Life-Cycle Readiness

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Weapon system design and development is achieved through a comprehensive system architecting and engineering process, the aim being that the resultant system design will be operationally feasible. This means that the system will perform its intended function or mission in an effective manner, as needed by the war-fighter. A system will consistently achieve its intended mission when its technical and operating characteristics are engineered into the design. As on date, traditional characteristics derived from the aerodynamic, electrical, mechanical, structural and related domains have been the area of focus in indigenous systems, but these are no longer sufficient by themselves.

A design for X or a design for abilities like reliability, maintainability, supportability, usability, producibility, disposability, affordability is an area that needs to be considered if desired operational outcomes are to be achieved throughout the life-cycle of the equipment. This is systems engineering for life-cycle readiness. We shall consider these aspects, one by one.

Design for Reliability: Every weapon system is developed to fulfill a qualitative requirement (GSQR) which is essentially the mission capability needed to fulfill some anticipated mission or function. The mission effectiveness of the system is measured by the extent to which the system meets this operational requirement. Reliability requirements, both quantitative and qualitative, are defined within the context of system operational requirements and maintenance philosophy, and include:

- Definition of system performance, mission profile, system requirements like operating environment, operational tempo, duty cycles.
- Definition of operational life-cycle or service life and basic maintenance concepts.

- Definition of the environment in which the system will operate and be maintained (temperature, humidity, vibration, transportation, handling, maintenance, storage, etc). System reliability requirements are usually expressed as Mean Time Between Failure (MTBF), Mean Time To Failure (MTTF), failure rate, successful operational cycles per period or combination thereof and Survival Function (Rt).

Many indigenous systems meet the functional requirement, but their reliability is marginal, with high down times.

Design for Maintainability: A primary aim of operational capability is to ensure that the system is available in a mission capable state when needed. The system availability is feasible if system reliability is as desired and it has the ability to be restored and returned to service rapidly and efficiently. Maintainability is a design dependent parameter related to ease, accuracy, safety and economy in performance of maintenance functions. Many indigenous systems meet the functional requirement, but their reliability is marginal, with concomitantly high down times. Maintainability is the counterpart of reliability and can be measured by maintenance factors like Mean Time To Repair (MTTR), Mean Corrective Maintenance Time (MCT), Mean Preventive Maintenance Time (MPT), Mean Active Maintenance Time (MAT) and excludes logistic delay and administrative delay time and Mean Down Time (MDT) – the total time required to restore the system to operational use.

Mean Time Between Replacements (MTBR) is a major parameter in determining spare parts requirements. A maintainability objective in system design is to maximise MTBR. While looking at maintenance cost, it may be useful to consider maintenance cost per operating hour and ratio of maintenance cost to total life-cycle cost. Operational availability (A_o) is not plain garage availability, as many understand, but the probability that when used under stated conditions, the system will operate satisfactorily.

$$A_o = \frac{MTBF}{MTBF+MDT}$$

System Effectiveness (SE) is the ability of a system to do the job for which it was intended and is a term used to reflect technical characteristics like system performance, availability, supportability, dependability, etc. Features like use of standardised components, built-in self-test feature, level and depth of diagnostics, accessibility, interchangeability, avoidance of short life components (duplicates), configuration control, proper labelling and identification of components help in robust design for maintainability. A LORA (Level Of Repair Analysis) is usually carried out to balance life-cycle readiness and life-cycle costs. The Main Battle Tank (MBT) Arjun has been designed for high maintainability as a result of the involvement of the Corps of Electrical and Mechanical Engineers (EME) in its design and development.

Design for Operability: Use of the system to accomplish tasks being the central aim of system design, it is important that the system is designed for normal use and also against misuse and abuse. A system, therefore, has to achieve objectives like ease of use, minimising human-induced errors, improving the work environment, maximising human safety, reducing training requirements, and so on. This calls for the study of anthropometric factors, human sensory factors, operators task analysis, error analysis, operational sequence diagrams, safety and hazard analysis, etc. True and complete Human Integration Systems (HIS) is the overall objective.

Design for Supportability: Most systems get designed/deployed with little or no consideration for maintenance or sustenance support over their life-cycles. It has primarily been an 'after the fact' activity leading to large down times as seen in the Arjun, Pinaca, indigenous T-90s, etc. It is essential that the design for supportability is addressed *ab-initio*. It is critical to integrate this with the higher level system performance factors as they pertain to the overall mission capability of the system.

The probability of mission completion can be determined by the general Poisson's expression.

$$f(x) = \frac{(n\lambda t)^{x}\, e^{-n\lambda t}}{x!}$$

n = no of systems.

t = mission duration.

λ = failure rate (failure per hour).

x = no of failures restored.

While fixing spare parts requirement, one has to look at a desired protection level or safety factor which is linked to mission completion, system effectiveness, operational availability, desired, cost, etc. Spare parts availability at the right place and time will impact mission completion of a system. Similarly, special facilities required for system support at the organisational, intermediate and depot levels must be analysed and specified during system design and production. Personnel skills, thoroughness of Built-In-Test Equipment (BITE), Automated Test Equipment (ATE), turnaround time, and spares availability have to be specified for effective life-cycle readiness. A supportability oriented design review and evolution of the system has to become an integral part of any system development. A technical measure of effectiveness of capability, availability and quality needs to be specified for supportability and supply chain management.

Design for Producibility and Disposability: These are design dependent parameters related to each other: one deals with 'bringing into being' and the other 'ceasing to be'. A badly manufactured weapon system 'ceases to be' very early in its life-cycle. The life-cycles of the AK-47 and the 5.56mm INSAS can draw suitable lessons in this context. The objective here is to influence the system design and engineering such that system elements and components can be produced effectively and efficiently. It is not uncommon for a system to be designed with the required characteristics and then be subjected to an existing production process, with product modification being required for purposes of compatibility. While manufacturability relates to how quickly and inexpensively a system can be manufactured, producibility encompasses manufacturability, packaging and shipping. Design for manufacturability adopts principles like use of gravity, fewer parts, design for ease of fabrication, reduction in non-standard parts, adding more function per part, etc. A few guidelines to good manufacturability are:

- Assemble to a foundation.
- Assemble from few positions.
- Make parts independently replaceable (power packs).
- Order assembly so that the most reliable goes in first and the least reliable last.
- Assure commonality in design.

In assembly, the following guidelines are of general importance:

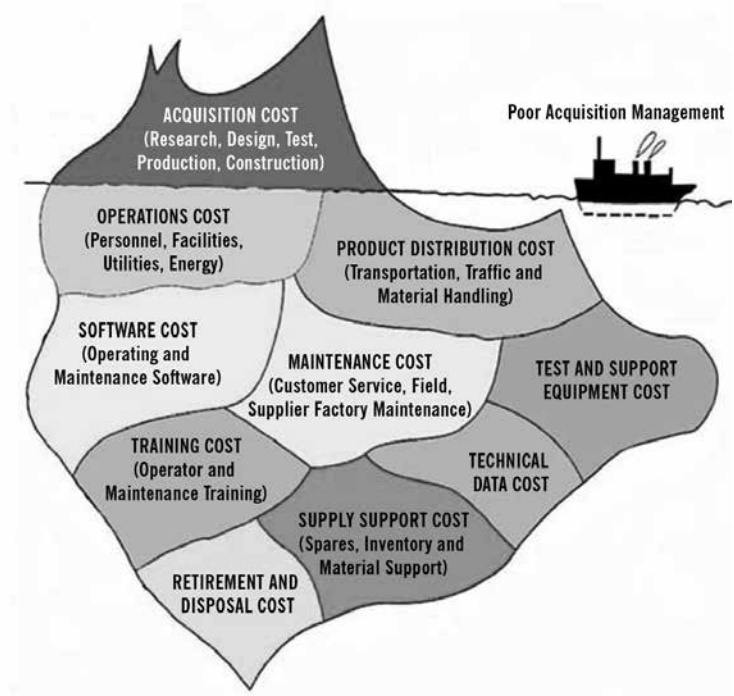
- Employ automatic inserters.
- Employ pre-oriented parts.
- Minimise sudden and frequent changes in assembly direction.
- Maximise process compliance.
- Maximise accessibility.
- Minimise handling.
- Avoid flexible components.

Design for disposability looks at reuse, remanufacturing and recovery. It is indeed to help environmentally friendly recycling and disposal procedures. An evolutionary design paradigm is green engineering or environmentally conscious design and manufacturing. Green products and environment friendly manufacturing processes are now being considered during design and development.

Design for Affordability (Life-Cycle Costing): Most military systems were planned, designed, produced and operated with little concern for affordability and life-cycle costs. With shrinking budgets, the military has to change, and consider the cost and economic factors.

Total life-cycle cost can best be explained by the 'Iceberg Effect'

Fig 1



Total Life-Cycle Cost

Life-cycle cost refers to all the costs associated with the system.

The life-cycle cost refers to all the costs associated with the system as applied to the defined life-cycle and includes Research and Development (R&D), production and construction cost, operation and support cost, and, lastly, discard and disposal cost. To ascertain the life-cycle cost, it may be prudent to focus on high cost/high risk areas. Areas of concern or importance are not only based on high cost but on criticality as it pertains to system/mission capability. Think economics and life-cycle has to come into our R&D ventures. Some of the critical issues are discussed below.

On Schedule: The schedule to produce a system is an essential part of the system design, often being a design driver. It is said that performance, cost and schedule cannot be specified independently. At least one of the three must depend on the others.

System Test, Acceptance and Operation: This is the most important, even traumatic, experience for the builder/designer. It is akin to passing a final exam as the system moves to the operating life-cycle. The requirement drift at times brings in added functional requirements and acceptance delays. Acceptance criteria and their corresponding qualification and acceptance test determine the system that will be built. The challenge for the designer is to design and build systems that can't be made obsolescent by a determined user.

Ultra Quality – Excellence Beyond Measure: It is a level of excellence so high that measuring it with certainty is a big challenge. These systems are mandated to have failures below one per cent – something that cannot be easily demonstrated to the user. Quality cannot be tested – it has to built in. Strategic command and control systems, Intercontinental Ballistic Missiles (ICBMs), and stealth aircraft could fall in this category. At least for the designer, this should be the objective. This can be achieved by careful design, minimal material defects, replication by use of Computer Numerical Control (CNC) machines, well instrumented process control, tight tolerances and detection of system and process weaknesses. The approach of progressive redesign is followed to record and analyse defects , track defects to the cause, make corrections and monitor changes. Reducing failure rates by a factor of two takes as much effort as the original development. For high quality systems, it is essential to have high quality documentation – complete, concise and error free.

Life-Cycle Readiness: Retaining mission capability or system dependability over the in-service life is the *sine qua non* for military systems. Yet military systems, like all others, degrade with Age, Usage and Deployment – known as the AUD effects. Whether it is mechanical components, or electrical and electronic devices, microprocessors develop a certain latency with AUD effects and renewal becomes necessary. The Corps of EME looks at these effects and initiates proactive reset actions to restore mission capability. An indepth knowledge of system Software (SW), Hardware (HW) and interfaces is the second nature of the EME's workforce of specialists. Association of these personnel in all design and development projects will lead to the comprehensive design of 'ibilities' during system design and development, upscaling the quality and robustness of products and getting the first iteration almost right. The association of the Defence Research and Development Organisation (DRDO) and EME in the Arjun ARRV project is a step forward in this direction and can become an example of how the tempo of indigenisation can be accelerated. Application of the system's engineering process will lead to reduction in the cost of system design and development, reduce acquisition time, give more visibility and reduce risks associated with the design decision-making process. Increased visibility is provided through viewing the system from a long-term and life-cycle perspective. It will greatly enhance the robustness and quality of indigenously designed systems and, thereby, life-cycle readiness. This will provide greater user acceptability and, hence, a positive spin to indigenous development and production of high quality weapon systems. An eco-system that will allow creativity and innovation, and a leadership style that promotes teaming among the development agency, EME specialists and the user is the need of the hour.

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