DEVELOPMENT OF TECHNICAL FACILITY LAYOUT FOR AVIATION ENGINEERING SETUP

By

Muhammad Umair

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Supervisor

Dr. Adnan Maqsood

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Approval

It is certified that the contents and form of the thesis entitled "**DEVELOPMENT OF TECHNICAL FACILITY LAYOUT FOR AVIATION ENGINEERING SETUP**" submitted by **Muhammad Umair** have been found satisfactory for the requirement of the degree.

Advisor: **Dr. Adnan Maqsood**
Signature: ____________________

Date: ____________________

Committee Member 1: **Engr. Sikander Hayat Mirza**
Signature: ____________________
Date: ____________________

Committee Member 2: **Dr. Shahzad Rasool**
Signature: ____________________
Date: ____________________

Committee Member 3: **Engr. Tanveer Ahmad**
Signature: ____________________
Date: ____________________

Certificate of Originality

I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution.

Author Name: **Muhammad Umair**
Signature: ________________

Dedication

I dedicate this effort to all those who have assisted me in any possible way to become what I am today. Their sacrifices seeded my success especially my parents and elder sister who showed their devoted attention and to faculty members who inspired me all the way.

Declaration

I hereby declare that the work presented in the following thesis titled as Development of Technical Facility Layout for Aviation Engineering Setup is my own effort, except where otherwise acknowledged, and that the thesis is my own composition. All the secondary data has been cited properly in dissertation report and accordingly sources have been mentioned in references.

Author Name: **Muhammad Umair**
Signature: ________________

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Abstract

Systems Engineering (SYSE) is a multidisciplinary approach that interrelates the basic principles of engineering and helps to organize different domain knowledge to makes effective insight into complex engineering projects. Industrial project selected for thesis work is Development of Technical Facility Layout for Aviation Engineering Setup (AES) in private Aerospace & Defence (A&D) sector of Pakistan. The methodology employed in planning the technical facility layout is a unique blend of multi-disciplinary approaches that have been amalgamated together to formulate a framework named as Technical Facility Layout (TFL) for AES. The process starts with the application of strengths, weaknesses, opportunities and threats (SWOT) analysis to identify all the possible known dimensions into four logical quadrants. Further to QFD, need analysis was performed, which included the identification of the stakeholders to the project and derivation of mandatory and preferential requirements. Systematic textual analysis helped to identify the major functions and then decomposition of these functions to map with customer needs, resources and formulation of organizational structure by using SysML and functional flow block diagrams (FFBDs). Three broad categories of technical performance measures (TPMs) are set to access the overall progress of the project. Allocation of functions to physical elements is carried out by making the facility layout model using the SysML. Creation of a system model necessitates the requirement to identify the interaction of physical elements within the system and with the external systems. This interface management is carried out using N2 matrices. Three different alternatives were evaluated through the linguistics evaluation and mathematical modeling to select the most suitable option. A risk assessment model is developed based upon the different stages of system life cycle to access the risks associated with the complex projects. Engineering development plan is made to define the timelines for different phases of the project. In the end, all these tools and techniques are organized in a logical sequence to give new way and essence to existing planning document called as System Engineering Management Plan.

List of Abbreviations

AEC	Aviation Engineering Complex
A&D	Aerospace & Defence
SEMP	System Engineering Management Plan
ERP	Enterprise Resource Planning
SYSE	System Engineering
CW	Civil Works
MRO	Maintenance, Repair & Overhaul
PMEL	Precision Measuring Equipment Lab
SP&HM	Small Parts & Harness Manufacturing
T&C	Training & Consultancy
I&O	Indenting & Outsourcing
AL	Assembly Line
PAC	Pakistan Aeronautical Complex
CAA	Civil Aviation Authority
FAA	Federal Aviation Administration
IATA	International Air Transport Association
CPEC	China Pakistan Economic Corridor
QFD	Quality Function Deployment
HOQ	House of Quality
PMP	Program Management Plan
SYSML	System Modeling Language

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Chapter 1

INTRODUCTION

The initial chapter of proposed research area covers the purpose, importance of aviation sector, need for establishing the required setup, thesis organization and relationship of project under consideration with the other projects of the same program.

1.1 Purpose

Industrial project selected for following thesis work is Development of Technical Facility Layout for Aviation Engineering Setup (AES) in private Aerospace & Defence (A&D) sector of Pakistan. Development of AES is a unique project and is envisaged to be an international standard, very high quality, private sector setup in the Aerospace & Defense (A&D) sector that will provide outsourcing services to foreign and local organizations for maintenance, repair, and overhaul (MRO) of aviation components and piston engines. Major focus will be on MRO of components from Instruments, Avionics, and Electrical system specialties. Aviation MRO will be the major component of AEC that will characterize itself with such essential elements as efficiency, quality certifications, automation, committed human resource, and enabling environment. Other components of this setup will be engaged in allied functions such as training, consultancy services, and indenting. The proposed project is divided in two segments keeping in view the diversity, requirements, complexity, areas of applicability and time constraint: first segment (thesis work) will cover technical facility (MRO, Small parts manufacturing, Assembly Line & Indenting) while the second part (covered in separate thesis work) will support technical facility operations through development of Corporate Sector (Head Offices, IT infrastructure, ERP and Software Department, Sales & Marketing, Library, Tax Returns & Legal Services & allied facilities). This document will serve as a customized System Engineering Management Plan (SEMP) because of tailoring and integration of various SYSE tools & techniques in the standard format of SEMP. This study will not only embolden future students to select the industry related projects but will also promote the stature of Research Center for Modeling and Simulation in pioneering role of SYSE field in Pakistan.

1.2 Importance of Aviation Sector

The aviation industry is a significant contributor towards economic development. It has increased world trade activity by enabling easier and faster movement of goods and passengers. According to the International Air Transport Association (IATA), this sector has provided jobs to 58 million of people [1].Aviation industry and various associated businesses are growing rapidly fast. Based on demographic and economic growth, IATA has projected Asia-Pacific, Middle East and intra Pakistan air traffic to grow at 7.6%, 9% and 9.9%, respectively over the next 20 years. Large scale inductions in PAF, PAC Kamra new commercial national and international business ventures and expansion in Pak Army & Naval aviation and increasing trends of commercial airlines in private sector has created new prospects in Pakistans aviation industry. [2] States that global commercial MRO business remained US$ 64.3 billion during the year 2015 with significant contribution of US$ 24.4 billion (38%) by America, US$ 18 billion (28%) from Asia, Europe with US$ 16.7 billion (26%) and Middle East US$ 5.2 billion (8%). The growth of commercial MRO business is expected to grow at 4.1% annually from US$ 64.3 billion to US$ 96 billion till 2025. Global Fleet & MRO Market Forecast Summary has projected that total commercial MRO expenses in 2017 are estimated to be US$ 75.6 billion [3]. The military aviation MRO business projected to remain US$ 18.5 billion in 2017 whereas defence sector revenue was likely to grow 3.2% in the same year [4]. However, MRO business in Pakistan is only 0.05% of the global market mentioned in national aviation policy 2015 [5].

1.3 Need of Private Setup

In Pakistan, local airlines including Pakistan International Airline (PIA), Air Blue Limited, Shaheen Air and Serene Air are operating commercial aircrafts whereas military aircraft are being operated by defence organizations including Pakistan Air Force as major contributor, then Pakistan Army and

Pakistan Navy. The MRO setups available in Pakistan include:

a. Pakistan Air Force

b. Pakistan Aeronautical Complex, Kamra

c. PIA Engineering Complex, Karachi

d. Pak Army Aviation Base Workshop at Qasim aviation base Rawalpindi

e. Pak Navy Air Engineering Department, PNS Mehran, Karachi

Military organizations have their own MRO setups with limited MRO services offered to friendly countries whereas PIA Engg. Complex and PAC Kamra are the only aviation setups to undertake commercial MRO business. However, these setups are unable to give required productivity keeping in view the infrastructure, equipment, facilities and technical manpower. The most noticeable reasons are lengthy procurement procedures, beaurocratic hurdles, payment schedules and long chain of command. Therefore, a private sector A&D setup will not only help country to achieve self-sufficiency in aviation industry but also provide opportunities to optimally utilize the PAC Kamra facilities through indenting and outsourcing business. Restoration of peace and one road concept in form of China Pakistan Economic Corridor (CPEC) has also opened new prospects for the growth of aviation industry in Pakistan. Furthermore, incentives in form of tax exemption on the raw materials and aviation components in National Aviation Policy 2015 are encouraging steps taken by Government of Pakistan to promote the aviation MRO business in Pakistan. Keeping in view the above cited facts, establishment of private sector AES will not only boost aviation sector in Pakistan but will also pay back through reduction of foreign reserves spending for MRO business, maximal utilization of local human resource, achievement of autonomy and generation of foreign reserves through MRO business with regional international customers. MRO will be the major focus of AES that will distinguish itself with such essential features as efficiency, automation, quality certifications enabling environment and committed human resource. AES will provide following Products & Services:

a. MRO of Helicopters and Aircraft's accessories, avionics and instruments from certified facilitiesof OEM.

b. Provisioning and MRO of ground handling and support equipment

c. Spares And Logistic Support (SLS) for assemblies, sub-assemblies and components along-with provisioning of aviation standard raw material and manufacturing consumables

d. Calibration and repair of Test Measurement and Diagnostic Equipment (TMDE), Precision Measuring Equipments (PME), instruments and testers through renowned setup and facilities

e. Manufacturing, Upgrades / Modification of Shop Replaceable Units(SRUs), Line Replaceable Units (LRUs) and components of aircrafts

f. Training in the fields of aviation manufacturing and auxiliary systems
g. Consultancy in QFD and ERP for aviation related problems

1.4 Research Objectives

Execution of multi-disciplinary projects requires timely identification of various constraints especially in countries like Pakistan where SYSE has not been adopted as essential component of planning phase for every complex project. Application of SE is mandatory for translating the requirements, meeting the time schedules and minimizing the various negative impacts on the performance along with the overall cost reduction of the project. The possible way out to theses constraints is the development of living conceptual planning document through the application of SE tools & techniques and tailoring of optimization & risk mitigation techniques. This thesis work contains customized SEMP for development of Technical Facility Layout for Aviation Engineering Setup.

1.5 Thesis Organization

This thesis is organized as follows.
Chapter 1 - Introduction
This chapter gives a brief introduction of aviation MRO industry, its importance, need for a private sector aviation setup in Pakistan and components of proposed setup.
Chapter 2 - Literature review
This chapter gives a summary of different research publications related to application of different tools & techniques those will be incorporated in the thesis work to address a number of issues.
Chapter 3 - Methodology and Site Selection
The chapter explains the detailed methodology employed to prepare a customized planning document (SEMP) for AEC.
Chapter 4 - System Engineering Processes
Different SE processes were employed to develop system requirements, organization structures, functions and system model.
Chapter 5 - Optimization & Engineering Specialty Integration
Linguistics evaluation method was used to facility layout planning whereas risk assessment model is proposed to formulate a risk mitigation strategy.
Chapter 6 - Conclusion and future work

The thesis concludes in where recommendations are suggested for future work.

1.6 Relationship With Other Projects

This proposed thesis is a part of AES Project Management Plan (PMP). AES will comprise of technical facility and corporate sector. The plan will interact with PMP, Corporate framework SEMP and other plans those will form PMP for development of AEC. Such projects require a strong relationship with other supplementary plans for incorporation of all mandatory rudiments to the program.

Chapter 2

LITERATURE REVIEW

This chapter consists of summary of different research publications related to the research question and literature gaps that current research study will try to address.

2.1 Relevant Studies

Systems Engineering (SYSE) is a multidisciplinary approach that interrelates the basic principles of engineering and helps to organize different domain knowledge to makes effective insight into complex engineering projects [6]. Quality Function Development (QFD) is a sort of conceptual map which provides the means for inter functional communication and planning. It translates customer requirements based on benchmarking data and marketing research into an applicable number of engineering targets to be secured for a new product design [7]. Maintenance, repair and overhaul (MRO) is a multifaceted process in the aeronautical industry that has austere and precise requirements defined by potential customers, airworthiness authorities and maintenance thespians to guarantee cost effectiveness, quality and the safety of passengers and aircrew. SWOT analysis is effective tool to give insight to maintenance, repair and overhaul practices in the aviation industry and the impacts of the outsourcing model from the perspective of stakeholders (airlines, OEMs, repair shops and system suppliers) [8]. Stakeholders may be a customer or user, system operators, system regulators, people directly or indirectly affected by the system, people monitoring the system life cycle and the system itself. Stakeholder identification, grouping and capturing of their interaction and influences is the salient aspects of Stakeholder Influence Map to formulate the mandatory and preferential requirements for a project [9].

Customer requirements are generally inconsistent, ambiguous, un-measurable and incomplete. So these requirements are also difficult to verify and validate. Customer requirements can be translated into system, functional, implementation, and non-functional requirements through a Holistic Requirements analysis by interpreting, clarifying and expanding the customer requirements [10]. System requirements are examined to ascertain functions which are mandatory to obtain the system objectives and each function is described in terms of, inputs, output sand interface requirements from the perspective of logical order of functions and sub functions. Identification of interface, inputs and outputs requirements and conflicts between the functions and sub functions can be resolved through N2 diagrams [11].

Time tested engineering of complex systems has proven that the functions that the system has to perform are the critical design elements and must be given more contemplation than the physical side of the system for the design process to be successful [12]. [13] Explains the decomposition of eight different system engineering processes into functions, then organization of these functions into hierarchies, establishment of relationship between functions and sub-functions and in the end creation of functional flow diagrams for each process. The physical architecture must be developed to provide resources for functions identified in the functional analysis. Therefore, for every phase of the system life cycle addressed in the requirements and functional analysis, there must be a physical architecture of identified functions for each system [12]. Identification of interconnections between system and sub-systems or between different systems in System of Systems (SoS) context can be visualized by N2 Analysis tool [14]. [15] Describes how the Industrial problem of Control Maintenance system (CMs): Integration of an avionic system with an aircraft fuel system was resolved through the application of Model Based Systems Engineering (MBSE) approaches (usage of Use Case Models, Sequence Diagrams and Block Definition Diagrams (BDD)). [16] Paul Pearce and Sanford Friedenthal present a consistent, precise, integrated and traceable practical design of submarine subsystems by using MBSE methodology built in the OMG Systems Modeling Language OMG SysML and integration of Failure Modes & Effects Analysis (FMEA) within the system model. Successful execution of maintenance, repair and overhaul of an aircraft can be accomplished by integrating the airlines technical proficiency, logistics configuration, supply chain and outsourcing practices. MRO is the important airline operation and covers the C and D checks require the extended lead time and higher cost as compared to A and B checks. [17] Proposes the Operation Management Model of MRO by introducing the concept of sustainable development and lean production into the maintenance and management processes for MRO setup. The MRO organization should emphasize on the cost, delivery, flexibility, and quality to meet the customer satisfactions.

The facility layout design has significant impact on the organization management discipline and has been dealt since the beginning of organized manufacturing of human beings. An effective facility layout design will shorten working hours, reduce the material handling cost and accelerate the asset turnover, thereby increase the overall productivity and competitive ability of the organization [18]. The human factors problems in aircraft maintenance are mostly related to technicians and working environment and can be addressed in the facility layout design. Noticeable considerations related to human factors in facility design are easy access for a fork lifter, separate storage room with a sunken floor for spillage, face wash facility with an easy access, centrally located facility to allow easy access to all work stations, improved ventilation, heating and lighting for the whole facility and multiple doors access for moving aircraft and equipment in and out from the hangar [14].Many approaches like quadratic set covering problem, quadratic assignment problem, integer programming model, linear integer programming and graph based construction method have been developed to solve the facility layout problem (FLP). Rui Pinto et al. formulated a genetic algorithm to solve a quadratic assignment problem of facility layout by dividing the each manufacturing plant into equal rectangular blocks and consideration of key factors to articulate the problem [19]. [20] Considers the manufacturing variability problem results in accumulation of work in progress (WIP). Queuing model is utilized to model the manufacturing facility to solve the optimization problem which invariably improved WIP in the system, total travelling time, quantity and utilization of material handling equipment, and required area. Facility layout effectiveness and reliability evaluation can be carried out through linguistic evaluation and mathematical modeling (interpolation theory) by considering additional performance factors of energies consumption and environmental impacts [21].

Systems Engineering is the systemic approach for realization, conceptual design, detail design, development, utilization & support and retirement of reliable system that fulfills the operational & system requirements [6]. Execution of this systematic approach is carried out through precise plans and processes. However, uncertainties in these plans may lead to different negative consequences therefore affecting the overall project. Assessment of risks associated with system engineering processes is deemed necessary and a major challenge for the efficient and timely execution of these processes. Risks involved in the new product development can be identified, assessed and prioritized through a three step Holistic Risk management approach by using the Fuzzy theory to obtain a single value for making Go or Kill decisions regarding product development [22]. The effective assessment of different levels of risk for a particular project cannot be realized without adopting the methods of SE in addition to methods of Factor Analysis, Analytical Hierarchy Process and Work Breakdown Structure [23]. [24] Proposes a three step Risk Assessment Framework, a systemic approach for risk management and analysis through identification of risks, their classification, and finally the prioritization of risks associated with systems engineering processes for a specific project. The application of risk management to the reengineering of operator console stations designed for a missile weapon system and system engineering processes give twelve important deductions, the significant ones are quantification of risks, systemic evaluation of risks, investment in the risk management, devising risk mitigation development strategies helps in design decisions and planning of risk management activities in the project plan [25].

Management of complex systems deals with a number of issues including processes, culture, environment, risks, time constraints and various combinations of these. [26] proposes different organization structures and system design reviews for effective management and timely execution of complex functions. [27] Emphasizes the importance of development and implementation of the performance measures or indicators to the key aviation processes those are aircraft production, aircraft operations, aircraft maintenance, aircraft supply support and crew assessment involved in operation, maintenance and supportive activities to provide higher management quantifiable information for correct and timely decisions.

2.2 Missing Links In Literature

Conceptual planning for any complex system/project involving multi disciplines is deemed necessary to maximize the productivity and minimize the project cost. SEMP is well known living document for the execution of the planning component of any project. However, application of different tools & techniques to address the issues faced during the conceptual planning phase is a weak link to make the SEMP more effective and practical. In this regard, integration of SysML, Linguistics evaluation & mathematical modeling for layout planning, Use Case models, risk assessment models, Quality Function Deployment and N2 diagrams would be a new systematic approach for making viable decisions during the planning phase of any project.

Chapter 3

METHODOLOGY & SITE SELECTION

The chapter explains the detailed methodology employed to prepare a customized planning document (SEMP) for AEC. The chapter also explicates the process of site selection and the feasibility study for proposed facility.

3.1 Methodology

The methodology employed in planning the technical facility layout is a unique blend of multi-disciplinary approaches that have been amalgamated together to formulate a framework named as Technical Facility Layout (TFL) for AES. The process starts with SWOT analysis, which depicts the strength, weakness, opportunities and threats of the project. This tool helps identify all the possible known dimensions into these four logical quadrants. The demarcation among the internal and external factors helps steer the project in a more structured manner. Then QFD helps to make decision regarding selection of site through a systematic approach. Further to QFD, need analysis was performed, which included the identification of the stakeholders to the project. Identification and classification of stakeholders is of utmost importance as it lets one to manage the project under the influence of different stakeholders group. After need analysis, a functional analysis was carried out which let ones elaborate all the functions mandatory for the project. A functional decomposition is a must have for any project, for the reasons of mapping with customer needs, resources and analyses of functionality purpose. The activity was performed using functional flow block diagrams (FFBD). The activity was followed by project organization as now the functions are clear and at this stage formulation of project organization is necessary rather mandatory. The project organization includes all the team members those are necessary to execute the functions of the project. These selected team members will also perform different type of design reviews to access the project execution and steering & performing decisive role in successful realization of the project. The design review is performed in a traditional three step process of preliminary, critical and detail design reviews. Former review output if positive is input of later review. To access the overall progress, three type of technical performance measures (TPMs) are set. These TPMs represent the realistic datum for the project. After detail design review allocation of functions to physical elements is carried out by making the facility layout model using the SysML. Creation of a system model necessitates the requirement to identify the interaction of physical elements within the system and with the external system. This interface management is carried out using N2 matrices. Definition of system model elements raises the question of their arrangement in form of facility layout design. Three different alternatives were evaluated through the linguistics evaluation and mathematical modeling to select the most suitable option. For the mathematical modeling, MATLAB code was developed of linear interpolation technique. Risk identification, assessment, prioritization and mitigation is mandatory to make the project successful. A risk assessment model is developed to serve the purpose. In the end engineering development plan is made to define the timelines for different phases of the project. Figure 3.1 depicts the overall methodology adopted to plan the technical facility layout.

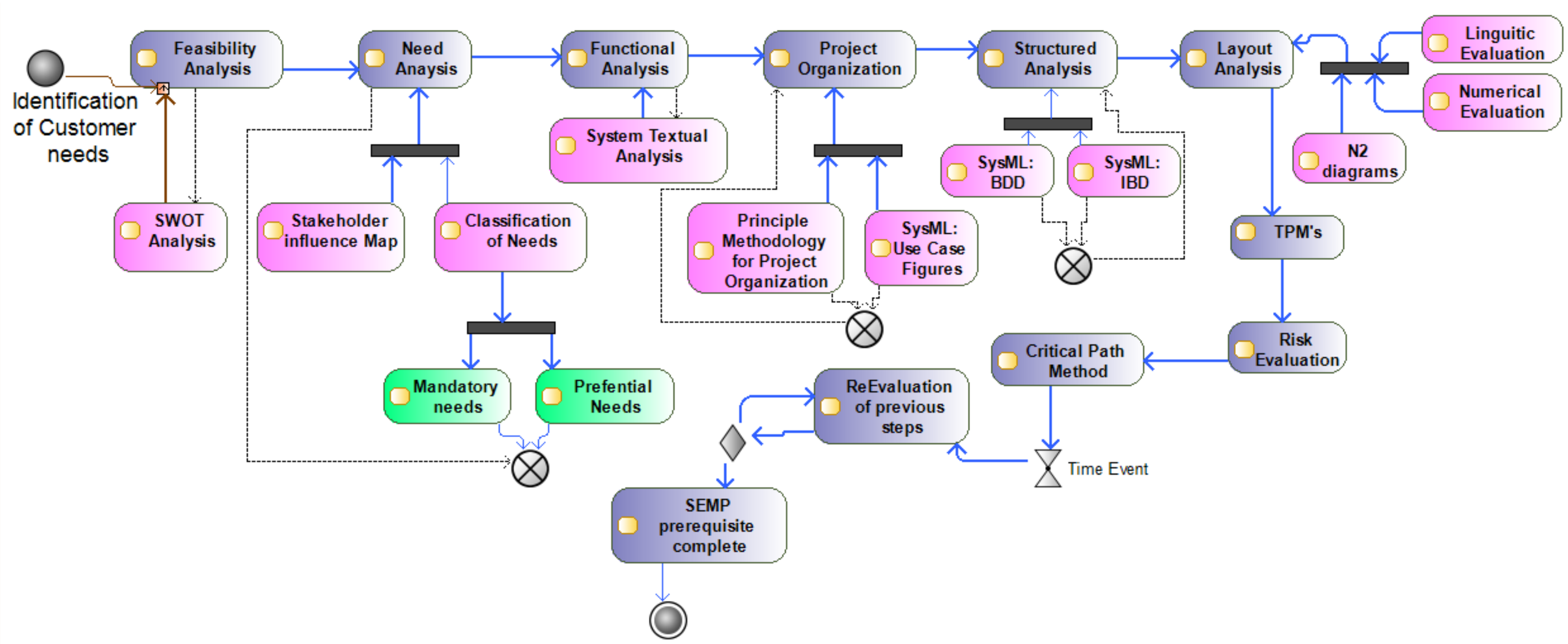

Figure 3.1: : Proposed Methodology

3.2 SWOT Analysis

SWOT analysis is a method that helps to understand an organization's weaknesses, strengths and identifies opportunities and threats. SWOT is basically an analytical framework and a part of planning process that assesses what an entity in form of a business, industry or product can and cannot do, for factors both internal factors (the strengths and weaknesses) as well as external factors (the potential opportunities and threats). A similar analysis has been conducted for the proposed Aviation Engineering Setup to find out its positive aspects regarding its execution and identification of weak areas for further improvement.

3.2.1 Opportunities

Following opportunities for establishing engineering facility are listed below: -

a. Air travel is witnessing tremendous increase especially within Pakistan. International Air Transport Association (IATA) has projected passenger traffic to reach 7 billion by 2034 with a 3.8% average annual growth in demand. This is almost double the 3.5 billion estimated to have travelled in 2015. Based on economic and demographic growth, IATA has projected intra Pakistan air traffic to grow at 9.9% over the next 20 years, more than twice the 4.1% projected annual world growth rate.

b. The introduction of new airlines in Pakistan is also a positive sign for countrys economy and aviation industry in terms of growth and competition.

c. Formulation of National Aviation Policy 2015, tax and duty-free Import of any General Aviation aircraft, maintenance kits and associated parts of aircraft are encouraging steps for growth of local aviation industry.

d. Large scale new inductions in the PAF have opened doors of new business opportunities in the military aviation industry of Pakistan.

e. New Super Mushshak contracts of PAC with Turkey, Nigeria and Qatar and JF-17 thunder have increased opportunities for the growth of local aviation industry as well.

f. Availability of highly qualified and experienced MRO technicians in the country who retire from government military aviation setups every year at relatively young age of around 40 and can be hired at relatively very low costs when compared with international market ($40-80).

3.2.2 Strengths of AES

a. Opportunities of business ventures with PAF/PAC because of increasing outsourcing trend of organization.

b. Proposed top management with very good personal reputation and higher qualifications along with following experience of aviation engineering (particularly MRO).

c. Its HR (technicians) that will be highly qualified, well trained, experienced, disciplined and ability to understand & apply instructions in the English Language.

d. Gaining generic, industry standard, and customer specific quality certifications like: ISO, CAA Pak, ICAO/FAA/EASA to make it an international standard, very high quality, private sector setup in the Aerospace & Defence (A&D) sector in Pakistan.

e. An industry standard ERP system will provide major boost towards success especially for high value business with international customers.

f. Very high-quality services, efficient supply chain, and very competitive prices on account of low paid qualified local HR as compared to International aviation Industry.

g. MRO pricing structures will be maintained at around 20% less than the foreign rates for PAC, PAF, Army Aviation, and other local customers.

3.2.3 Weakness

Achievement of internationally recognized quality certifications is crucial to the success of MRO business.

3.2.4 Threats

a. Negative perception about Pakistan regarding business environment, political instability, and general security state may deter customers.

b. Changes in government policies regarding aviation industry will affect working of AES.

c. Converting thinking patterns of PAF and PAC retired HR, which will form bulk of technical manpower, to match demands of corporate and private sector.

3.2.5 Potential Customers

a. Pakistan Air Force (PAF)

b. Pakistan Aeronautical Complex (PAC) Kamra (along with its own local and international customers)

c. Pak Army Aviation will be next most valuable AEC customers.

d. Other regional and international A&D customers.

3.2.6 Products & Services

a. Maintenance, Repair, and Overhaul of Selected A/C Components.

b. Overhauling of piston engines

c. MRO support for overhauling of jet engines:

d. Aerospace / avionics components assembly & testing line:

e. Indenting of engineering equipment, end-items, and raw materials:

f. Training services in aviation technologies and management:

g. Consultancy services in the A&D sector in Pakistan.

h. Representative status of AMF and other PAC factories:

3.3 Site Selection

The perfect technical site can be envisioned as generally level with some good geographical location having complete utilities, transportation system, and availability of qualified manpower with low wages rates, well connectivity and protection from excessive weather patterns with ample space for development of planned infrastructure having provisions for future expansions if any at economical rates.

A location close to existing Aviation Setup to take advantage of engineering capabilities of setup, clean / secure environment, good civic infrastructure, and possible access to social facilities of the area would be ideal for the development of AES. In this regard three Aviation/Defence sites are short listed for comparison and further analysis.

3.3.1 House of Quality

Quality Function Deployment (QFD) uses a matrix format to capture various issues that are important to the planning process. The House of Quality (HOC) Matrix is the most widely used and recognized format of this method. It translates customer stated needs into an appropriate number of technical requirements and engineering targets to be met by a new product design.

Table 3.1: Site Selection

Factors	**Factor Weightage (0-1)**	**Factor Score (0-100)**			**Weighted Score**		
		PAC	**AWC**	**NDC**	**PAC**	**AWC**	**NDC**
Connectivity	0.1	80	70	65	8	7	6.5
Energy, Transportation & Telecommunication	0.1	80	80	70	8	8	7
Secured Area	0.2	75	70	60	15	17	12
Economical	0.1	75	80	85	7.5	8	8.5
Availability of Space	0.1	85	80	85	8.5	8	8.5
Civic Development	0.05	70	70	60	3.5	3.5	3
Environmental Conditions	0.05	70	75	65	3.5	3.75	3.25
Availability of Utilities	0.1	70	70	60	7	7	6
Availability of Qualified Manpower	0.2	85	65	55	17	13	11

Basically, it is the nerve center and a kind of conceptual map that provides the means for inter-functional planning and communication.
It is generally consisting of six major components. These include customer requirements, technical requirements, a planning matrix, an interrelationship matrix, a technical correlation matrix, and a technical priorities/benchmarks and targets section.
First of all 9 most important customer needs are listed in the customer requirement box. Then a relative customer ranking is determined through relationship table of customer needs. Then these needs are translated in to technical/design requirements to fulfill the customer needs. In next step, a planning matrix is built through a survey by giving weighted importance of each customer requirement for PAC and AWC. Next an interrelationship matrix is built to establish a relationship between the customers requirements and the technical requirements. The technical correlation matrix referred to as the Roof, is established to aid in developing relationships between customer requirements and technical requirements and identifies where these units must work together otherwise they may be in a design conflict. In the end, final value for each technical requirement is calculated to determine the most important design requirements to fulfill the customer needs.

The above HoQ shows that presence of a high quality MRO industry in the vicinity, ease of accessibility, nearby availability of national electrical and gas supply network, high quality social / civic facilities, and good law & order situation are the top 5 requirements for site selection where AES could be made. Huge engineering potential of PAC and provision of its commercial usage, excellent Communication facilities including rail and road Motorway & National highway) links, availability of national electricity and natural gas distribution networks, reasonably good network.

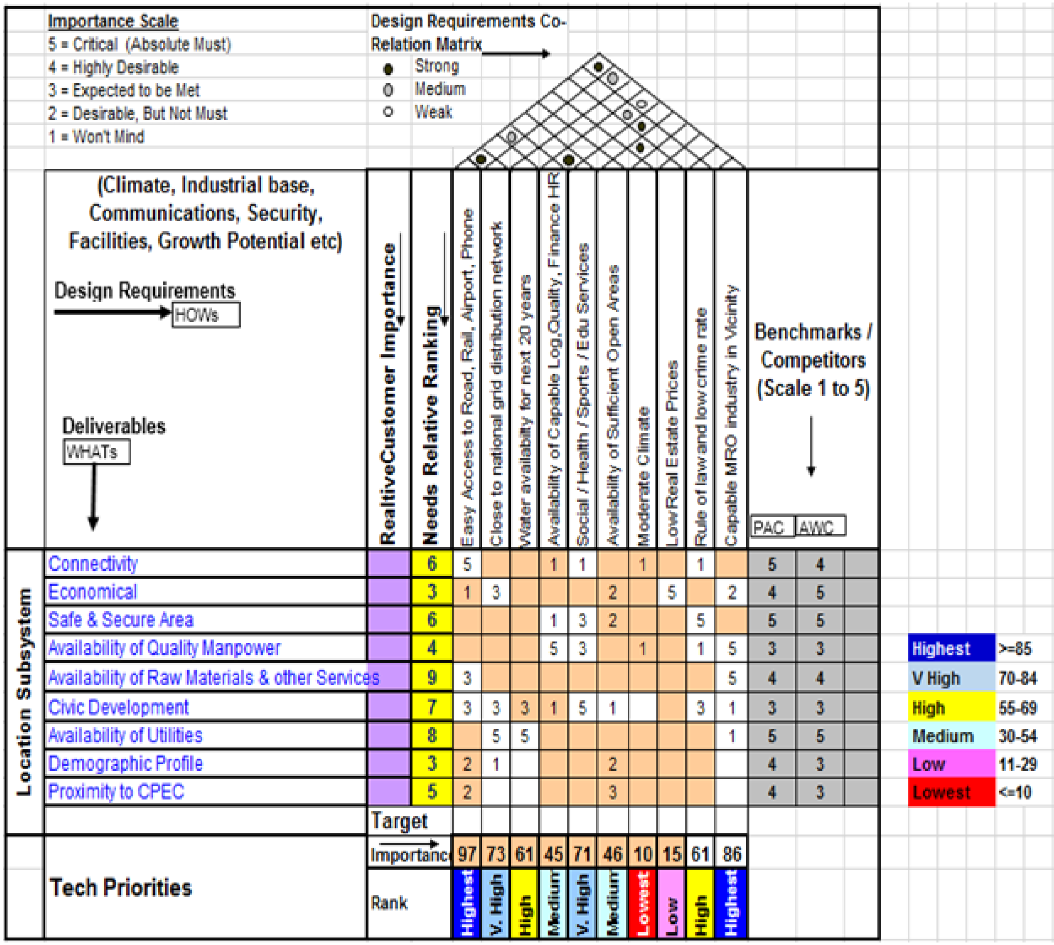

Figure 3.2: : HoQ For Site Selection

Chapter 4

SYSTEM ENGINEERING PROCESSES

The outcome of System Engineering processes chapter is an engineered or technical system that will fulfill the requirements of envisioned system in the feasibility study phase of the project. System concepts, systems thinking and general systems theory provide the scientific foundation that will follow the organized set of activities for bringing the engineered system into being. To execute the complex engineering project, it is necessary to define the requirements of the project through mission requirements analysis.

4.1 Mission Requirement Analysis

The need analysis is carried out in two phases. First Stakeholder Influence Map (SIP) is constructed for identification and grouping of similar stakeholders attached to the project into the same class. In second step, mandatory and preferential requirements relevant to the project establishment and execution are derived from identified classes.

4.1.1 Stakeholder Influence Map

A Stakeholder Influence Map (SIM) is derived from the standard influence map. The tool captures the probable stakeholders related to the project and finds the interactions & influences that exist between different stakeholders and may affect the project execution and operations.

a. **Construction of SIM:** The Stakeholder Influence Map is constructed in four steps:

Step 1 - Brainstorm all probable stakeholders: Figure 4.1 shows the outcome of a brainstorm session of likely stakeholders in the box.

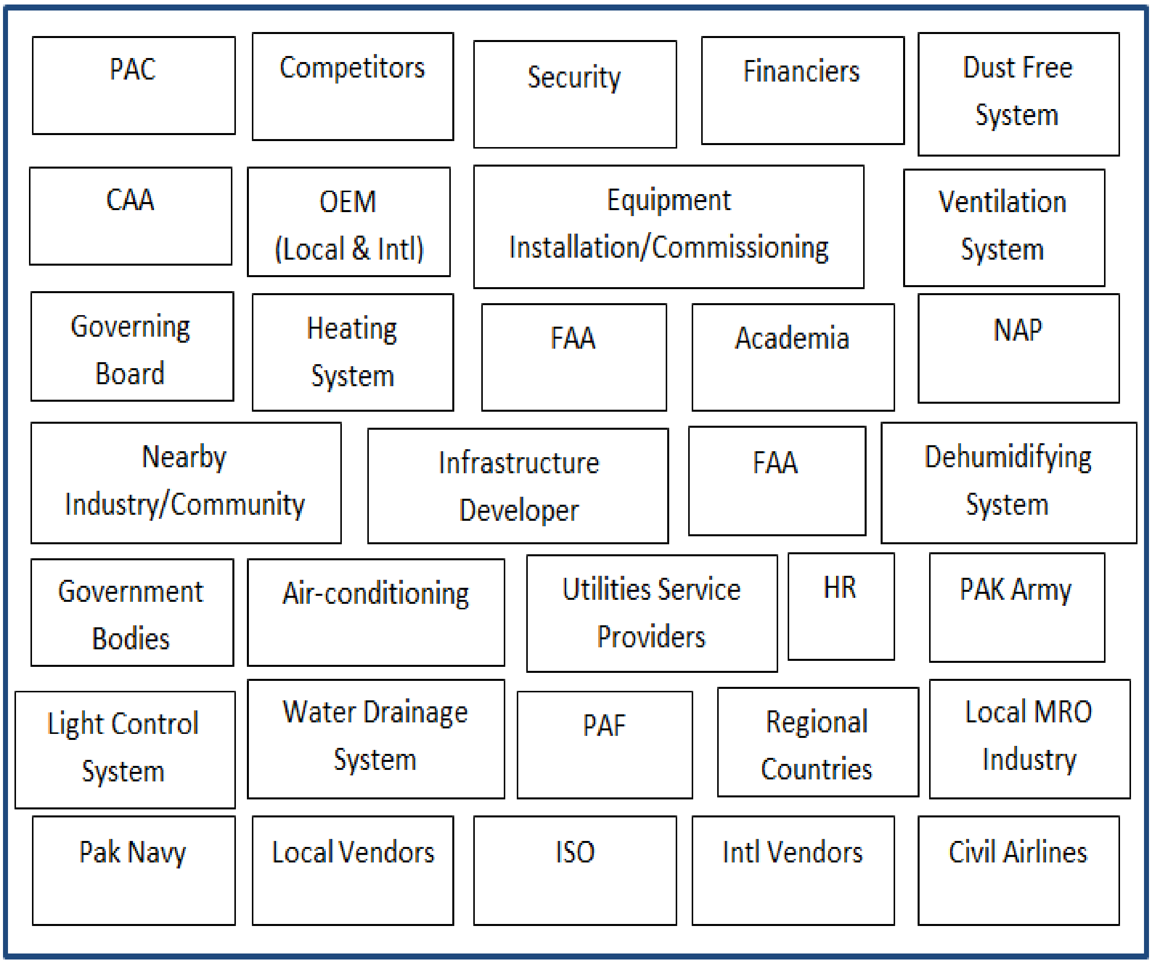

Figure 4.1: : Brainstorming of Potential Stakeholders for AES

Step 2 - Formulate all identified stakeholders into similar groups: Figure 4.2 shows the grouping of various stakeholders identified in step 1. The grouping of stakeholders is carried out between stakeholders having common or similar requirements. Then a suitable name for each group is defined.

Step 3 - Construct Stakeholder Influence Map using the stakeholder groups: Figure 4.3 shows the constructed Stakeholder Influence Map. It represents the likely influences and interaction between the identified stakeholder groups.

Step 4 - Review Stakeholder Influence Map: The purpose of Stakeholder Influence Map is to manage the cost, time and efforts in providing and capturing various stakeholder requirements. It helps to reduce the

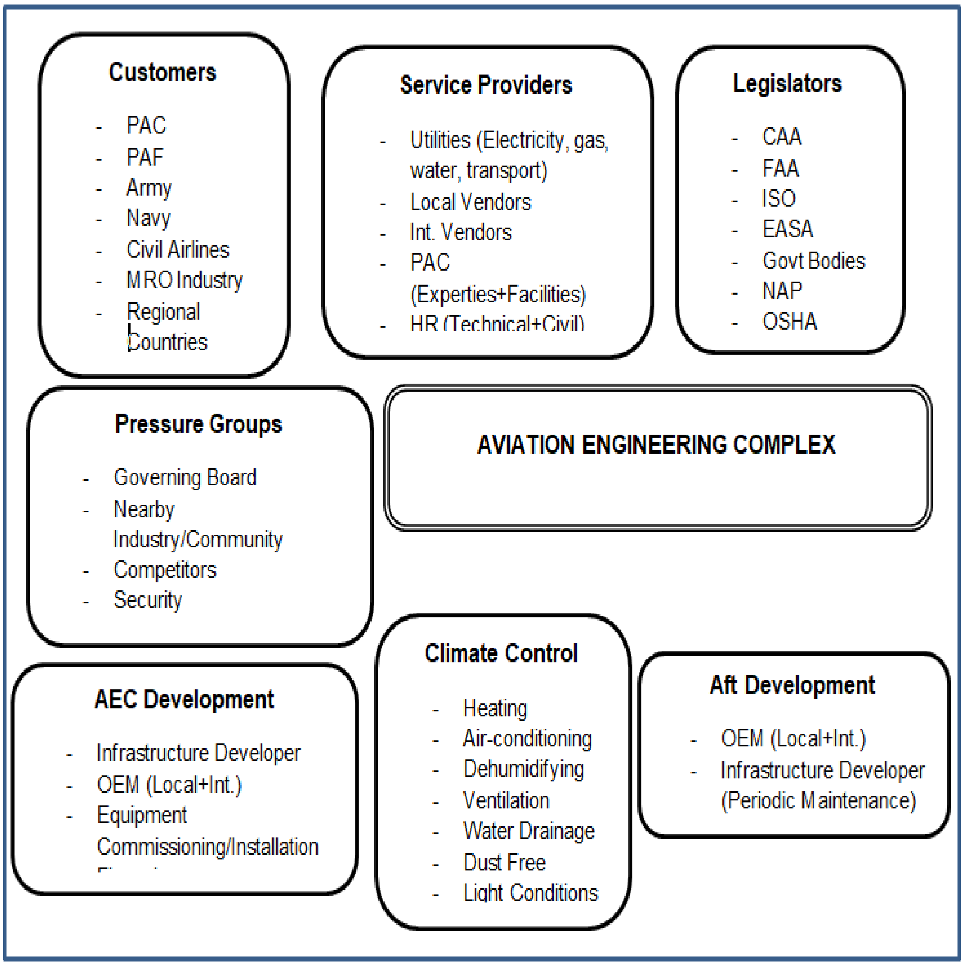

Figure 4.2: : Grouping of identified stakeholders

requirements collecting effort. It also assists the decision makers to decide not to capture requirements from a particular group.

Analysis of constructed SIM revealed that four groups i.e.; Customers, service providers, after development and climate control group will contribute significantly in drawing mandatory and preferential requirements. Whereas AEC development and pressure group will influence the decision-making process of AES management. However, legislator will restrict the overall AEC decision making process.

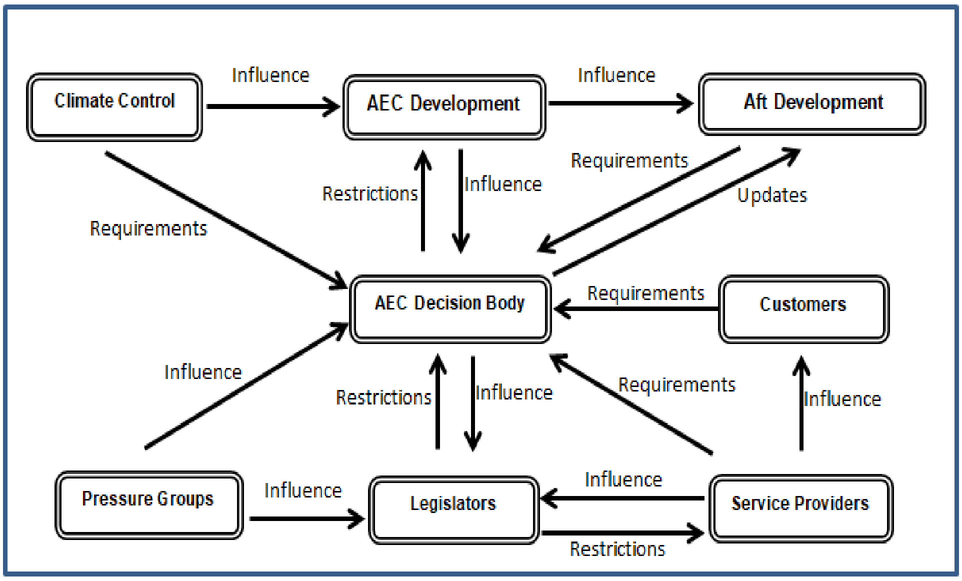

Figure 4.3: : Stakeholder Influence Map

4.1.2 Need Analysis

Establishment of exact system needs is often an arduous process and it was the case with this particular project as well. It took several meetings with the top management of AES and experts from the academia to work out these system needs. Extensive web browsing and e-mail exchanges were also part of this process. These needs may be classified into two categories: -

a. Mandatory Requirements: Mandatory requirements are those effective and necessary conditions that a minimal system shall have in order to be acceptable. (written with words "shall" and "must"). These are specified in definitive terms and are not susceptible to trade-offs between requirements. All alternate candidate designs must satisfy the mandatory requirements. Following are the mandatory user requirements for this project:

Site Selection

i. Following aspects must be considered during site selection for Aviation Engineering Setup (AES):- Well connectivity, security, economical, availability of technical manpower, MRO industry in close proximity, availability of utilities and raw materials, civil development and environmental limitations.

ii. Local building codes, Civil Aviation Association Pakistan, nearby MRO industry and international certification agencies regulations must be considered while planning and implementing the design codes for the said facility.

iii. The site selection, facility design and development must be consistent with the intended functions and be able to adapt facility expansion to accommodate additional facility development in future.

MRO Shops

iv. Avionics maintenance facility must support repair & overhaul, software modification & up-gradation, testing and traceability of radio & radar (Air & ground) components and navigational aids.

v. Instrument shop must support scheduled & unscheduled maintenance, testing & calibration of aircraft instruments.

vi. Electrical shop should have electrical equipment maintenance cell, battery servicing cell for aircraft & ground support equipment components and batteries. Shop must have a storage space, an emergency eyewash and shower station equipped with an alarm system to inform other building staff when the shower/eyewash system is activated. Shop must be facilitated with fume hood.

vii. Piston engine overhaul and test facility should deal with engine components repair & maintenance, engine overhaul & testing, serialized engine parts tracking and storage of lubricants/fuels both for engine shop and mechanical room.

PMEL

viii. PMEL should be equipped to perform calibration, repair/maintenance, cleaning and traceability of equipment requiring calibration. Special consideration regarding vibrations, moisture, north & south directions, dust, temperature and traffic should be kept in mind while selecting the site for establishing the PMEL. PMEL should deal with following performance parameters: Ultrasonic, Vibration, Mass, Pressure, Force and Dimensions.

Harness Manufacturing Facility

ix. The facility should be capable of manufacturing aircraft electrical and avionics looms for a given specification, drawing and pin configuration layout. The facility must perform shielding & conductivity test of A/C looms, cable tests and shielding of looms.

Small parts Manufacturing Facility

x. The facility should manufacture rivets, bolts, nuts, studs, washers, shims, spacers, screws and cam lock screws for a given specification. Facility must comprise of workshop and a separate computer terminal (CAD/CAM) room to communicate design parameters to CNC machines for automatic parts fabrication. This room must be near enough to the workshop to allow efficient communication and cabling between the two nodes.

Assembly Line for Super Mushak Aircraft

xi. The facility must support assembly process of complete Super Mushak aircraft. Trained technical manpower, specialized tools, international standard packaging and vibrant logistics & transportation system must be the backbone of whole process. Attainment & adaptation of quality certifications & less costing as compared to International Aviation industry should be the vital tools for customer attraction and satisfaction.

Indenting & Outsourcing Unit

xii. The unit must provide indenting of end items, raw materials, aerospace equipment and engine components & accessories to local MRO industry. The facility must utilize PAC kamras expertise & facilities to capture regional countries MRO business.

Training & Consultancy Unit

xiii. The unit must train & provide consultancy services in the field of A&D sector to local and international customers.

Support Areas

xiv. Storage area must house bench stock, traffic section, raw materials and hazardous materials. Centrally located storage area must support operations of all shops in the AES and any requirement from the corporate block.

xv. The mechanical room should include Heating, Ventilation, Air-Conditioning (HVAC) and Fire Protection System (detection/prevention/alarming) equipment.

xvi. The electrical room should include wiring, receptacles, distribution equipment, grounding, interior and exterior lighting, emergency lighting, controls and standby power generation system. It must be able to provide 28VDC, 220 VAC (50 Hz) and 115 VAC (60 Hz) at the required workshops.

xvii. The communication room should house commercial telephone, intercom and local area network (LAN), internet and wireless network equipment and services. The room should also equip with main server for ERP.

xviii. A central tool store (CTS) and technical library should support tools storage, tools inspection, tools repair/replacement, technical publications and automatic tracking of tools & publications

MISC Requirements

xix. The facility must have a proper ramp for loading/offloading the items to accommodate truck bed height and permit direct drive-in access.

xx. The facility must have small fork lifter, specialized for warehouse inventory and transportation among facilities.

xxi. Uninterrupted power supply for computer terminals for whole AES offices and workshops.

xxii. A slip/chemical resistant coating system must be integrated into floor finishes.

xxiii. Furnishing of maintenance shops with task lights for safe & effective maintenance practices.

b. Preferential Requirements: Following are the preferential requirements.

i. Facilities may be equipped with RFID and Biometric systems to ensure safety measures.

ii. Facilities may be equipped with surveillance cameras.

iii. The facility may utilize solar energy for lighting, HVAC and general-purpose equipment.

iv. Facility may be provided with centralized rectifier for the whole facility.

v. The facility may be provided with towing tractor to support equipment transportation operations.

vi. Domestic fire tender (DFT) may be provided in case of emergency.

vii. Keeping in view the proposed maintenance facility, certifications accreditations and experienced HR in Aviation field, AES may offer Specialist Diploma in Aircraft Maintenance and Engineering (SAME) field having duration of 1 year for local & international students.

4.2 Systematic Textual Analysis

Systemic Textual Analysis (STA) basically analyses the mandatory and preferential customer requirements for interpreting, clarifying & expanding and identifying missing requirements. This approach is adopted to identify deficiencies and omissions during the need analysis by expanding the identified requirements into system, functional, non-functional and implementation requirements.

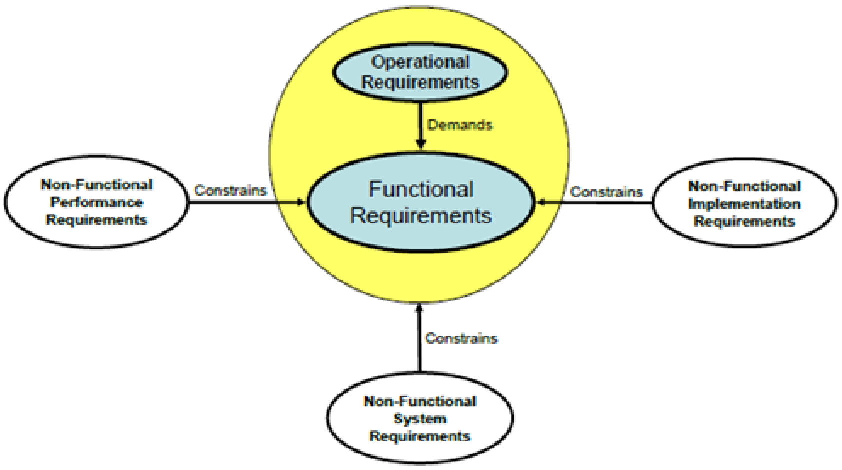

Figure 4.4: : Decomposition of Customer Requirements

4.3 Functional Analysis

A function is a discrete action or series of actions or operation that the system has to perform to achieve a predefined goal, objective or mission. During the STA, nine major functions are identified for the successful realization of technical complex. Figure 4.5 describes these functions. Next step was to determine that what needs to be skilled and how it should be accomplished. Functional analysis decomposes the system level functions into subsystem and component level functions to determine the people, equipment, software, facilities and data or combination of any.

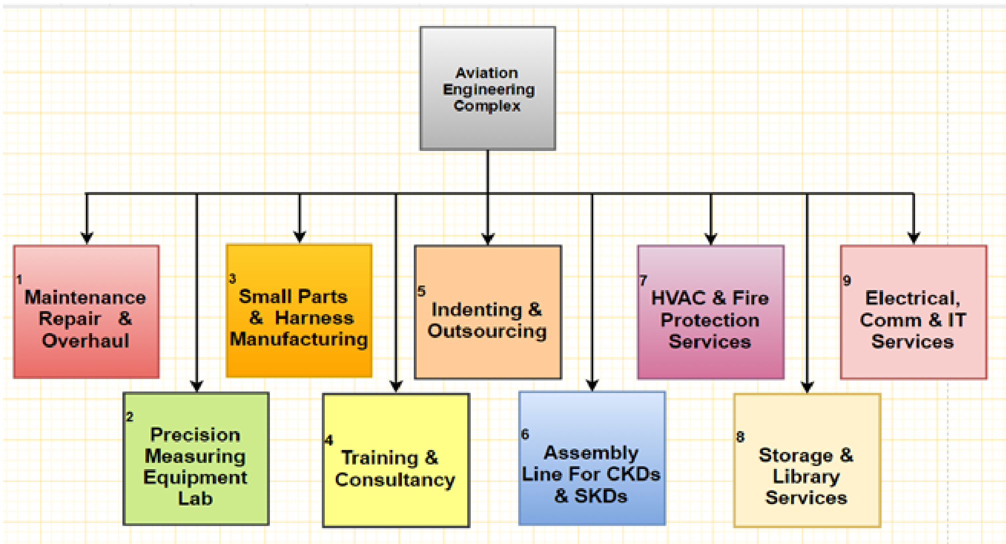

Figure 4.5: : Major Functions Identified in STA

Sixteen different but interrelated sub functions are identified for the successful execution of MRO function. Establishment of MRO unit will require identification of customer needs, requisite infrastructure, tools & testers and HR requirements. Analysis also catered the safety, IT and supply support considerations. Analysis also proposed the customer feedback mechanism to improve the customer schedule effectiveness.
Most of the functions identified for MRO would be required for PMEL including special considerations for site selection and special construction requirements. Analysis covers the complete life cycle of the equipment with special emphasis to the periodic maintenance and calibration of the equipment.
SP & HM unit establishment is divided into six segments starting with the identification of parts to be manufactured, their production process plans, training of HR and equipment installation and acceptance.
T&C unit will provide consultancy and training services to various local and international customers of A&D sector through highly qualified and experienced staff from the industry.
I&O unit has two sub-units i.e; Indenting for supply of engineering end items,

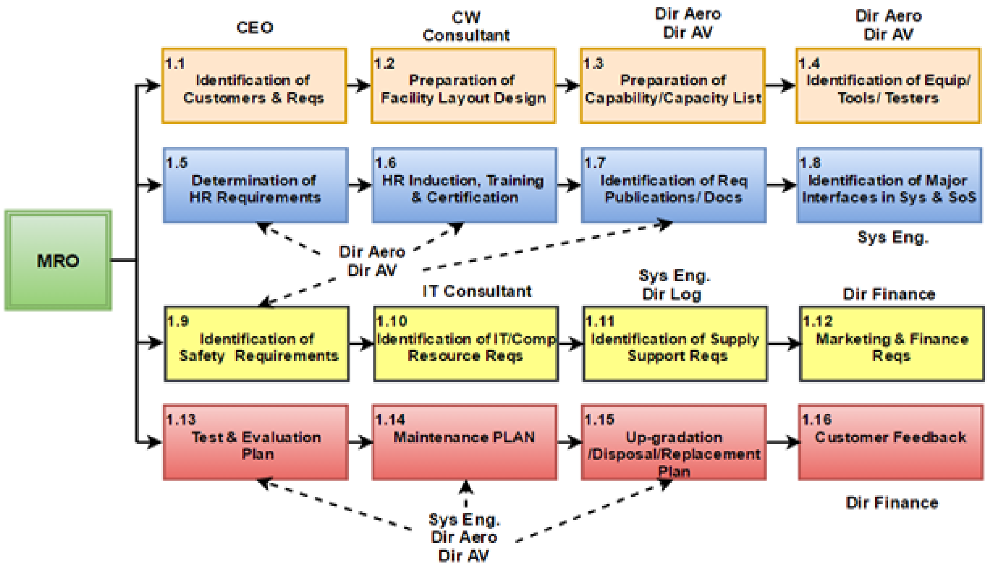

Figure 4.6: : Functional Analysis of MRO Unit

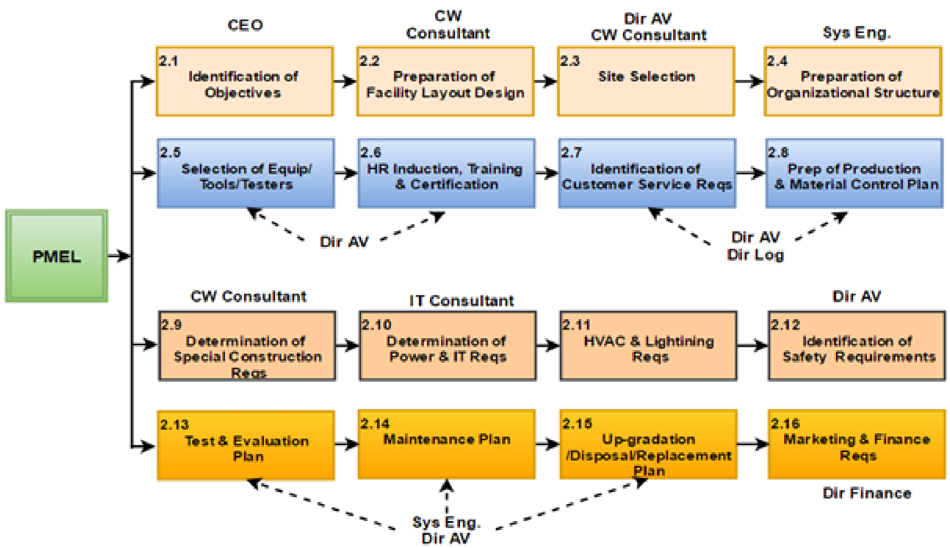

Figure 4.7: : Functional Analysis of PMEL Unit

spare parts, raw material to local and international customers as vendor whereas production requirements will be outsourced to PAC Kamra.
AAL unit will deal with the assembly of light aircrafts such as Super Mushak manufactured by PAC Kamra and aircraft of the same type available for commercial and hobby flying.

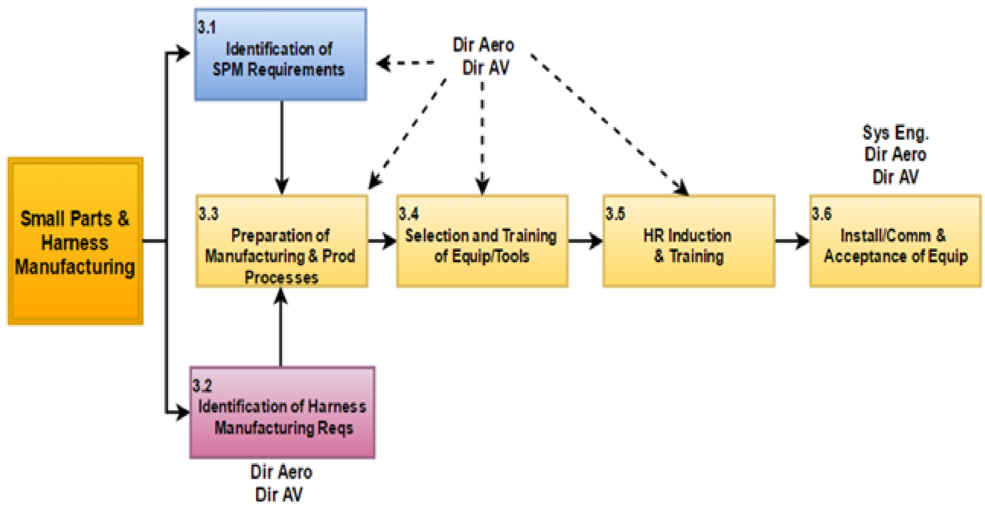

Figure 4.8: : Functional Analysis of SP&HM Unit

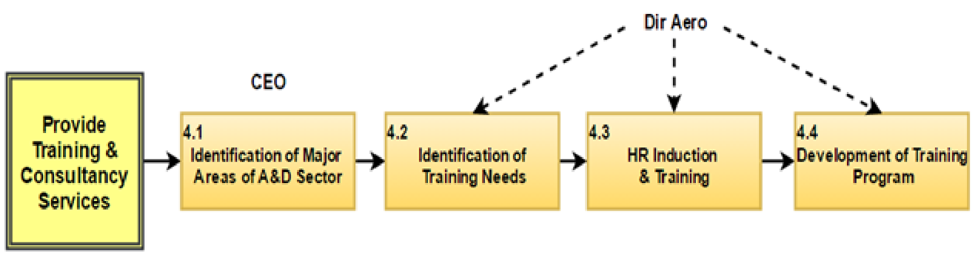

Figure 4.9: : Functional Analysis of T&C Unit

The last two analysis covers the establishment of HVAC, fire protection system, library, storage area, IT and communication services for the AES.

4.4 Technical Programme Planning & Control

Technical program planning describes the organization structure, their responsibilities and the execution of various types of system reviews through the appropriate combination of organization team members.

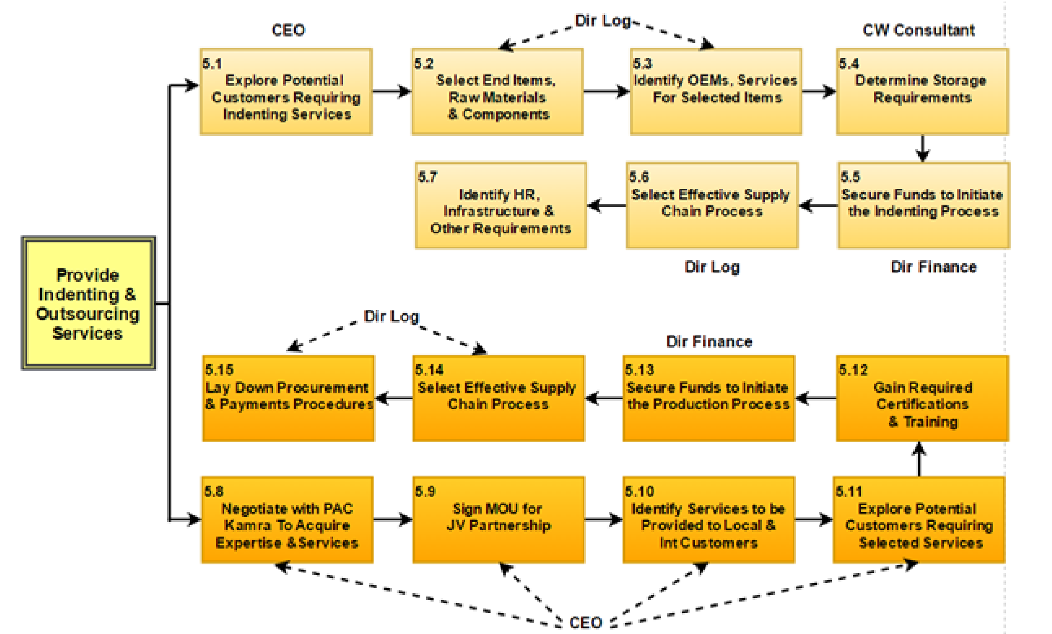

Figure 4.10: : Functional Analysis of I&O Unit

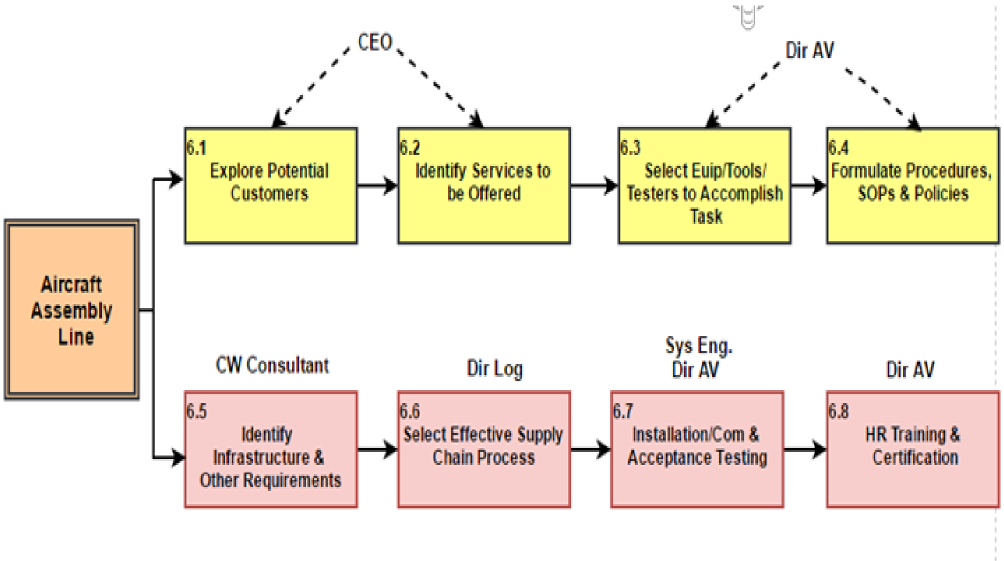

Figure 4.11: : Functional Analysis of AAL Unit

4.4.1 Project Organization

The organizational chart of the project is quite unique where Project Manager through 04 different directors having specialty in their respective fields

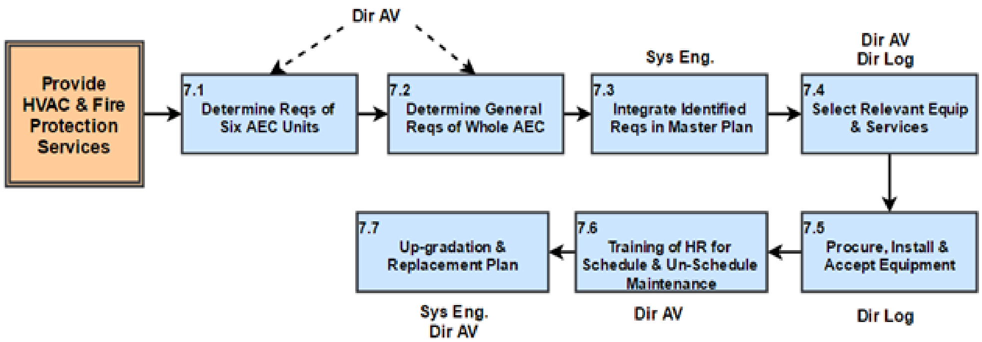

Figure 4.12: : Functional Analysis of HVAC Unit

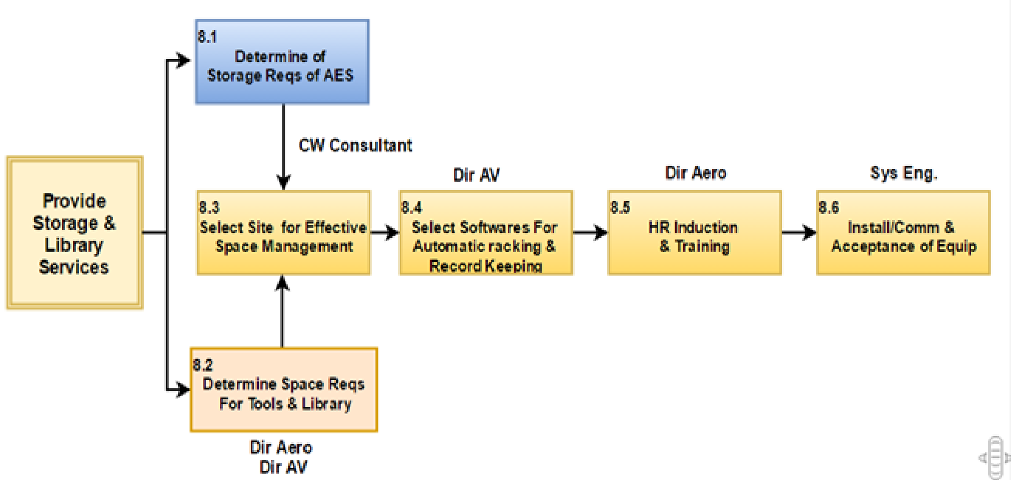

Figure 4.13: : Functional Analysis for Allied Facilities

will manage the development of AEC. In addition to directors, Information Technology and Civil Works consultants will render their expertise for the successful planning and execution of the project. Keeping in view the involvement of various engineering disciplines and complexities of the project, inclusion of System Engineer in the team is deemed necessary which will not only integrate the individual sweats into a coordinated team effort but also look after the important interfaces in the system of systems (SoS) context. The project organizational structure is given below:
In early phase of the project, SE activities are system level and highly focused. Therefore selection of few key personnel with appropriate skills and experience levels would be good enough. However, organizational structure

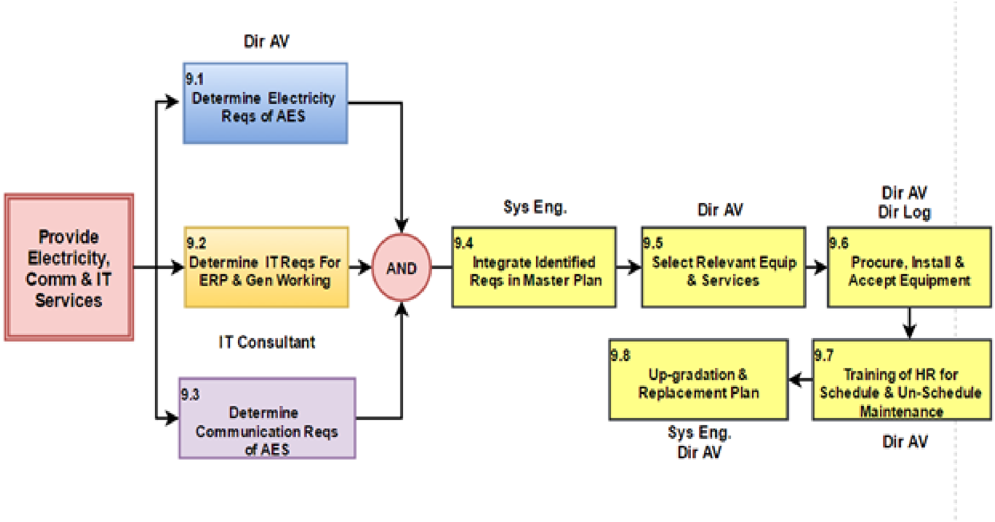

Figure 4.14: : Functional Analysis for Utilities

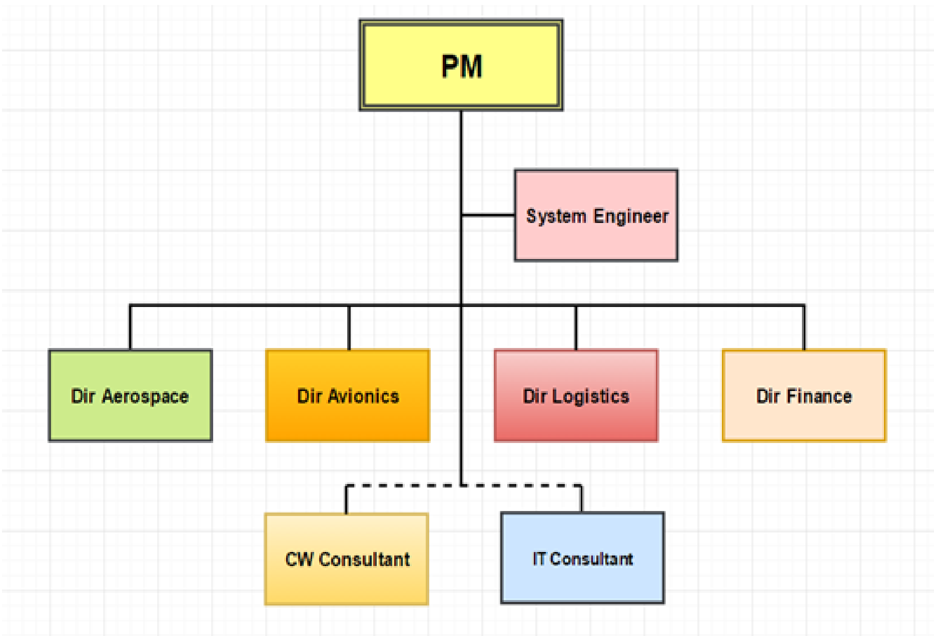

Figure 4.15: : Project Organization for Execution

and numbers will vary during the operations of AES. Matrix Organizational structure would be followed in later stages as each unit will work on the principal of being independent but mutually supportive entity. The project organizational structure in latter stage is given below:

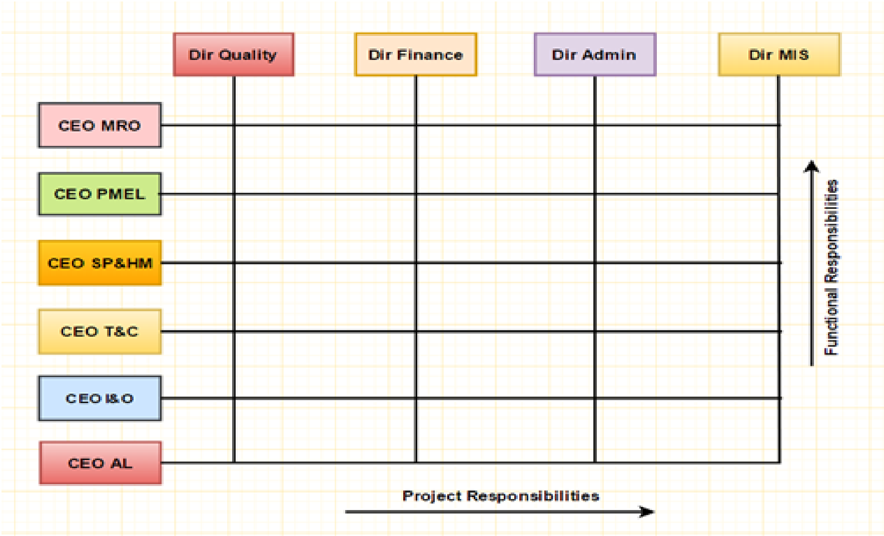

Figure 4.16: : Functional Project Organization

4.4.2 Authorities And Responsibilities

The authorities and responsibilities of the main players involved in this project are narrated below:

a. Project Manager: PM will be the final authority in all matters pertaining to decisions regarding development and will also be the chief arbitrator to decide any disputes among different directors. He will be responsible to formulate qualified and experienced team as mentioned earlier and generate adequate funds from local and foreign investors for the project execution. His other domain areas include:

i. Identification and selection of potential customers for MRO, PMEL, Assembly Line, Indenting and Outsourcing business.

ii. Selection of Aerospace and Defence sector fields to be offered to various customers for Consultancy and Training services.

iii. To negotiate with PAC Kamra to acquire their expertise and facilities regarding Outsourcing business.

iv. Signing of MOUs with PAC Kamra to finalize the joint venture business.

v. He will also support a number of activities including marketing, promotion, delivery and quality of programs, products and services, financial, tax, risk and facilities management, human resource management, community and public relations.

b. System Engineer: System Engineer plays a decisive role in guiding

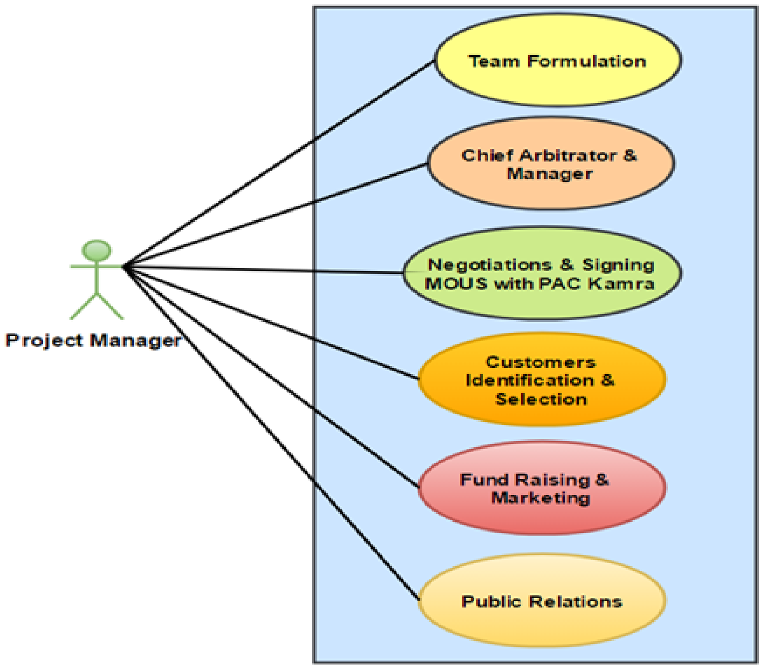

Figure 4.17: : Responsibilities of Project Manager

complex projects starting from conception to completion by managing the diverse disciplines and specialty groups. His responsibilities for the proposed project are:

i. Definition of User Requirements.

ii. Preparation of organizational structure of AES (Execution & Operations).

iii. Identification of major interfaces within a system and Systems of System.

iv. Preparation of preliminary and detailed planning documents.

v. Identification & Integration of safety requirements into the planning documents.

vi. Ensure successful completion of equipment Installation, commissioning and acceptance phases.

vii. Preparation of equipment modification/up-gradation, disposal and replacement plans.

c. Director Aerospace: Dir Aero along with Dir AV will be the Officer of Prime Importance (OPI) for the execution of this project. He will decide the User Requirements. He will also be the main advisor to PM on matters

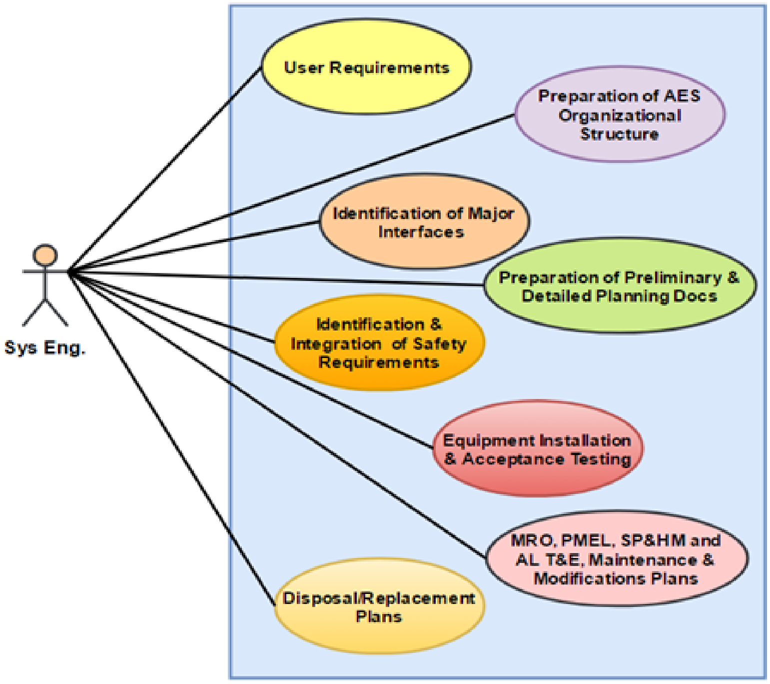

Figure 4.18: : Responsibilities of System Engineer

pertaining to equipment, technical performance measures (TPM), and figures of merit (FOM). His other responsibilities include:

i. Preparation of capability/capacity list for MRO unit.

ii. Identification of Small Parts and Harness manufacturing requirements.

iii. Identification of equipment/tools/testers for MRO, Small Parts and Harness manufacturing units.

iv. Identification of training needs and development of training program for Training & Consultancy unit.

v. Determination of requirements for central tool store and tech library.

vi. Determination of HR requirements and preparation of HR induction, training and certifications plans for MRO, Training & Consultancy and storage facilities.

vii. Preparation of test & evaluation, maintenance and Up-gradation/modification plans for MRO unit.

d. Director Avionics: Dir AV along with Dir Aero will be the Officer

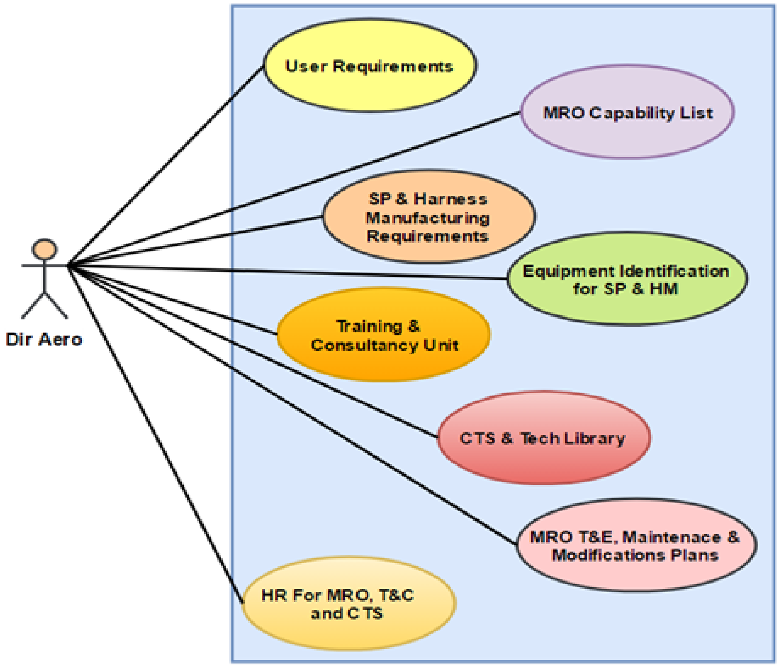

Figure 4.19: : Responsibilities of Director Aerospace

of Prime Importance (OPI) for the execution of this project. He will decide the User Requirements. He will also be the main advisor to PM on matters pertaining to equipment, technical performance measures (TPM), and figures of merit (FOM). His other responsibilities include:

i. Preparation of capability/capacity lists for MRO and PMEL units.

ii. Identification of Small Parts & Harness manufacturing requirements.

iii. Identification of equipment/tools/testers for MRO, PMEL, Small Parts and Harness manufacturing and Assembly Line units.

iv. Identification of customer service requirements and preparation of production plans for PMEL and Assembly Line unit.

v. Determination of requirements for central tool store & tech library and relevant software for automatic tracking of tools and documents.

vi. Selection of equipment and HR training for HVAC & fire protection services.

vii. Determination of HR requirements and preparation of HR induction, training and certifications plans for MRO, PMEL and Assembly Line Units.

viii. Preparation of test & evaluation, maintenance and Up-gradation/modification plans for MRO, PMEL, Small Parts and Harness manufacturing and Assembly Line units.

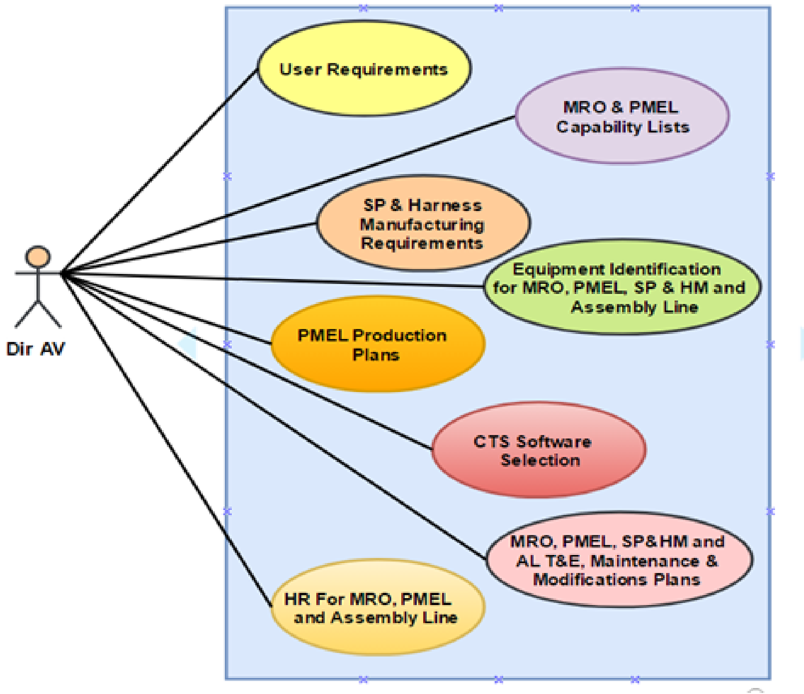

Figure 4.20: : Responsibilities of Director Avionics

e. Director Logistics: Dir Log having logistics experience in PAC/PAF with hands on experience of any Automated Logistics Management System will be responsible to create policies & procedures for logistics activities. His additional responsibilities are:

i. Determination of spare support requirements for MRO & PMEL for effective implementation of material flow management systems to meet production requirements.

ii. Identification of raw materials, end items, engineering components and engine accessories to be offered to local and international customers.

iii. Identification of OEMs and service providers for procurement of selected items.

iv. Procurement of Equipment for 06 units, HVAC, IT, Electric and fire protection system is the responsibility of Dir Log.

v. Definition of supply chain process for MRO, PMEL, Assembly Line and Indenting & Outsourcing units.

vi. Lay down procurement and payment procedures for outsourcing business with PAC kamra.

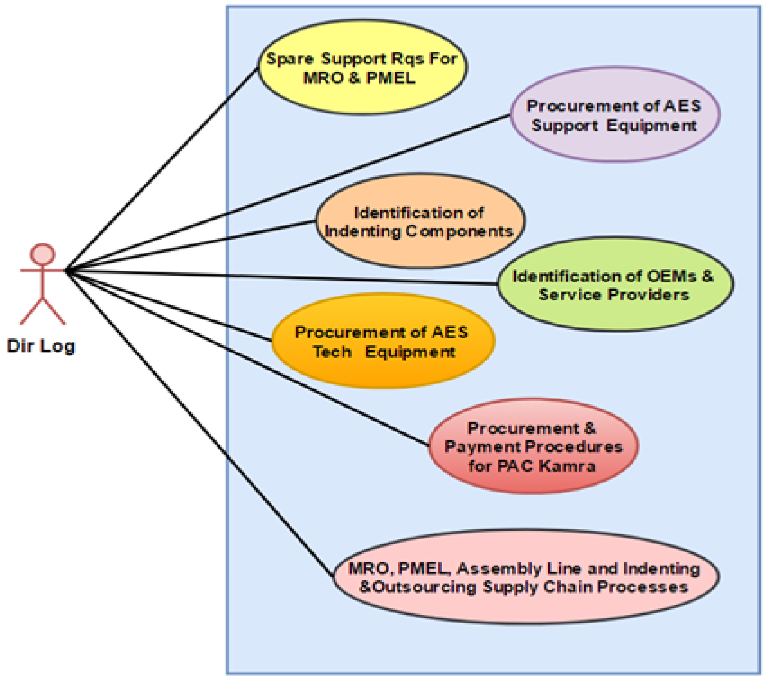

Figure 4.21: : Responsibilities of Director Logistics

f. Director Finance: The finance director having corporate sector experience will be responsible to manage funds in coordination with PM for the execution of the project. He will also secure funds for 1 year for startup of AES operations. In addition to this, securing funds for Indenting & Outsourcing will be the main focus area for the director. The director will also device marketing and customer feedback strategies for the AES.

g. CW Consultant: CW consultant is responsible to prepare facility layout of complete AES. He will also consider special construction requirements for special facilities. He will also determine storage requirements required by different units.

h. IT Consultant: The IT consultant will be responsible to determine the overall IT & Computer resource requirements of 06 units of AEC, IT infrastructure, installation and operations. He is also responsible for the development of an effective planning process, for the creation of an integrated project schedule that incorporates all aspects for the ERP Program and for the actual execution in conformance to plans and the continuing update and adjustment of plans and execution to accommodate changing circumstances. He is also responsible to set deadlines, assigns responsibilities, and monitors progress for the ERP system.

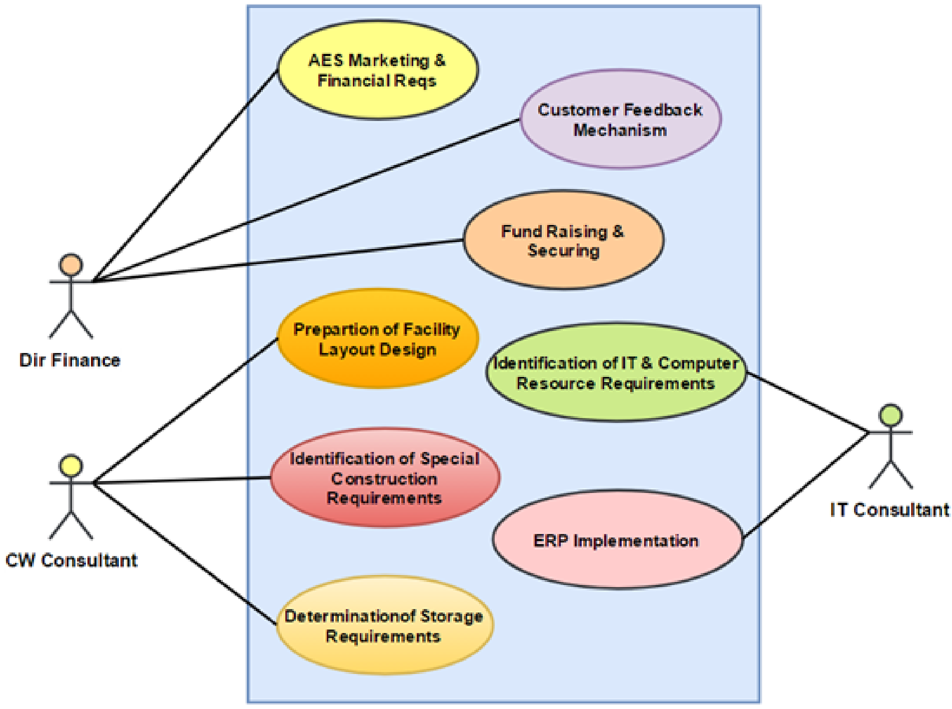

Figure 4.22: : Responsibilities of Director Finance, IT & CW Consultants

The figure 4.23 gives the visual depiction of overall common responsibilities of the project organization identified at the start.

4.4.3 Programme Reviews

Two types of reviews will be conducted during the planning and execution phases of this project. These are Informal and Formal Design Reviews (FDR). FDR is further classified into Critical Design Review (CDR) and Programme Management Reviews (PMRs). Informal Design Review will be conducted by the respective director and system engineer team on day to day basis. CDR will be chaired by Project Manager and conducted just prior to approval of the detailed planning and start of the execution phase. This will be a totally in house affair of the AES.

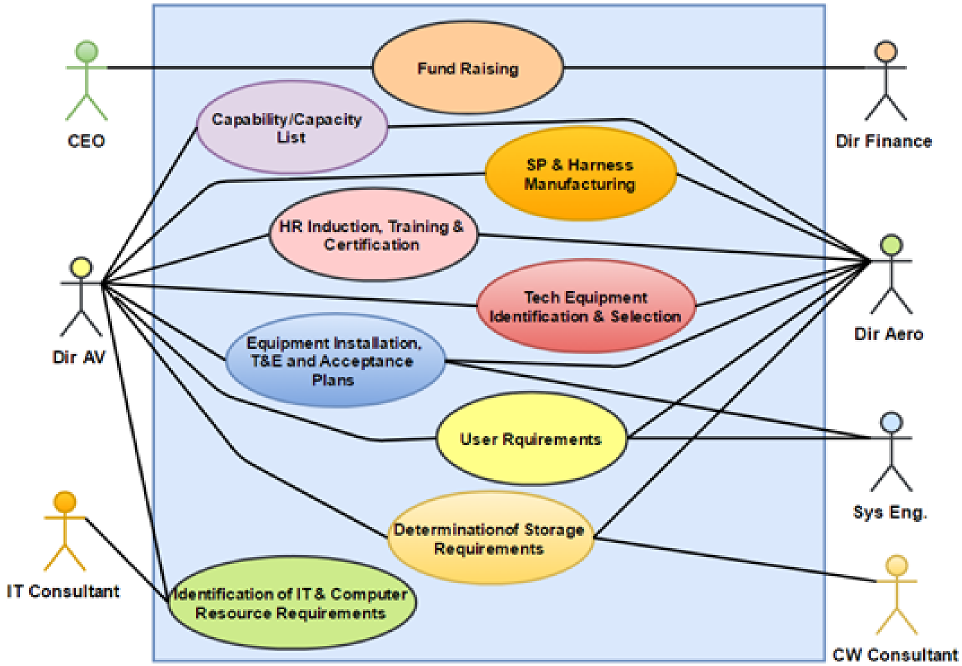

Figure 4.23: : Common Responsibilities

Regular fortnightly PMRs will be conducted during the execution phase of the project. These meetings will provide AES management and the vendor the opportunity to discuss any questions or issues identified in the programme implementation or any recent changes to the programme or configuration. All these reviews will be chaired by PM AES and also attended by the respective directors, consultants and contractors involved in the project execution phase. Following process diagram explains the complete process of reviews.

4.5 Technical Performance Measures

Technical performance measures (TPMs) access the attributes of a system element to determine how well a system element or system is expected to satisfy or satisfying the predefined technical requirements or goals. For the thesis work, TPMs are divided into three categories described below: -
TPMs are categorized into three types. First type will assess the overall project performance, second type will highlight various TPMs related to op-

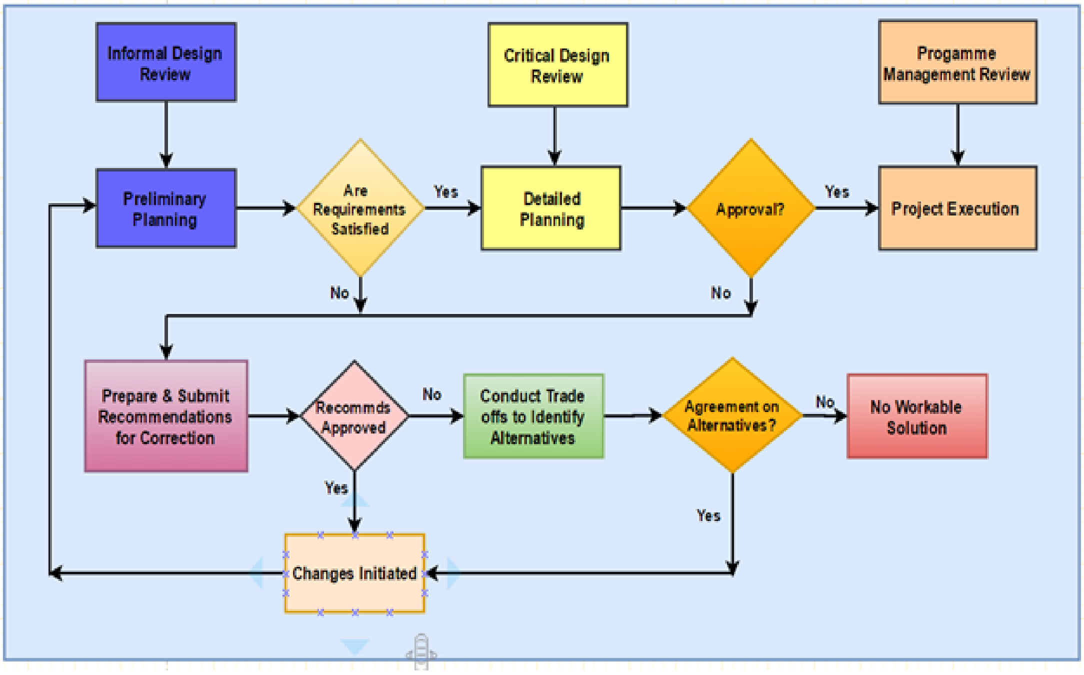

Figure 4.24: : Programme Reviews

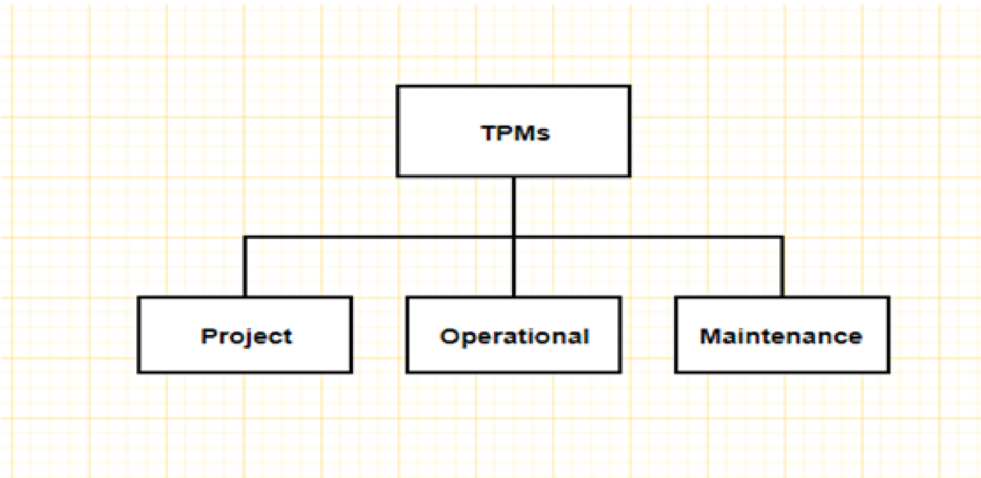

Figure 4.25: : Type of TPMs

erations of technical complex and the last type will deal with the maintenance activities. Project related TPMs are described below:

a. Establishment of technical complex should be completed within an estimated cost of US$ 3.02 Million. This estimation includes cost of infras-

Table 4.1: Technical Performance Measures

S No	TPM	Formula	Acceptable Threshold
	Operations		
g.	Customer Scheduling Effectiveness (CSE)	$CSE = \frac{TotalScheduledCommitments}{TotalCustomerRequests} \times 100$	$> 80\%$
h.	Maintenance Scheduling Effectiveness (MSE)	$MSE = \frac{TotalAccomplishedTasks}{TotalScheduledTasks} \times 100$	$> 80\%$
i.	Dispatch Reliability (DR)	$DR = \frac{OnTime}{TotalDeliveries} \times 100$	$> 95\%$
j.	Technician Availability Rate (TAR)	$CSE = \frac{AvailableTechnicians}{TotalEmployedTechnicians} \times 100$	$> 90\%$
	Maintenance		
k.	Mean Time Between Failures (MTBF)	$MTBF = \frac{TotalAvailableTime}{TotalNumberofFailures}$	May be determined from OEMs data sheets
l.	Mean Time to Recover (MTTR)	$MTTR = \frac{TotalDownTime}{TotalNumberofFailures}$	Economical and reduced MTTR with downward trend
m.	Excess in Inventory (EI)	$EI = \frac{TotalnumberofItemsnotissuedfor12months}{TotalNumberofAssets} \times 100$	$> 5\%$
n.	Mean Supply Response to Time (MSRT)	$MSRT = \frac{TotalSupplyResponseTime}{TotalNumberofSupplies}$	Economical and reduced MSRT with downward trend
o.	Inventory Accuracy Rate (IAR)	$N = \frac{TotalNumberofOverandShortItems}{TotalNumberofBalancedInventory}$ $IAS = (100 - N)\%$	$> 95\%$

tructure, equipment, ERP and quality certifications. Additional cost of 20% as risk factor and 10% for unforeseen contingencies has also been included in cost estimates.

b. Project must be completed within 21 months.

c. Technical complex should occupy an area of 20,000 Sq Ft with a provision to accommodate the future expansion if required.

d. Installation of safety/support equipment inside AEC facilities & their serviceability must be ensured in accordance with international health, safety & environmental standards.

e. Facility must include storage area, library and central tool storage with automatic tracking system.

f. Facility must include fuel/lubricant and battery storage area separate from the main facility to ensure the overall safety of equipment and personnel.

Operational and maintenance TPMs are tabulated below with requisite formulas to compute and respective threshold to access the overall performance of MRO technical facility.

4.6 System Modeling

Exploring and defining of system concepts have now formalized with the advent of system modeling languages such as UML, SysML and a new subclass of systems engineering and systems architecting has formed from obscurity to significance. In other words, the system architecture can be used to represent system model or the system concept. Models are developed to explore any viable alternative concepts. System models can be in the form of mathematical models, computer simulations, flow diagrams or block diagrams etc. The SysML (block definition and internal lock diagrams) are used to develop the conceptual model of technical facility for AES. MRO unit is divided into Production Cell, Avionics Shop, Instrument Shop, Electric Shop, Engine Shop and miscellaneous shops. MRO unit will perform independently with its own focused quality, marketing and finance setup. PMEL Unit having four subsections will perform calibration of A&D sector equipment. The other four units are training and consultancy, Indenting and outsourcing, small parts and harness manufacturing and assembly line for Super Mushshak aircraft. System model also includes centralized storage area, tool store, technical publication library, communication, mechanical and electrical rooms. These units with the proposed subsections will work independently and mutually supportive for each other.

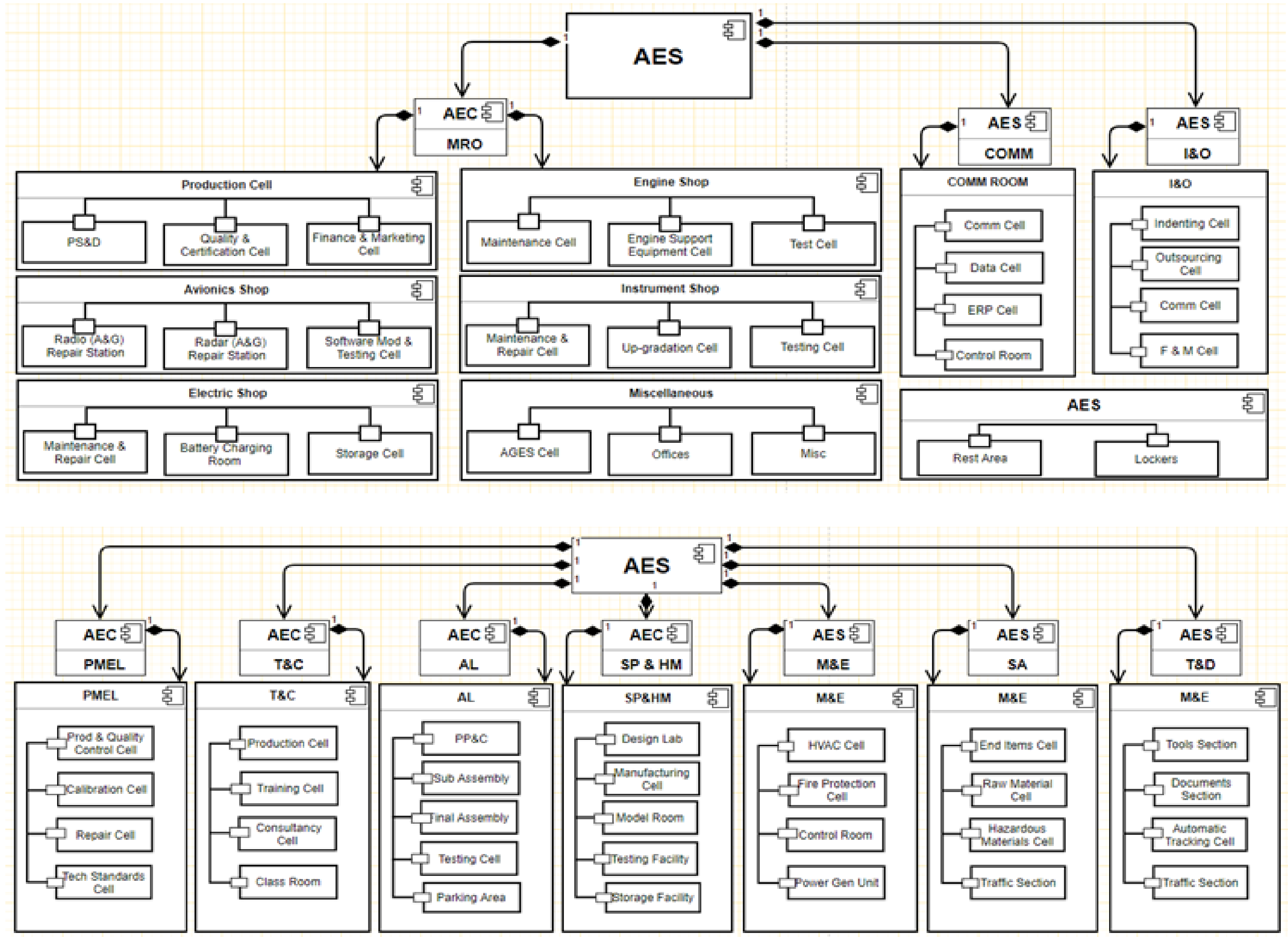

Figure 4.26: : AEC Model Using SysM

4.7 Interface Design And Management

An interface is a boundary or point of contact between entities working for a common purpose or project. The point can be organizational, physical, contractual, functional or resource. Interface Management is a practice that is intended to establish a process to manage the key interfaces that are identified during the planning and execution of the project between system, its subsystems and with the external systems. Interface Management is also a risk mitigating process.
The tool used for the process is N2 diagram that uses a nxn matrix to record the interconnections between different elements of a system. The system behaviour is mainly determined by the interconnectivity of the elements of that system particularly planning for complex systems. N2 Analysis helps to identify the natural interfaces that exist in all systems and latterly exploit this in determining the most suitable architectural design or to understand and analyze the behaviour of existing systems. In N2 diagram, system elements are on the leading diagonal. These system elements have inputs and outputs. Whereas outputs of each element are mentioned in rows and inputs are contained in the columns. External Inputs to the respective element are shown within each element box.
Keeping in view the AEC model, entire process is divided into three phases: -

a. AEC interfaces with the external systems
b. AEC interfaces with the corporate sector of AES
c. Internal interfaces within different units of AEC

4.7.1 AEC & External Systems Interface (SoS)

Six external stakeholders/functions were considered while identifying the external interfaces of AEC in the system of systems context. These are: -

a. National & International Customers
b. Utility Services
c. Local & foreign Suppliers
d. Legislators as mentioned in SIM
e. Custom Services
f. Shipping & Transportation

The type of data, products and services exist between these identified interfaces are: -

a. Requirements initiated by the customers for AEC and from AEC (R)
b. Product & services offered by AEC and required by AEC (PS)

c. Utility services required by AEC (US)
d. Financial Transactions (F)
e. Rules & regulations required to acquire a product or service (RR)
f. Shipping & Transportation services (ST)

Customized N2 diagram representing the interfaces between AEC and external stakeholders & functions is added below.

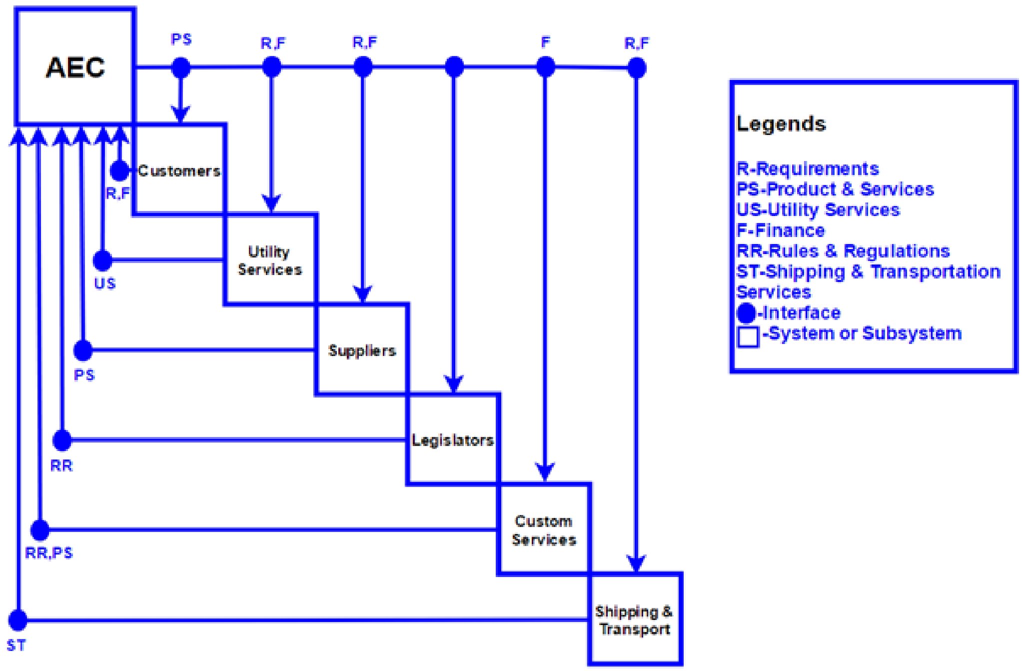

Figure 4.27: : AEC and External Systems Interface

4.7.2 AEC & Corporate Sector Interfaces

Five corporate sector departments were considered while identifying the interfaces of AEC with the corporate sector. These are: -

a. Human Resource department
b. Quality Certifications department
c. Enterprise Resource Planning department
d. Administrative department
e. Finance & Marketing department

The type of data, products and services exist between these identified interfaces are: -

a. Requirements initiated by AEC (R)
b. Recruitment & Training of required HR (RT)
c. Utility, transportation, civil works and maintenance services (US)
d. Finance & marketing services (FM)
e. Financial Transactions (F)
f. Certification and Training (CT)
g. ERP operations and support services (OS)

Detailed N2 diagram depicting the above-mentioned interfaces between AEC and different departments of corporate sector is appended below.

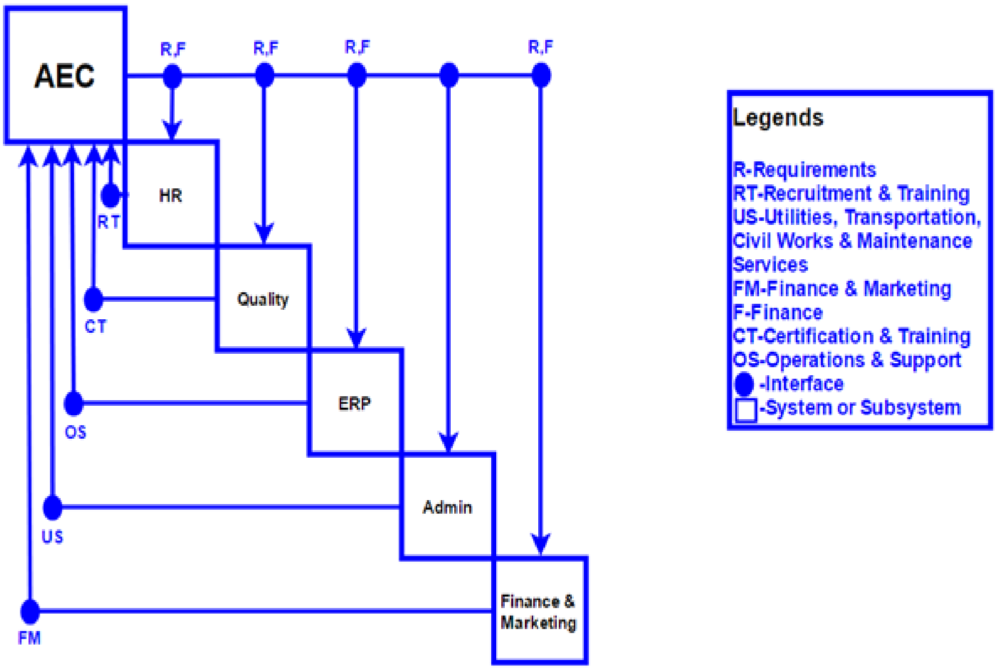

Figure 4.28: : AEC and Corporate Sector Interfaces

4.7.3 AEC Units Interfaces

In third phase, interfaces among six units of AEC are identified. During the identification process 4 internal and 3 external inputs were considered. The internal interfaces are: -

a. Electrical, telecommunication and IT interface will connect all six units for active & standby power, intercom & landline communication and IT infrastructure for ERP & LAN setups.

b. Exchange of technical services, expertise, manpower and equipment would be shared through the technical interface.

c. Training interface is introduced between Training & Consultancy and rest of five units of AEC.

d. Financial Transactions

The external units mentioned within each unit box are includes: -

a. Tools & documents required to carry out different tasks available at the centralized facility in AES.

b. Storage place for raw materials, end items and final products available at the centralized facility in AES.

c. Supply chain interface for acquiring required products and services and shipping of final products to respective customers.

Detailed NxN matrix is prepared for the six units of AEC.

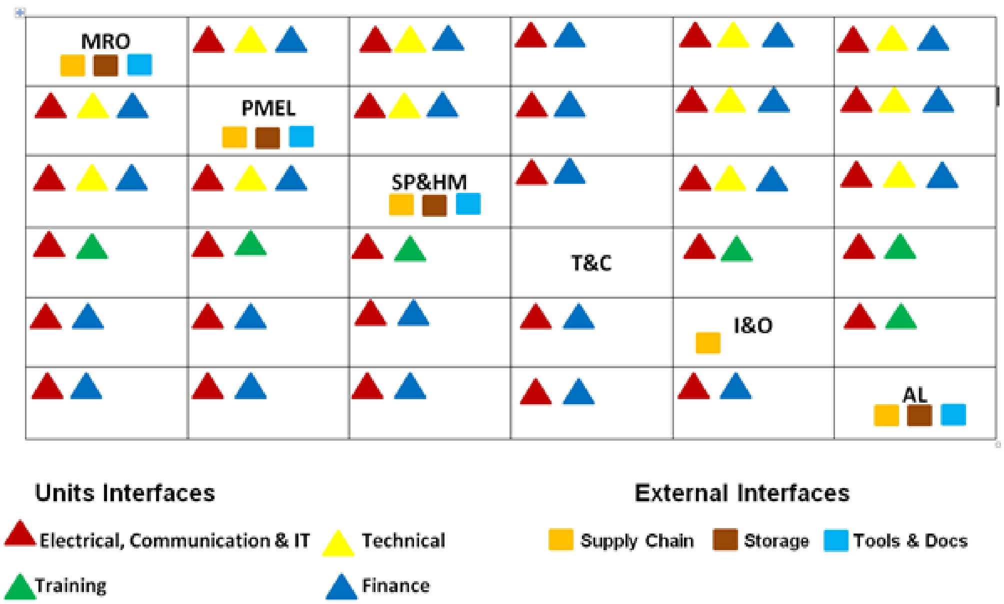

Figure 4.29: : AEC Units Interfaces

4.8 Life-Cycle Cost Aanlysis

Life cycle cost analyses are performed periodically to update and include the cost of acquisition and ownership. This effort is an ongoing process that results in identification of the economic consequences of the project. The life cycle cost of every project can be divided into two main categories of fixed cost and recurring cost. Details of fixed and recurring costs are tabulated below.

Table 4.2: Life Cycle Cost Analysis

Cost Category	**Fixed Cost (US$)**	**Recurring Cost (US$)**
Preparation of SEMP, Business Plan, Feasibility Study	42,857	5000 per annum
Present SEMP, hold negotiations, and Secure Funds	28,571	
Preparation of Master Plan / General Layout	7,143	
Preparation of Sub Plans for each Functional Area	1,429	
Development of SOPs and Business Processes	7,143	
Contracts for Construction / Development - Tech Area	28,571	
Contracts for Utilities in Technical Area	1,429	
Planning, Documentation, Presentations, Contracting	*145,714*	
Machines, Eqpt, Tools, Testers	500,000	10000 per annum
Acquire Training on Generic Machines, Eqpt, Testers	14,286	
Freight/Ins, GST/Duty for Generic Machines & Eqpt	100,000	
Install Basic Engineering Equipment	7,143	
Test and Commission Basic Engineering equipment	1,429	
General Machines, Equpt, Tools, Testers	*622,857*	
Select Gen Avn Engg Eqpt/Tools/Testers	2,857	25000 per annum
Acquire Eqpt/Tools/Testers/Spares for Gen Avn Engg	1,500,000	
Acquire Training on Generic Avn related Eqpt	28,571	
Freight/Ins, GST/Duty for Generic Avn Engg Eqpt	420,000	
Inspect, Install, and Test Generic Avn Engg Eqpt	7,143	
Generic Avn Engg Eqpt, Trg, F&I, Duties	*1,958,571*	
Select PAF/PAC Specific Eqpt/Tools/Testers	1,429	15000 per annum
Acquire Eqpt/Tools/Testers/Spares/Routings	1,000,000	
Acquire Training on PAF/PAC related Eqpt	28,571	
Freight/Insurance & GST/Duty PAF/PAC related Eqpt	280,000	
Inspect, Install, and Test PAF/PAC related Eqpt	1,429	
PAF/PAC Jobs Tools/TestersTooling/Routings, Spares	*1,311,429*	
Total Cost	**4038571**	**55,000 per annum**

Chapter 5

CHAPTER 5 OPTIMIZATION AND ENGINEERING SPECIALTY INTEGRATION

The chapter describes the Multi-attribute decision making process for solving the facility layout problem. A risk assessment model based on the different stages of system life cycle to access the risks associated with the complex projects is also proposed. Engineering development plan is made to define the timelines for different phases of the project

5.1 Development of Alternatives

The design of the proposed facility is a complicated task and selection of the suitable block arrangement requires multi-attribute selection / decision making process based on various criteria. Criteria comprises of qualitative, quantitative and conflicting features usually having vital importance with long processing computations to find the optimal solution or arrangement. The effectiveness and quality of any production and manufacturing facility is highly dependent on the layout planning for the said facility. Various approaches and methodologies are reported in literature to solve the facility layout problem. In this context, linguistics evaluation and mathematical modeling through linear interpolation is selected to solve the AES technical facility layout problem because of many advantages of the selected approach which are; inclusion of the environmental factor to gauge the efficiency, inclusion of mathematical modeling and easier & faster quantification of efficiency and reliability of facility block layout. The problem solution comprises of two parts; first one is description of the proposed methodology and second part deals with the customization & implementation of the method to the AES facility layout problem.

5.1.1 The Proposed Methodology

The methodology comprises of two steps:-

a. Linguistics Evaluation step deals with the definition of key performance parameters for evaluation, then selection of various alternatives and finally the assignment of numerical value to identified parameter for each alternative.

b. Second step is concerned with the Mathematical Modeling of the selected alternatives. The data for each alternative is presented in the form of set points in space as (x_i, y_i). To evaluate data associated with each alternative is then interpolated using linear approximation given by piecewise defined function: -

$$f(x) = a_i + b; x \in [x_i, x_{i+1}] \tag{5.1}$$

where

$$a_i = \frac{y_{ij} - y_{i+1}}{x_i - x_{i+1}}; \tag{5.2}$$

$$b_i = \frac{1}{x_i - x_{i+1}}(x_i y_{i+1} - x_{i+1} y_{ij}); \tag{5.3}$$

The effective level of alternative A_j is given by

$$EL(A_j) = \int_{x_1}^{x_n} f(x)dx; \tag{5.4}$$

By using the trapezoidal method (5.4) can be represented as:

$$EL(A_j) = \sum_{i=1}^{n} \frac{1}{2}(x_{i+1} - x_i)(y_{ij} + y_{(i+1)j}); \tag{5.5}$$

Table 5.1: Linguistic Evaluation

Linguistic Term	Acronym	Numerical Value
Very Low	VL	1
Low	L	2
Medium	M	3
High	H	4
Very High	VH	5

5.1.2 Implementation Of Methodology

Selected methodology is implemented through a number of steps which includes: -

a. Definition of Key Performance Parameters: Six parameters were assumed to evaluate the alternatives proposed in the subsequent step. The figure5.1 describes the parameters with their sub-divisions: -

b. Selection of Alternatives: Three types of block arrangement of

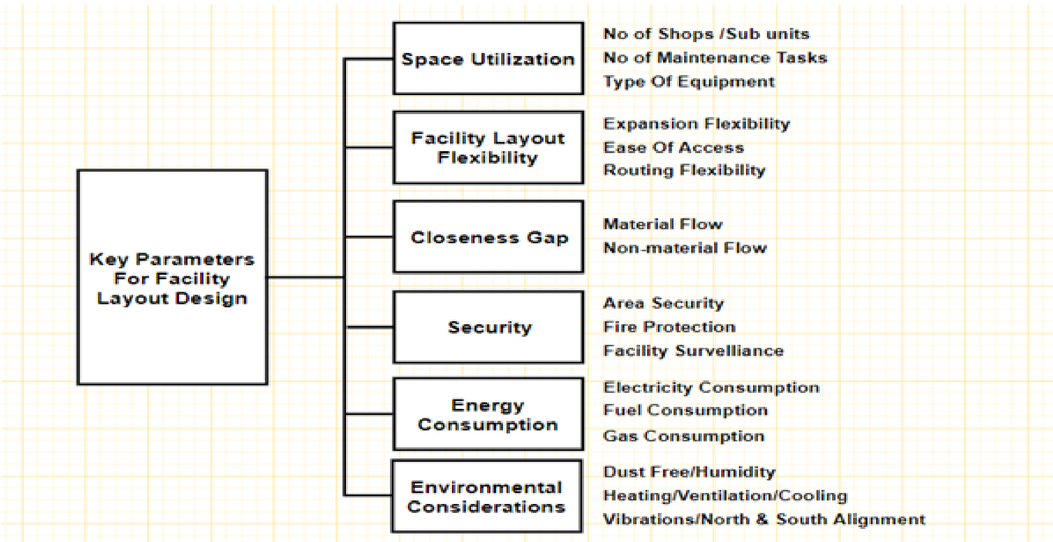

Figure 5.1: : Key Performance Parameters

identified sub-sections in system model are considered for evaluation.

c. Linguistics Evaluation: First linguistics terms along with their corresponding values were defined in table 5.1.

Then six identified parameters were evaluated using the above defined terms and their corresponding values. Table 5.2 summarizes the entire process.

Table 5.2: Evaluation of Performance Parameters

Performance Parameters (PF)	linguistic Evaluation (LE)	Numerical Assignment (NA)	Ranking (R)
Space Utilization (SU)	VH-H	4.5	1
Facility Layout Flexibility (FL)	H	4	2
Closeness Gap (CG)	M-L/M	2.5	4
Security (SE)	M	3	3
Environmental Considerations (EV)	H	4	2
Energy Consumption (EN)	M	3	5

Table 5.3: Linguistic Evaluation For Block Layout Alternatives

	SU		FL		CG		SE		EV		EN	
	LE	NA	LE	NA	LE	NA	LE	NA	LE	NA	LE	NA
A1	VH	4.5	VH	4	M	3	M	3	M	3	L/M	2.5
A2	M	3	M	3	H	4	H	4	H-VH	4.4	M	3
A3	M	3	L/M	2.5	H-VH	4.3	M	3	H	4	H	4

Table 5.4: Effectiveness Value of Layout Alternatives

Layout Alternative	Effectiveness Value
A_1	5.63
A_2	4.25
A_3	5.15

Table 5.3 summarizes the linguistics evaluation for the above considered 3 alternatives for the technical facility model for AES.

d. Mathematical Modeling: Six parameters were considered. For each alternative, the respective effectiveness level is calculated by using the relation mentioned in equation 5.4. In order to solve the integral, Matlab program was compiled. : -
The effectiveness level of each alternative is tabulated below. Graphical results of effectiveness level interpolation are also presented. Table 5.4 shows that A1 comes out to be the most suitable alternative layout. The complete facility layout of alternative A1 is presented in figure 5.2.

5.2 Risk Management

Systems Engineering is the systemic approach for realization, conceptual design, detail design, development, utilization & support and retirement of reliable system that fulfills the operational & system requirements. Execu-

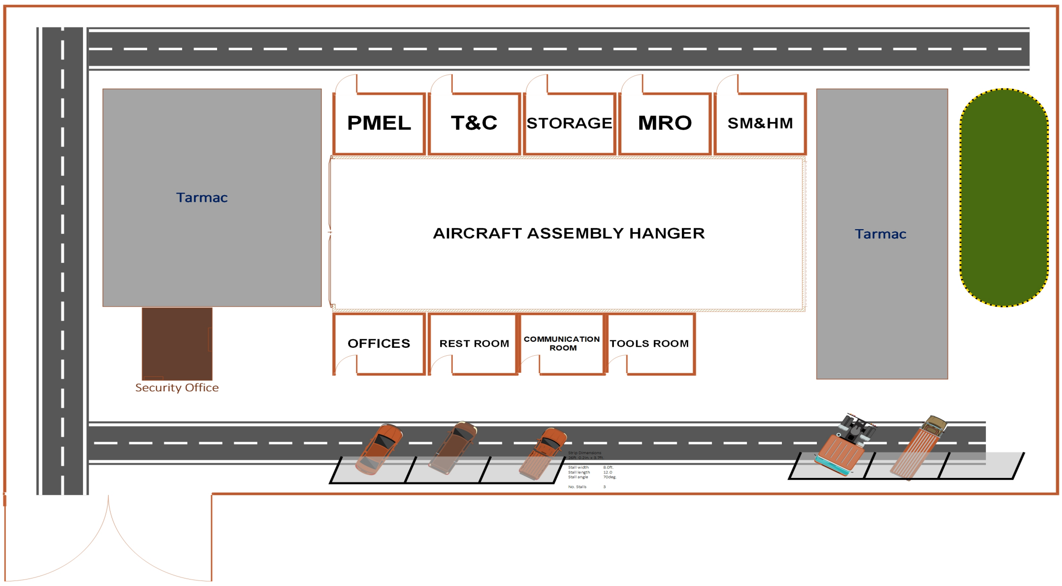

Figure 5.2: : Preferred Alternative Layout

tion of this systematic approach is carried out through precise plans and processes. However, uncertainties in these plans may lead to different negative consequences therefore affecting the overall project. Assessment of risks associated with system engineering processes is deemed necessary and a major challenge for the efficient and timely execution of these processes. To address the above stated problems, two steps strategy is devised that will involve development of Risk Assessment Model (RAM) and implementation of RAM for the MRO project.

5.2.1 Development Of Risk Assessment Model

A risk assessment model is proposed that will identify the overall SYSE processes involved for the successful realization of project, categorization of risks experienced in these projects, their evaluation and finally the prioritization based upon their probability of occurrence and their relative consequence. RAM also includes the risk mitigation through internal and external SMEs depending upon the criticality of the risks. However, keeping in view the scope of the thesis, only steps to mitigate the identified risks suggested by internal SMEs are considered whereas external SMEs opinion may be included in the detailed planning.

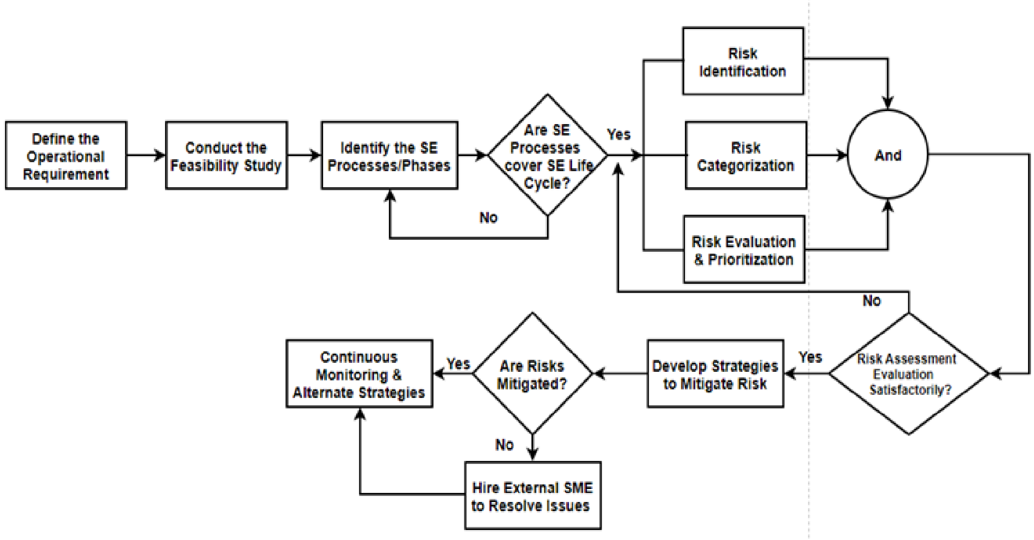

Figure 5.3: : The proposed Risk Assessment Model

5.2.2 Implementation Of RAM

The proposed RAM is applied to overall SYSE processes involved for the successful execution of the MRO project through four interrelated subsections: -

a. Identification of stages of SYSE process
b. Identification of associated SYSE process risks
c. Evaluation and Prioritization of identified risks
d. Mitigation steps proposed by the internal SMEs

a. Identification of Stages of SYSE Process: SE is an iterative process to technical management, system design, product realization, acquisition and supply at each stage of the project throughout its entire life cycle. A series of SEP stages corresponding with the typical MRO project is drawn through brainstorming with SMEs, literature review and personal field experience. Table 5.5 provides the brief description of the nine SEP stages involved in the project.

b. Identification of Associated SYSE Process Risks: The proposed risk analysis started with identifying a set of probable risks corresponds with the identified stages of a SEP. A set of six major risks tabulated below are the most appropriate set of risks associated with the project. Table 5.6 also gives the operational definition of identified risks. Guidelines from the literature and SMEs opinion suggest that identified risks almost cover the whole

Table 5.5: Stages of System Engineering Processes

S No	System Engineering Processes	Description
1	Need Analysis	Requirement analysis of potential customers and stakeholders
2	Feasibility Analysis	Evaluating the system with respect to available resources and customers
3	Preliminary System Design	Defining the project organization, functional analysis, alternative analysis and TPMs at system level
4	Detail Design & Development /Procurement	Detail design for system, subsystem and components subsequently their development or procurement
5	System Installation & Commissioning	Installation of developed or procured systems and subsystems
6	System Integration and Interface Management	Interface design and management between systems and subsystems
7	System Test, Evaluation and Validation	Planning, preparation and conduct of system test for evaluation and validation
8	System Operational Use and Sustaining Support	Defines the system maintainability, logistics and supportability plans
9	System Modification, Retirement and Replacement	Defines the system possible upgrades, retirement and replacement plans

Table 5.6: Risk Identification and Their Operational Definitions

S No	Risk Categorization	Operational Definition
1	Financial/Cost Risks	The risk dealing with financial/monetary loss or exceeding the specified allocated budget to several phases of the project
2	Time/Schedule Risks	Likelihood of failing to meet the stipulated deadlines for above defined phases of the project
3	Programmatic Risks	Disruption in organization working and processes due to formulation of inadequate and incomplete plans
4	Technical Risks	The possibility that the system will not meet the technical requirement or specified performance
5	Socio-political & Legal/Contractual Risks	The possibility that the project may face uncertainty due to political & legal/contractual issues throughout the system life cycle
6	Quality Certification Risks	The risk associated with the attainment of different quality certification to capture the national and international market of A&D sector

project areas.

c. Evaluation and Prioritization of identified risks: The third stage for this research process is evaluation and prioritization of the risks to establish the order of preference. This was done through feedback provided by 10 professionals from the aviation industry regarding identified risks in table 5.6. They were asked to assess the likelihood of identified risks on a scale ranging from Very Low (1) to Very High (5). Similarly, they identified the probable consequence of the proposed risks on the scale of 1-5. The cor-

Table 5.7: Response Data to Risk Probability/Criticality

Survey Response	Levels	Probability/Criticality Value
1	Low	0.1
2	Minor	0.3
3	Moderate	0.5
4	Significant	0.7
5	High	0.9

Table 5.8: Feedback of Subject Matter Experts

Field Expert	Financial		Schedule		Programmatic		Technical		Political or Legal		Quality	
	P_i	C_i	P_i	C_i	P_i	C_i	P_i	C_i	P_i	C_i	P_i	C_i
FE1	0.7	0.7	0.9	0.9	0.7	0.5	0.7	0.5	0.7	0.7	0.9	0.7
FE2	0.7	0.9	0.7	0.9	0.7	0.9	0.7	0.9	0.7	0.9	0.7	0.9
FE3	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.7	0.5	0.7
FE4	0.7	0.7	0.7	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
FE5	0.9	0.7	0.9	0.7	0.5	0.7	0.5	0.7	0.5	0.7	0.9	0.7
EF6	0.5	0.9	0.7	0.9	0.5	0.9	0.5	0.9	0.5	0.9	0.7	0.9
FE7	0.7	0.7	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
FE8	0.7	0.5	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.5
FE9	0.7	0.5	0.7	0.9	0.7	0.5	0.7	0.5	0.7	0.5	0.7	0.7
FE10	0.9	0.7	0.9	0.7	0.5	0.7	0.7	0.7	0.9	0.7	0.9	0.7
$\frac{\sum_{i=1}^{n}(p_i * c_i)}{N}$	**4.72**		**6.02**		**4.06**		**4.20**		**4.48**		**5.32**	

responding risk value was then calculated using the following mathematical expression.

$$R_j = \frac{\sum_{i=1}^{N}(p_i * c_i)}{N}; \tag{5.6}$$

Where,
R_j is the value of the jth risk
p_i is the probability of the risk occurrence as provided by the ith expert
c_i is the consequence of the jth risk as provided by the ith expert
N is the total number of experts

Table 5.7 describes the various levels of probability and criticality of the risks along with the assigned numerical value.

Table 5.8 gives the responses on the likelihood and respective criticality gauged through the feedback from subject matter experts.
Table 5.9 gives the mean value of each identified risk, standard deviation and their order of criticality as concluded from the adopted systematic evaluation.

Table 5.9: Mean and Standard Deviation of the Identified Risks

Risk associated with distinct phases of project	Mean Value	Standard Deviation	Ranking
Time/Schedule Risks	6.02	1.16	1
Quality Certification Risks	5.32	1.09	2
Financial/Cost Risks	4.72	1.09	3
Socio-political & Legal/Contractual Risks	4.48	1.18	4
Technical Risks	4.20	1.04	5
Programmatic Risks	4.06	1.03	6

Based on the assessed data, the most important risk to the MRO project is meeting the predefined timeline following the attainment of quality certifications and rest of identified risks. Furthermore, comparatively low value of standard deviation indicates that the experts are fairly in agreement regarding the relative ranking of the identified risks associated with the MRO project.

d. Mitigation Steps Proposed by The Internal SMEs:

Table 5.10 lists the different mitigation strategies for the identified risks to propose an optimized implementation plan for the technical facility.

Table 5.10: Mitigation Strategy Proposed By Internal Subject Matter Experts

S No	Risk Categorization	Mitigation Strategy
1	Financial/Cost Risks	20% of overall cost of the project may be included as risk factor to cater cost overruns and 10% for unseen circumstances.
2	Time/Schedule Risks	Preliminary design reviews and critical design reviews may be scheduled for timely completion and adjustment of timeline.
3	Programmatic Risks	Most members of the required team may be from PAF retired personnel for smooth functioning in addition to selection of few members from the private sector. Same practice may be adopted for formulation of procedures and policies.
4	Technical Risks	Selection of COTS available technical equipment with a provision to hire services of the available public A & D sector.
5	Socio-political & Legal/Contractual Risks	In the first phase, only customers and organizations having good working relationship may be considered. Selection of site may be given due importance to mitigate the said risk.
6	Quality Certification Risks	Process of acquiring certifications should be through bits and pieces rather concentrating to achieve planned certifications at the same time. Same sequential approach may be adopted for customers.

Risks identified in table 5.6 will serve as vital assessment indicators for the listed SE processes. These SEP and respective risks can further be revised in detail studies for the successful implementation of the project. A systematic approach for identification, evaluation and risk mitigation is adopted for overall project life cycle.

5.3 Production Plan

Production plan basically deals with the organization planning for production and manufacturing. It utilizes the available resources, management of employees activities and production capacity to meet the customer requirements. Preparation and integration of production plan into the overall organization strategy is essential for economical and efficient operation. Salient components of production plan are quality management, scheduling, inspection, dispatch, equipment management, inventory management and supply management.

Keeping the view, the necessity of production plan, a comprehensive production plan for MRO technical facility is prepared. Six deliverables are selected to prepare the plan. Then 19 different technical requirements are deriver to meet the predefined deliverables mentioned below.

a. Quality Products
b. On Time Deliveries
c. Responsiveness & Flexibility
d. Economical Costs
e. Sustained Business Growth
f. Long Term Products Supportability

Proposed plan was evaluated by three different SMEs and final plan was prepared by taking the average of three evaluations. QFD method is used to prepare the production plan.

(Production, PP&C, Logistics, Quality, Gen Engg Shops, and Plant Maint) Design Requirements → HOWs; Deliverables WHATs ↓	RealtiveCustomer Importance	Customer Importance Scale	High Quality Engg Infrastructure (Machines)	Capable Support Infrastructure	Availability of Sufficient Funds (Money)	High Quality HR (Men)	Documentation of Business Procedures / SOPs	Implementation of Generic/Industry Standards	Implementation of capable ERP System	Implementation of Specialized Software	Good Quality Raw Materials	Timely Availability of Raw Materials (Materials)	Availability of Utilities	Efficient Customer Care / Service System	High Quality (Minimum Wastages) Lean System	Sufficiebnt Capacity with Growth Potential	High System Availability on Sustained Basis	Perfect Interface with Support Systems	Good Indoctrination & Refresher Training Progra	Fairness and Justice for all Stake Holders	Formal PMRs with Customers and Suppliers
Quality Products		5	5	5	3	5	5	5	5	5	5	3	1	1	5	1	5	5	1	1	3
On Time Deliveries		4	0	3	3	3	3	3	5	3	0	5	3	0	1	1	3	5	0	3	3
Responsiveness & Flexibility		0	3	3	3	3	3	3	5	3	0	5	1	5	1	1	3	3	3	5	5
Economical Costs		2	3	3	1	5	3	3	5	1	5	3	1	0	5	1	3	1	1	1	1
Sustained Business Growth		3	3	5	3	3	3	3	5	3	1	5	3	5	3	5	5	3	3	5	5
Long Term Products Supportability		1	3	5	5	3	1	3	5	3	1	3	1	3	3	5	3	3	3	5	5
	Target																				
Tech Priorities	Importance		43	63	43	59	53	55	75	51	39	59	29	23	51	31	61	59	19	39	49
	Rank		Medium	High	Medium	High	Medium	High	Highest	Medium	Medium	High	Low	Low	Medium	Low	High	High	Lowest	Medium	Medium

Figure 5.4: : : Production Plan

5.4 Reliability Programme Plan

A 'Reliability program plan' is required to assure attainment of the reliability requirements of the acquisition. This plan provides basis for measuring the system reliability. A minimum of 90 percent reliability should be set as an achievable target. This would of course mainly depend on the reliability of equipment, maintenance practices and the qualification and experience of the workers.

5.5 Maintainability Programme Plan

A Maintainability program is prepared for every project to improve overall readiness, reduce life cycle cost & maintenance requirements and to provide data essential for management. It is suggested that a complete transfer of technology (ToT) may be carried out for engineering equipment acquired from foreign countries. This endeavor will not save valuable foreign assets but time of transactions for shipping and transportation activities. It is also suggested that a target of 85 percent serviceability be set for the system.

5.6 System Test Plan

This plan is prepared to establish the strategy and philosophy for qualifying the System. The vendor will prepare this plan after necessary coordination with AES management, lead consultants and all the users at the respective sites.

5.7 Engineering Project Plan

The data is described graphically in the form of PERT charts. It identifies the major milestones and events required by the 'Statement of Work'. This plan shall be revised prior to a formal progress review. Activity framework of AEC technical facility was developed and shown below:

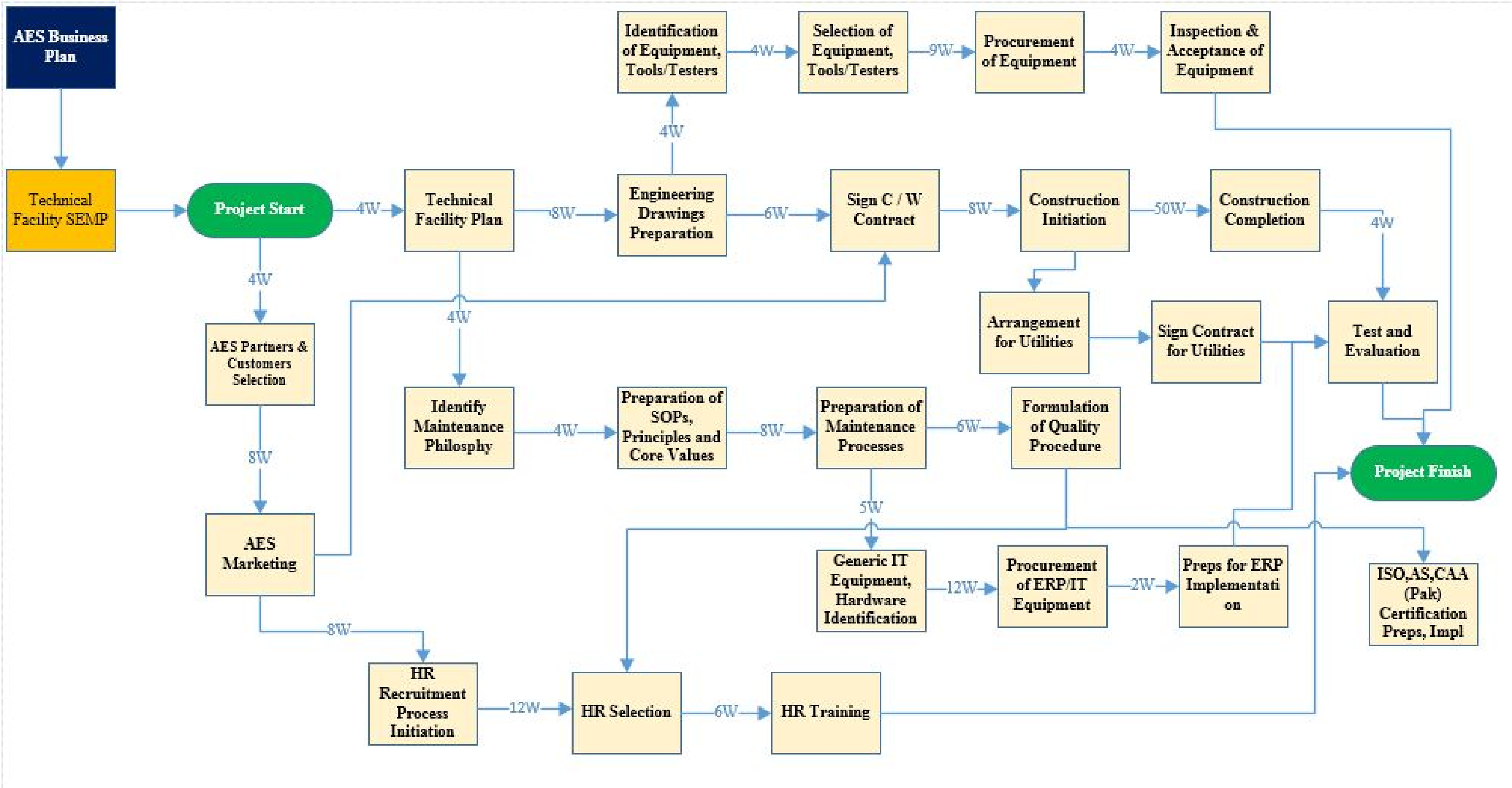

Figure 5.5: : Engineering Project Plan

Chapter 6

CHAPTER 6 CONCLUSION, RECOMMENDATIONS/ IMPLICATIONS

6.1 Conclusion Of Research Study

Systems Engineering is an interdisciplinary approach and means to enable the successful realization of complex engineering systems. SE integrates all the specialty groups and disciplines into a team effort that helps focus on complete life cycle management of such systems. This applied thesis work provides a life cycle based balanced system design for any new industrial set up in the exclusive Aerospace & Defence sector. Thesis work was undertaken through the active collaboration between Academia and A&D Industry.

Execution of complex and large sized engineering project faces numerous constraints particularly in a developing country such as Pakistan. These constrains can be fully identified and effectively managed through Top Down process of Master Planning followed by Bottom Up process of Integration. The product of this life cycle based planning effort is a living document known as System Engineering Management Plan (SEMP). It is one stop reference for fully integrated engineering and management effort. SEMP is part of overall Program Management Plan (PMP) and defines project scope, organizational structure and responsibilities of key team members. It also covers SE processes, need analysis, functional analysis, maintenance and operational concepts, value engineering, identification and management of interfaces, system level Test & Evaluation methodology, and finally the System Retirement/ Disposal and recommendations for recreation of the new replacement system.

The interdisciplinary approach adopted during the research work includes the integration of various tools and techniques starting from SWOT analysis to identify all the possible known proportions into four logical quadrants and QFD to make decision regarding site selection. Need analysis helped to twig the mandatory and preferential requirements followed by the Systematic textual analysis for functions identification and FFBDs for functional decomposition. Then TPMs are defined in three broad domains; project, maintenance and operations. SysML was utilized to map the identified functions to physical chunks by making the system model. The interactions between these internal and external physical chunks are captured through N2 matrices. The facility layout problem was resolved through the Multi-attribute decision making process involving the linguistics evaluation and mathematical modeling to select the most suitable alternative. A risk assessment model is also developed based upon the different stages of system life cycle to access the risks associated with the complex projects. Engineering development plan is made to define the timelines for different phases of the project.

In the end, all these tools and techniques are organized in a logical sequence to give new way and essence to existing planning document called as System Engineering Management Plan. This plan basically provides necessary information to project execution team regarding complete details of six business units of AES and their intended functions, development of facility layout design within an area of 20,000 square feet and a time span of 21 months. The plan also contains preliminary and critical design reviews to access the execution of the project and life cycle cost estimates of engineering equipment as 41 million USD. Six type of risks mentioned in table 5.9 will enable the project management to develop less risky strategy, thereby increasing the overall efficiency of AES.

6.2 Addition To Body Of Knowledge & Implications For Future Work

The research work was based on the application and integration of various tools and techniques: quality function deployment, systematic textual analysis, system modeling using SysML, N2 analysis, linguistic evaluation and mathematical modeling and risk assessment model to the conventional SEMP which opens a new direction for optimization & amp; utilization of SE processes and academia industry linkages for execution of complex projects. Same concept of research may be extended by providing valuable solutions to industry through the active collaboration of subject matter experts, industry and academia. Furthermore, same research work scope may be protracted by modeling the complete AES technical facility explaining the integration and working using SysML.

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