, however as far as the development of critical technologies for national defence are concerned, the cost is not the important criteria for deciding for development. However, it does play an important role in other factors like time duration for complete development of a system is largely affected, which later on results in the recalculation of the project cost. The cost estimation methodology defined in this paper will intellectualize the program manager with the expected cost risk in the project. Therefore, it is essential to understand that the estimated cost of the R&D projects is uncertain in nature and the Work Breakdown Structure (WBS) estimate is neither definitive and nor exhaustive. Hence, it becomes important for the cost analyst to quantify the risk and uncertainty to achieve the desired level of confidence with the WBS estimate developed; it must include expenses that are not allocated to any resource or operation but in case of risk and uncertainty.

- *Need of Cost Estimation*

Cost Estimation is required for project feasibility study and early design stages, selection of reliable sources, what if exercises, affordability studies, financial analyses and analyses of alternates, budget allocation as well as to support numerous decisions related to project.

System costs must be a design variable to help focus on major cost drivers during design and to challenge estimates that deviate strongly from history. [1]

The decision-maker understands the cost of risk and uncertainty exists in the R&D Projects, alternates of cost in the project and also makes the resource allocation decision with the help of cost estimation.

The Cost Estimate provides management with critical cost risk information to improve the control of resources in the present and future and some insight into the impact of project changes on the program budget.[1]

[1] NASA Cost Estimation Handbook Version 4.0 Washington, D.C., 2015

II. LITERATURE REVIEW

A systematic study of existing literature is carried out to understand the existing processes, cost estimation methodology of India and other foreign nations. The study undertaken of the foreign nations is as United States of America and Canada. The focus of the literature review is to understand the cost estimation methodologies of all these nations. This section is divided into 3 segments for each of the nations. It takes into account an in-depth analysis of processes and models of each nation.

A. India: Defence Research & Development Organisation (DRDO)

DRDO is the R&D wing of Defence, Government of India. The mission of the organization is to achieve self-reliance in critical defence technologies and systems while equipping its armed forces with state-of-the-art weapons systems and equipment following requirements lay down by the three services and vision is to empower India with cutting edge defence technologies. It is a scientific organization and has a dedicated pool of trained scientists, engineers, and technicians under various domains of science and engineering. They contribute to the strategic strength of the organization.[2]

DRDO undertakes projects under various technology clusters namely, missile cluster, Naval systems cluster, Electronics cluster, etc. The project plans are raised based upon the life of the projects of the user requirements as well as technology roadmaps generated within the organization.

Program/Project is defined as the development of system/platform, multiple subsystems, in the category: MM/TD/S&T, cost is less than Rs 500 Cr, maybe multi-lab effort and Project differs from the Programme only because the cost is less than Rs 500 Cr.[3]

- *Project Cost Estimation Methodology*

The cost estimation process followed by DRDO, India is a 5 steps process. The first step is to broadly describe the specifications of the new products to be developed. Secondly, extract a design from past records that closely match to the newly developed design. The third step is to find out what is missing in the past design or changes in the design specifications. The fourth step is critical it is to clearly examine all the past records and find out if the changed parts exist in those records or a new it is critically important to design those parts. Lastly, incorporate all the new changes until it is conventional to the required specifications.

The methodology uses historical data and combines it with state-of-the-art technology by critically analysing the design specifications of historical R&D projects and new requirements. This approach not only minimizes the efforts of designing from the beginning but also reduces the estimation time by using historical cost data for newly designed R&D projects.

However, the methodology has one limitation, this process needs to have past designs that are similar to the new project to include related cost data for the cost estimation.[4]

The method of project costing is dependent on various factors:

- Scope of the project
- Method of execution of the project, which in turn derived from the type of project
- No. of deliverables/outcomes/ by-products of the project and their type I.e. prototype, engineered, qualification tests (QT), deployable by the user, etc.

Assumptions on which costing is based should also be defined:

- Rate of inflation and Foreign Exchange (FE) rates of the year considered
- Percentage of escalation in the above year is taken into account
- Basis of calculation of numbers/spares of modules/ systems/ sub-systems taken for costing.

The general principle of costing for product costing should be applied for the project costing too. Every estimated cost should have a basis/ a supporting data in the form of one of the following:

Internal cost estimation based on experience

- In case of previous cost, then the percentage of work to be done should be indicated to give an idea of proportionate additional cost over the Non-Recurring Engineering (NRE) cost of the referral order
- In the case of new development: BOM (Bills of Material) + Development/ NRE Cost break-up. Assessed LRUs/components with approximate numbers and cost+ estimated work (skilled members + unskilled members with prevailing man-hour rates taken for cost estimation).[3]

B. Canada: Defence Research &Development Canada (DRDC)

DRDC is the leader in defence science and technology in Canada and develops and deliver new solutions and advice to the Department of National Defence (DND), the Canadian Armed force, other federal department, and the safety and securities communities in Canada. DRDC's mission is to provide a strategic knowledge and technology advantage. DRDC supports defence and security operations at Canada and abroad with knowledge and technology; provides S&T to forecast, cost and deliver future-readiness levels to meet operational requirements and generates knowledge and technology for a robust, connected and multi-jurisdictional security and intelligence environment.

[2] http://www.drdo.gov.in/about-drdo/

[3] Procedures for Project Formulation and Methodologies 2016, DRDO India

[4] (Dai, May 2006)

DRDC has approximate 1400 employees across eight research centres within Canada, namely, DRDC Atlantic Research Centre, DRDC Valcartier Research Centre, DRDC Ottawa Research Centre, DRDC Toronto Research Centre, DRDC Suffield Research Centre, DRDC Centre for Operational Research and Analysis, DRDC Director General Military personnel Research and Analysis and DRDC Centre for Security Science.[5]

➢ *Project Cost Estimation Methodology*

DRDC uses Life Cycle cost estimation for the defence research projects as followed by many NATO countries. In the methodology, generally, phases are considered for a credible cost estimate. It is considered that any defence research project passes through 4 phases in its life cycle. The project starts with development phase followed by the acquisition phase. The corresponding asset is then operated and sustained during the in-service phase until it reaches its disposal phase.[6] Annexure A provides the definition and the lower sub-elements of the mentioned activities of all the phases in the typical Canadian context.

- *Development Phase:*

The main decisions about the system shape are taken in the development phase. This phase requires collaboration between the main stakeholders engaged in the project. It incorporates three different steps: (1) The identification, where military capability needs are determined and the feasibility of the project is analyzed; (2) The options analysis phase, where solutions to meet the required capability are explored; and (3) definition, where the design, concept characteristics, and/or implementation plans are refined.[6]

- *Acquisition Phase:*

In this phase, estimator defines the cost associated with the components that need to be purchased by the organization and with the integration of those components to operational capabilities as per the project's requirements.

- *Operations & Sustainment Phase:*

This phase corresponds to the operational utilization of the equipment.[7] The equipment under consideration is operated at the intended sites to deliver the required services.[8]

- *Disposal Phase:*

In this phase, the equipment is no longer required and should be withdrawn from the service at the end of its useful life. In this phase, safety and environmental pressures are the most important considerations[9]. Many systems can cause safety hazards as well as environmental damage at this stage. These systems are generally demilitarized and de-armed to make them safe. Depending on the selected option, different activities may be undertaken: (1) Disposal planning, (2) Demilitarization, (3) Disposal of hazardous materials, (4) Dismantle or destruction, (5) Storage, (6) Transportation, (7) Resale.[6]

➢ *Cost Decomposition*

There are many ways of organizing a cost structure. [10] Examples of such decomposition include (but are not limited to):

- The product-oriented structure that focuses on the end product and organizes cost elements by subsystems.
- The activity-oriented structure that focuses on function and organizes cost element by activity.
- The organization-oriented structure that focuses on individual organizational units that perform the work.

This provides a cost breakdown structure that overlaps the activity-oriented structure on product-oriented. Annexure B shows a generic cost breakdown structure for military equipment.[5]

➢ *Overall Cost of Military Systems*

The NATO nations generally use 3 different concepts to define the cost: (1) Life Cycle Cost, (2) Total Ownership Cost (TOC), and (3) Whole Life Cost (WLC).[11] However, a relationship is defined in Fig. 1 between these costs.

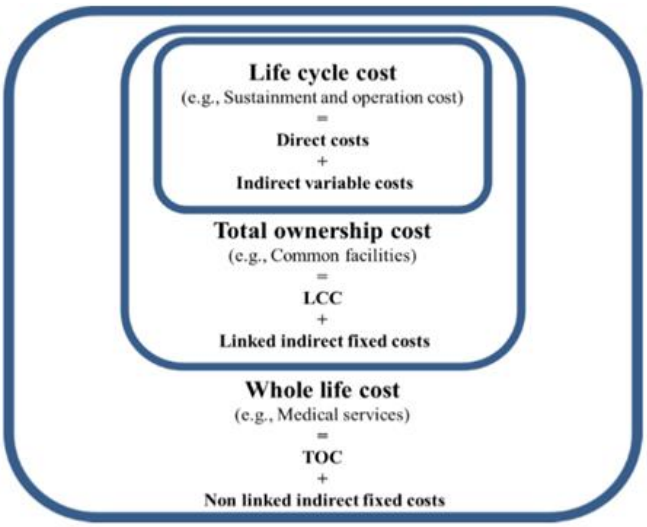

Fig. 1:- Overall Cost of Military Systems [6]

C. USA: Department of Defence, DARPA

The Defence Advanced Research Projects Agency (DARPA) is an R&D organization which was created by the Department of Defence (DOD) in 1958.[12] When the Soviet Union launched its first satellite, Sputnik, and other early Soviet missile left U.S. astonished and coerce them to create ARPA, to compete with its rival in the technologies of

[5] www.drdc-rddc.gc.ca
[6] Sokri, A.; Ghergari, V.; Wang L, Development of Cost Breakdown Structure for Defence Acquisition Projects.
[7] Colabella et al. 2012
[8] NATO 2007
[9] US Department of Defence (DoD) (2000). The Air Force System Safety Handbook, MIL-STD-882D, NM, USA.
[10] NASA Cost Estimation Handbook Version 4.0 Washington, D.C., 2015
[11] NATO 2003
[12] Defence Advanced Research Projects Agency: Overview and Issues for Congress, CRS Report- R45088

warfighting and defence. ARPA was later renamed as DARPA.

DARPA focuses on achieving transformative changes using technology. [13] Its history of achievements reflects a major contribution to the disciplines of computer science, telecommunications, and material sciences, among other areas. Specifically, DARPA investments have resulted in a number of significant breakthroughs in military technology, including precision-guided munitions, stealth technology, unmanned aerial vehicles, and infrared night vision technology.[14]

DARPA's role in the DOD R&D enterprise has been to cut across the traditional jurisdictions of the military services and to explore new and unconventional concepts that have the possibility of leading to revolutionary advances in the technological capabilities of the military—potentially revising the traditional roles and missions of the military services.[12] Therefore, DARPA does not indulge in any cost estimation process. However, the Department of Defence has established its cost estimation process.

- *Product Cost Estimation*

United States Government Accountability Office (GAO), defines the significance of cost estimation as an essential building block for the defence acquisition process because important decisions like resource allocation and budget allocation are possible through cost estimation. Cost estimates are fundamental to shape and communicate schedules and cost structure that helps in planning all the phases of a project.

The feasibility, design, development, and resources of a project could be determined using the cost estimation. Moreover, cost estimation is essential for the analyses of program, technical and schedule and to sustain decisions like the selection of sources, design trade-offs, and other requirements.

For a credible cost estimate, DOD follows a practice that it claims as to the best method for cost estimation as it generates a high-quality cost estimate that is accurate and comprehensive and easy to understand for the decision-maker.[15] Fig. 2 represents the 12 Steps process of Cost Estimation used by DOD. According to GAO 2009 Cost Estimating and Assessment Guide, this process results in a valid and reliable cost estimate that helps management to make informed decisions.

It is divided into 4 sections:

a) *Initiation and Research:* This section basically reinforces the knowledge estimator with the audience's requirements and drives the purpose of estimation.
b) *Assessment:* This section has iterative steps and does not precisely have an order they can be achieved as per the requirement.
c) *Analysis:* The confidence in the point or range of estimates is important to the project manager.
d) *Presentation:* Documentation and presentation make or break a cost estimating decision outcome.

III. COST ESTIMATION METHODOLOGY

The cost estimating methodology should carry out certain criteria such as it should be fundamental to the objective, vision, mission to the organization. And also, should be adaptable to changes as the project develops. It is often observed, as the project develops through its life cycle the cost risk and uncertainties tend to shrink.

The cost estimation model presented in this paper is a sequence of 8 consecutive steps for instructional expediency. The model gives the liberty to analyst to perform the process as often as needed. Steps are accomplished mostly in an iterative manner rather than linear. The accomplishment of steps is based on need, opportunity, and availability of data. The methodology derived by analysing the aforementioned methods. The method complies with the research projects undertaken by DRDO, India. Fig. 3 provides an outline of the cost estimation methodology.

The first stage of the cost estimation process is *Project Definition.* At this point, the estimator performs market research to understand the potential vendors and labor rates. At this stage estimator tries to gain all the required knowledge concerning the project, defines the expectations and scope of the estimate. One of the major activities that take place in this stage is Work Breakdown Structure (WBS) definition and technical baseline description after a clear understanding of the project and discussing it with all the stakeholders. This part is revisited when any new data is extracted.

Stage 2 of the cost estimation methodology, *Assessment,* in this estimator prepares the methodology for the cost estimation and collects data and normalizes it under the model. It creates an approach and framework for the estimate. At this stage, the analyst or estimator revisits the step of developing ground rules and assumptions most of the time.

The last stage of the cost estimation process is *Analysis.* In this estimator develops the cost-risk estimate using probabilistic techniques and then incorporate it to the point estimate. It includes the actual conduct and analysis of the cost estimate.

After stage 1, the results need to be revisited due to many reasons, like change in previous information, change in the technical or programmatic baseline, or experts' intellect suggesting an incomplete estimate. The revised

[13] http://www.darpa.mil/about-us/about-darpa
[14] Defence Advanced Research Projects Agency, DARPA Accomplishments: Seminal Contributions to National Security, Defence Advanced Research Projects Agency, Arlington, VA, October 2015.
[15] GAO's Cost Estimating and Assessment Guide, http://www.gao.gov/products/GAO-09-3SP

results and findings are then formulated and presented, along with the estimating methods and information, made available for ensuing estimating and analyses.

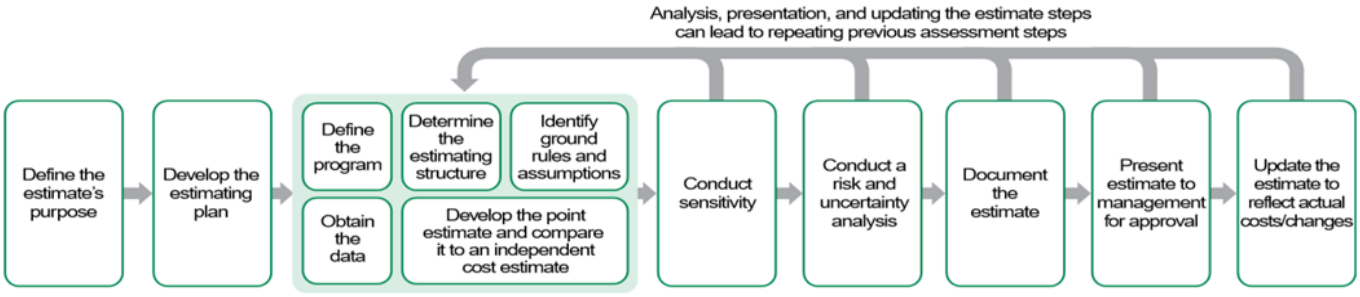

Fig. 2:- The 12 Steps of Cost Estimation Process[15]

For generating high-quality estimate, it is highly important to understand the user's requirement. In order to gain enough understanding of the user's requirements, an estimator or analyst is suggested to discuss sufficiently with the user. For this estimator needs to follow the following steps:

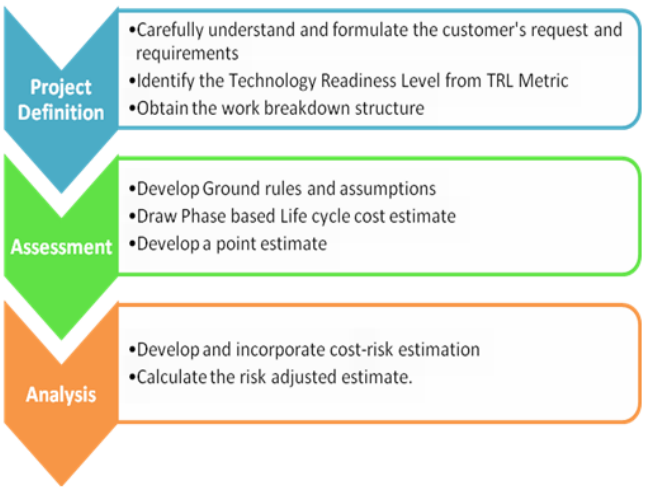

Fig. 3:- Cost Estimating methodology
Source:- Created by Author

1) Identify the stakeholders of the deliverable of the estimate. And communicate with the users.
2) Manuscript requirements of the project. The manuscript should take account of, the purpose of the project; mission needs, objectives, and goals; the operating environment and the life cycle phase.
3) Collect and reassess all relevant project data for evaluation such as an existing technical baseline description, past cost analysis data, previous estimates, lessons learned, user feedback, budget data, and project schedules. Discuss schedule, data, expectations and resource requirements with the requesting user.[1]

A. Stage 1: Project Definition

1) Step 1: Clearly understand and formulate the user's request and requirements

4) After the collection of relevant data, subject experts would determine what shall be the project closure date, magnitude of work, resources required and the relative priority of the project concerning others.

It is important to address the issue like personnel, Schedule, technologies and cost drivers of the project at the early stage of development, which can have a major impact on the risk and to do that we need to move to the next step of this stage.

2) Step 2: Identify the Technological Readiness Level from TRL Metric

Technological Readiness Level describes the technological maturity of the R&D project. The readiness level describes a measurable risk associated with developing state-of-the-art technology. The TRL metric used by DRDO indicates the development of core technology during the selection process of a project. The TRL metric ranges from 1 to 10, where 1 representing new research and 10 representing technology already under production and available from the industry. Table 1, represents the TRL Metric.

It becomes possible for the cost analyst to evaluate the risk associated with the assumption of technology availability. For instance, in TRL Metric, level 7, required prototype tested in the testbed and qualified, at this level the core technology inherent low risk for the development of the project.

Now that the TRL level of technology is obtained, the estimator must make sure that achieved TRL level is true, the evidence must suggest that the technology has a well-documented specification of user manual with the definition of the physical and functional interface and verify the claims.

TRL No.	Status of Technology
1.	New Research
2.	Basic technologies are known and documented
3.	Laboratory level demonstration of similar technology
4.	Similar technology prototype developed and proved at the actual working environment
5.	Detailed Design finalized, reviewed, vetted by experts
6.	Required prototype developed and tested in the laboratory
7.	Required prototype tested in the testbed and qualified
8.	Required module integrated into the system and proved in the testbed
9.	Required module integrated into the system and proved in the actual environment
10.	The required module is already under production and available from the industry

Table 1:- Technology Readiness Level Metric
Source:- Kumar K., Ajith, *Systems Engineering Based Feasibility Rating Model for Defence Research project*, Anna University, 2016

3) Step 3: Obtain Work Breakdown Structure of the project

The key element of project management is WBS which makes it an essential element in the cost estimation process as well. WBS not only helps estimator and analyst to critically understand the project but also make sure that all the work to be performed on the research and development of the project is performed as per the scope of the project, it breaks the work into a hierarchy of elements which are performed as the project will mature. Each element of WBS represents the cost associated with it. This structure becomes the cost estimator's framework for ensuring full coverage.

The framework should include the following elements:

1) Project Technical planning and scheduling.
2) Cost Estimation and budgeting formulation of similar Projects which are undertaken in the past.
3) Statement of scope shall be defined and the specifications of the vendors' efforts, resources required, integrated cost, schedule data.
4) System Engineering Management Planning (SEMP) and drawings and specifications, other documentation products.
5) All life cycle phases of the project.

The WBS defines the project in a manner that is comprehensible to the users as well as stakeholders[1]. It shall be included in the feasibility report of the project.

A WBS Structure mechanizes as a vital tool for the analysis, collection, and communication of the data. It is suggested for the estimator to keep a track of all the baseline description of the project which will help the stakeholders to develop the project.

B. Stage 2: Assessment

1) Step 4: Formulate Ground Rules & Assumptions

At the early design stage, the estimator may not be aware of every programmatic or technical parameter which could lead to risk or uncertainties in a project. To prevent such situations, it is essential to formulate a set of Ground Rules & Assumptions (GR&A) which increases the reliability of the cost estimation and the project team is aware of the environment and context at which the estimate is being developed. More the comprehensiveness of the GR&A more reliable will be the estimate. GR&A specific to the levels of WBS helps in determining the requirement of resources and schedule plans. A set of GR&A generally includes the descriptions of rate of inflation, FOREX rates of which year is considered, percentage of escalation on the above year is taken into account, basis of calculations of numbers/spares of modules/systems/sub-systems taken for costing.

Develop a set of GR&A that is compatible with two main parts of any R&D project that are, the technical and programmatic sections of the project. The developed GR&A should be approved by the project director and stakeholders. GR&A shall be documented during the whole cost estimation process and must be revisited as need arises.

2) Step 5: Draw Phase based Life Cycle Cost Estimate

The estimator and subject matter experts (SMEs) select or a combination of cost estimation method, either for every level of WBS to ensure a credible cost estimate or for each of the life cycle phases for high-quality estimate. Mostly, three methodologies are used *Analogy Cost estimating Methodology, Parametric Methodology and Engineering build-up (also called 'grassroots')* which fits all the R&D projects. It is important to note that every methodology shall be combined with the experts' opinions.

There are other cost estimation methodologies available around that could be used in the life cycle cost estimate of the project like an expert's opinion and learning curve.

3) Step 6: Develop a Point Estimate

After each WBS element has been estimated with one of the methods discussed above. The elements should be added together to arrive at the total point estimate. After this, the cost estimator should validate the estimate by checking for errors like double-counting and omitted costs. The cost estimator shall perform a cross-check on cost- drivers to see if the similar results can be produced.[1]

C. Stage 3: Analysis

1) Step 7: Develop and incorporate the cost-risk estimation

It is important to understand that the point estimate developed above is not ultimate and it still inherent with uncertainties and risks which estimator needs to take care of.

This paper suggests the cost-risk estimation approach historically developed by NASA; this approach is compatible with defence R&D projects as well. The approach uses probabilistic techniques for the estimation of risk. The probabilistic technique helps two sets of a group of a project, project team and management; it helps the former by effectively communicating the impact of changes to planned or requested resources by providing quantified effects on the probability of meeting planned cost and schedule baselines. And latter by providing essential insights of the cost drivers of the developing project and allows them to actively manage and develop mitigation strategies to reduce cost.[1]

Before, getting to the methodology of cost- risk estimation, it is important to understand the meaning of risk and uncertainty.

i. Risk: It can be defined as a situation that is possible to occur and may cause an undesirable outcome. The situation here is not a part of the project's definition hence it is expected to affect the project's outcome.
ii. Uncertainty: It is ambiguity in the project's definition which may cause an undesirable outcome. It is due to the lack of ability in formulating the project description or perceiving the upcoming situation.

The objective is to produce a credible project cost cumulative distribution function for the range of costs of the projects. By adhering to the guidelines mentioned below, cost estimators and analysts will improve the quality and accuracy of project cost estimates help to generate realistic budget plans and provide decision-makers with accurate and realistic.[1]

➢ *Hybrid Approach to Cost Risk estimation*

Guidelines are as follows:

1. Subject Matter Experts (SMEs) identify the risks to the project.
2. SMEs determine the likelihood of occurrence of each WBS element.
3. Determine the associated cost consequence with each identified risk.[16]
4. Span the full range of the Standard Risk Matrix (Fig. 4)
5. After the matrix has been prepared, use Monte Carlo simulation which will result into a distribution of cost-risk impact that identifies confidence levels associated with each cost value in the range of a cost-risk distribution.
6. Use the qualitative results produced above and produce random drawings.
7. Add the cost consequences for each identified risk with a likelihood value of equal to or less than the random number generator.
8. Identify the probability that the actual cost is less than or equal to the point estimate.
9. Recommend sufficient risk-adjusted future expenses to achieve the desired percent of confidence level.

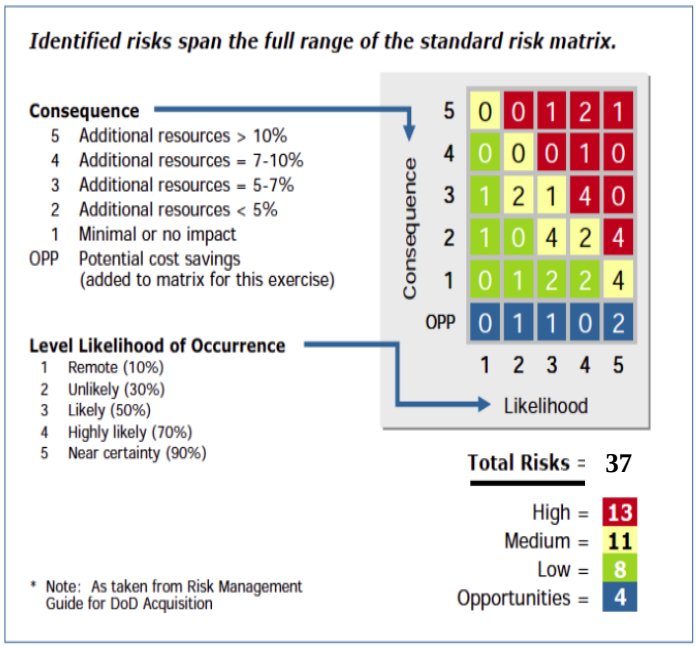

Fig. 4:- Standard Risk Matrix
Source:- Risk management guide for DOD Acquisition

2) Step 8: Calculate the risk-adjusted estimate

For each risk, starting from the high risks, outline a possible strategy to overcome the likelihood of occurrence, to mitigate risk. The estimated cost-risk needs to be added to the point estimate only after they both have been converted to the present value of cost. The difference between the risk-adjusted estimate and the WBS estimate is the unforeseen cost. This amount is adjusted to the present value of cost.

Once the amount of unforeseen cost has been identified, the cost needs to be identified and set aside for the WBS elements that harbour the most risks so that funding will be available to mitigate risks quickly. To identify which WBS elements may need contingency reserve, results from the uncertainty analysis are used to prioritize risks, based on probability and impact as they affected the cost estimate during the simulation. Knowing which risks are important will guide the allocation of contingency reserve.[15]

IV. CONCLUSION

This paper extensively studies the cost estimation processes undertaken by different defence organizations over the world, the nations taken under consideration were based on their defence R&D expenditure, availability of resources for the research. It was found that the methodology followed by DRDO, India does not consider cost-risk estimation. Risk Analysis plays an essential role in

[16] It is important to note that the first three steps are to be performed by subject matter experts who, with their experience with similar projects.

cost estimation methodology as limiting the risk is connected with the decision making, rational thinking is used by managers to estimate costs and profit from implementing the innovation based on material measures. The study thus provides a cost estimation model that complies with the defence R&D projects undertaken. The new framework follows the way of combining relevant information from secondary data available on the internet and primary data from the experts' opinions. This study helps to gain keen knowledge of the cost risk estimation of projects undertaken in several nations. Although the study conducted is not exhaustive, it provides a comprehensive source for carrying out further research in that area.

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