Requirements analysis of aviation standards Applicable to Production Organizations

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ABSTRACT

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Standards are the bottleneck of any aviation industrial action. Thus, meeting standards is not an option but an obligation throughout a given product life cycle. This thesis contributed to producing a SIPOC diagram of aviation standards and collecting pertaining information, beginning with international standards, and ending in national codes. Particularly, the requirements which are applicable to a production organization in the aviation industry. A detailed view of the rulemaking process in the aviation industry is provided. The implementation of the standards and the evaluation process are complicated and need considerable resources. Simultaneously, Extra costs and concerns may be imposed on the aviation industry due to improper requirements. Thus, the quality of standards should be comprehensively assessed to obtain a satisfactory final result. System engineering introduces requirement analysis to solve this problem. As a significant contribution, this thesis provides a model of requirement analysis based on the structured strategy. The criteria were defined practically. Diagram, process, sub-process, and techniques including RTM and WBS were either developed or deployed to investigate the conformance of requirements with the criteria. Applying this model, any sort of requirement is evaluated accurately. Plus, it shows a specific and root cause of the problems if the requirement is unacceptable. Furthermore, a novel way to measure system affordability is proposed through the application of DFMEA. Lastly, the model is applied on CFR-14 Part-21 Subpart-G (FAA production organization requirements) to show the need for systematic improvement of aviation standards' requirements of production organization.

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In addition, the government of Quebec generously offered us Francisation which is a program to learn French. Although it was not easy to improve English proficiency as my second language and learn the third language along with pursuing my second master's program, the fact of how productively the Francisation program can affect my life is inevitable.

Furthermore, the government of Canada during the daunting Covid situation helped us regardless of our nationality which is another epitome of humanity for me. I must admit that I would not forget their support.

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List of abbreviations

Abbreviation	Meaning	Definition
EASA	European Aviation Safety Agency	EASA belongs to European Union (EU) as an agency that is responsible for civil aviation safety. Certification, regulation, standardization, and performing investigation and monitoring are some of its tasks. [1]
FAA	Federal Aviation Administration	The United States assigns the FAA to administrate all angles of civil aviation in the soil and over its surrounding international waters. [2]
ICAO	International Civil Aviation Organization	United Nations (UN) Assigns the ICAO as a specialized agency. Member states established it in 1944 to manage the administration and governance of the Convention on International Civil Aviation (Chicago Convention). [3]
AMC	Acceptable Means of Compliance	AMCs are considered an approved way by EASA to demonstrate a means to comply with the Basic Regulation and its Implementing Rules. [5]

GM	Guidance Material	"GM is non-binding explanatory and interpretation material on how to meet the requirements contained in the Basic Regulation, the IRs, the AMCs, and the CSs. Including information, examples". [6]
AC	Advisory circular	AC is a type of publication offered by the Federal Aviation Administration (FAA) to guide compliance with airworthiness regulations, pilot certification, operational standards, training standards, and any other rules within the 14 CFR Aeronautics and Space Title. [4]
USOAP	Universal Safety Oversight Audit Program	ICAO's USOAP was initiated in January 1999 in response to widespread concerns about the adequacy of aviation safety oversight globally. [7]

Chapter 1:

Introduction

This chapter will discuss the motivation of this thesis, the objectives, and the organization of this report.

1.1 Motivations

As standards are the bottleneck of any aviation industrial action, [26, 48] meeting standards is not an option but an obligation throughout a given product life cycle ranging from design, production, maintenance, training to operation [4, 12]. Therefore, the quality and safety of all the above-mentioned organizations' activities should be evaluated based on the relevant standards [27]. The implementation of the standards and the evaluation process are complicated and need considerable resources. [10, 11]. However, this is an inescapable price to pay for safety and quality.[38]

Simultaneously, there is a risk of dealing with an unreasonable cost due to the lack of standards quality itself.[42] Thus, the quality of standards should be comprehensively assessed to obtain a satisfactory final result. Otherwise, all of the resources allocated to drafting, implementing, and evaluating those standards would be wasted.[36] Plus, extra costs and concerns are imposed on the aviation industry due to hierarchy, complicated, ambiguous, unachievable, incomplete, unverifiable, and inconsistent requirements. [37,13]

Various significant authorities are critical factors in this regard, named ICAO, FAA, and EASA [11, 48, 57]. These organizations develop their own regulations and standards as well as their

interpretations[58], which can be taken into account as a source of potential either non-conformity or repetition [10, 55-56]. At the same time, there are other sorts of considerations like the strategy of requirements analysis when it comes to the rulemaking process [24].

Probably, aviation is one of the most developed industries in terms of industrial standards and requirements [28, 48]. However, there is a need for these standards' requirements to explore the possibility of systematically analyzing and improving aviation standards' quality. Therefore, this thesis uses proper methods and techniques, including those introduced by six sigma and systems or requirements engineering theories, to satisfy the mentioned need.

Six Sigma provides an effective method, DMAIC, to Define, Measure, Analyze, Improve, and control processes [14, 59]. This method is applied to find if there is an opportunity for improvement. A possible solution is also sought in this thesis by applying different techniques and tools recommended by systems and requirements engineering [24,13].

1.2 Objectives

This research analyses the requirements of aviation standards, particularly those applicable to industrial aviation organizations such as "Design" or "Production", based on DMAIC and Systems and Requirements engineering theories.

1. The first objective is to investigate various sorts of regulations, their stakeholders, and interfaces in the aviation industry. After that, to clarify the one being responsible for the rulemaking and the rulemaking process.
2. Once sufficient intended information is collected regarding standards in the aviation industry, the next objective is to identify approaches and methodologies to develop a model to evaluate aviation industry standards. It is critical to know all aspects of this model to ensure the result of this evaluation is reliable and practical.

3. The last objective is to apply the mentioned model to determine if it works properly. In addition, to analyze the requirements of the chosen standard (CFR-14 Part-21 Subpart-G) in the aviation industry.

1.3 Overview and contributions

The organization of this thesis is as follows:

- Chapter one: The subject is introduced. The motivation and objectives are determined.
- Chapter two: The problem is stated in this chapter. The previous attempts and background are elaborated. Some technical definitions regarding design and production organizations in the aviation industry are introduced.
- Chapter three: All relevant definitions and contributing factors such as national and international codes are identified and explained. The various standards, the study about who does the rulemaking (authorities), and how are that process are the backbone of this chapter.
- Chapter four: The tools, techniques, and methodology to deal with the problem are investigated. A model is defined and proposed based on the systems engineering theory with some quality and reliability measures. DFMEA, requirement analysis, and the relevant strategies, diagrams, and attributes are explained in this chapter.
- Chapter five: This chapter belongs to the implantation of the model to analyze CFR-14 Part-21 Subpart-G. The sampling method, RTM, SIPOC, and building-block diagram are drawn and explained in this chapter to demonstrate the result of the analysis and determine the contributing factors.

- Chapter six. The last chapter is dedicated to the conclusion, proposed future work and, which barriers impacted this project. Also, recommendations are mentioned in this chapter.

Chapter 2:

Problem statement

The aviation industry has various legislations: the international convention, annexes, national regulations, standards, and their requirements [56-58]. Certain products and services and related organizations such as “Design” or “Production” must comply with these requirements [60-61]. Thus, the following problems are stated.

1. It is vital to figure out which requirements are applicable to which products and relative organizations.
2. As systems or any products and services should meet the mentioned requirements, in the best-case scenario, the result may approve that the system complies with the requirements. However, in the first place, it needs to be investigated whether the requirements could be met anyhow; plus, whether the final result would be satisfactory and reliable.

2.1 Background

Recent papers have studied the implementation of several aviation standards in an organization like design or production. In addition, various series of aviation standards are described throughout the studied books and regulations. Besides, DMAIC and system engineering (SE) or requirements analysis (RA) are well-known subjects for literature review. It is necessary to mention, this thesis comprises all these resources. On the contrary, the topic is a new initiative. Therefore, it is helpful to begin with the implementation of the relevant standards and requirements in a design or a production organization to familiarize with specific terms and

processes. After that, we run through DMAIC, SE, and RA. Later on, in the following chapters, these topics are elaborated, and other resources are discussed.

2.1.1 Implementation of aviation standards in a design organization

The research explained the result of a project on the characteristics and functions of a design organization based on EASA versus FAA structures and requirements. The Design Organization Approval requirements (DOA) separately in accordance with EASA regulations and FAA Organization Designation Authorization (ODA) have been implemented. After that, the compatibility of these two requirements was investigated. This project provided an example of a design assurance system to meet parallel airworthiness requirements. [10]

Certificates required before EIS (Entry to Service) are DOA, TC (Type Certificate), POA (Product Organization Approval), and C of A (Certificate of Airworthiness). Thus, DOA is a means to qualify and oversee the civil aircraft design organization in Europe.[10]

DOA is a certificate for the organization which designs the aircraft and has specific duties regarding production, maintenance, etc. This certificate demonstrates that the product typically complies with the requirements. [10]

What is necessitated by Commission Regulation (EC) No 1702/2003[2] is to hold DOA under EASA Part 21 subpart J as an applicant of TC. Therefore, holding DOA is a condition for the applicant of TC, in accordance with the EASA regulation. On the other hand, the workload would be decreased by holding DOA. The DOA holds their TC or supplemental type certificate (STC). Its main functions are design function, airworthiness function, and independent monitoring function. Moreover, the DOA has some privileges to approve minor changes and minor repairs, plus the design of major repairs for the aircraft. [10]

While the aircraft manufactured in the United States are required to hold three certificates, including TC, PC (Product Certification), and AC (Airworthiness Certificate), for type certification, the applicant is the first responsible person in charge of all airworthiness responsibilities. FAA initially authorizes some privileges to individuals (not an organization) as the designated representatives, including DER (Designated Engineering Representative), DMIR (Designated Manufacturing Inspection Representative) and DAR (Designated Airworthiness Representative), etc. [10]

2.1.2 Implementation of aviation standards in a production organization

There is another research, the target of which is to establish a production organization. That is not limited to an aircraft, but for the organizations in which a component or item of equipment or part of an aircraft is manufactured. This project is to produce an aircraft; there is no way except holding EASA/FAA approvals, plus Civil Aviation Airworthiness approvals of Directorate General of Civil Aviation (DGCA) India, which is the local authority.

The project objective is to investigate AS/EN9100, EASA, FAA, and DGCA (India) requirements to follow harmonization and preparation of an integrated Production Organization Exposition (POE) which can meet all requirements. It includes the development of the Production Organization Exposition (POE) manual to meet requirements of Quality Management Systems for Aviation, Space and Defense Organizations (AS/EN 9100), EASA Part 21 G, Code of Federal Regulations (CFR) 14 Part 21- subpart G of FAA, and DGCA Part 21 Subpart G. The objectives of mentioned research are as bellow.

- Optimization of a Production Organization Exposition which complies with the airworthiness requirements,

- Preventing duplication of procedures to meet AS/EN Quality Management System needs and
- Minimizing demonstration time for Civil Aviation Airworthiness

Compatibility of EN/AS9100 requirements and EASA, FAA & DGCA, India requirements were analyzed to identify the following items.

- FAA and AS/EN 9100 requirements need In-service feedback and Quality escape. In comparison, EASA and DGCA requirements do not mention it.
- EASA and DGCA, India requirements address Certifying Staff, Offsite Working conditions, and pre-delivery Aircraft Maintenance Procedures, whereas FAA requirements do not.
- Production Organization Approval has specific requirements ranging from Nomination of Accountable Manager, List of Certifying Staff, Scope of Work & Terms of Approval, Notification Procedure for Civil Aviation Authority, Amendment Procedure for changes in POE, Certifying Staff Qualification & Training, to Airworthiness coordination with Design Organization Authority and pre-delivery Aircraft Maintenance Procedures. Whereas AS/EN 9100 does not mention it.

The study recommends conducting more research on Civil Aviation Authorities working together to harmonize concise production organization exposition. As figure 1.1 shows, this POE can support all the requirements of AS/EN 9100 Quality Management System requirements; standardize and recognize the civil airworthiness certification process of the respective country to reduce differences and cost of certification without compromising quality and requirements. [11]

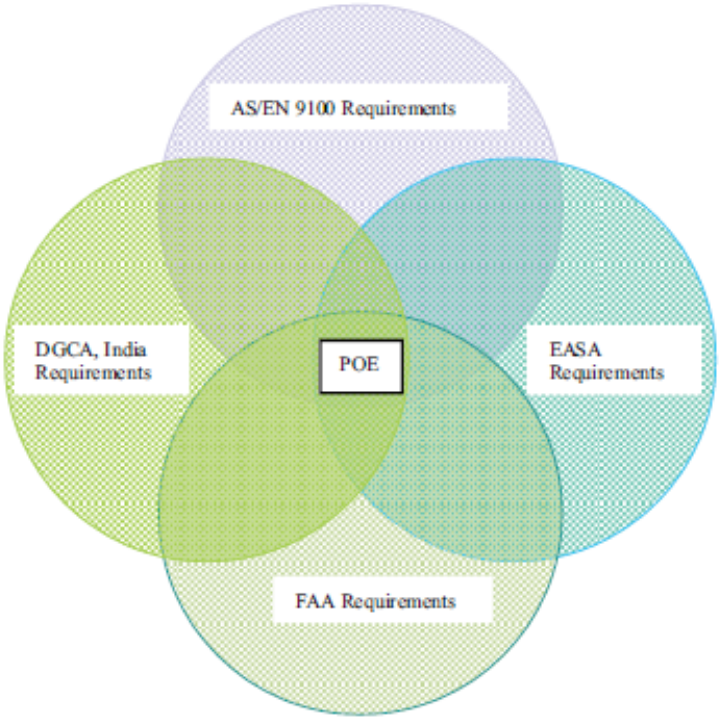


Figure 2.1 Integrated Production Organization Exposition (POE) [11]

2.1.3 Requirement analysis

As mentioned earlier, this thesis's backbone is DMAIC which is the fundamental methodology of Six Sigma. Plus, this methodology is systematic and fact-based to supply a rigorous framework of results-oriented project management. In the case of a flexible or unconventional process, DMAIC provides the best results. [50, 51]

Based on the DMAIC, the Define and Measure phases should be followed to reach the Analysis. The previous papers are reviewed on aviation standards' requirements to define the situation. However, it needs to comprehensively identify the rulemaking process and standards stakeholders, which will be studied in the following chapters.

Although the earlier attempts to implement aviation standards in a design and a production organization show an approach to integrating various requirements from diverse authorities, none concentrate on the requirements. Thus, it is presumed that the requirements are flawless and acceptable to be met by all available means. [47] As a result, the compatibility analysis of various standards applicable to specific aviation organizations has been developed. [10,11]

In contrast, lack of requirements analysis posed the risk of unsatisfactory results even on the occasion of well-implementation of any systems, including those mentioned. [47] System engineering theory insists on the order of actions to develop a system, as the following diagram depicts. [13]

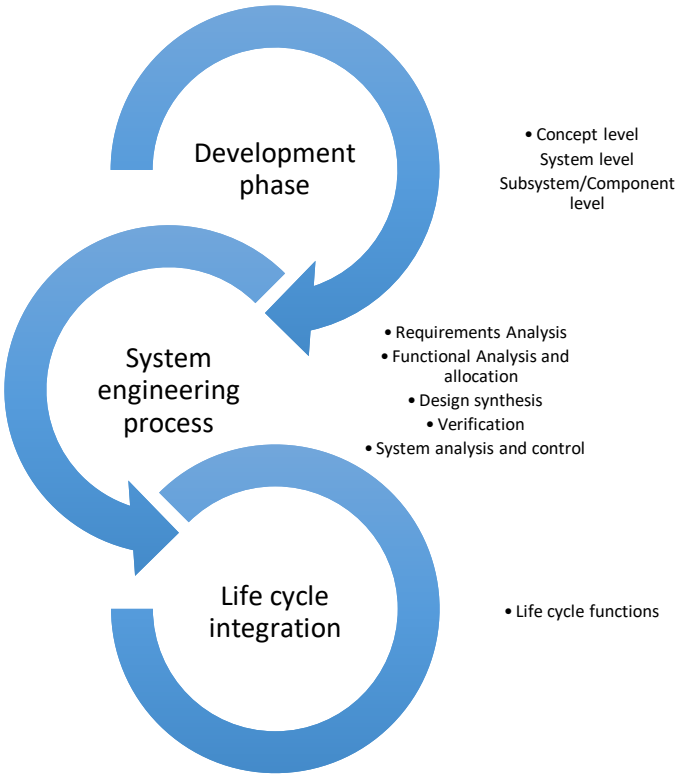


Figure 2.2 System engineering diagram

Thus, some vital steps such as requirements analysis are missing. However, beneficial results and conclusions are coming from mentioned studies regarding implementing DOA and POA considered throughout this thesis.

Chapter 3:

Literature Review

To better understand the problem and prevent any rework, it is vital to study the various sources, ranging from scientific papers, books, standards, national organizations' manuals to international agreements regarding aviation standards.

3.1 Airworthiness

It is essential to understand the '*airworthiness*' definition as it is the main keyword throughout the aviation standards. An Italian Technical Regulations document belonging to RAI-ENAC mentioned, '*Airworthiness is complying with the mandatory requirements for flying in safe conditions, not beyond allowable limits for an aircraft, or aircraft part,*.' There are three key elements worth considering: **safe conditions**, **necessary requirements**, and **allowable limits**.

(1) Safe conditions relate to the ordinary course and satisfactory conclusion of the flight. In other words, it could be seen as '*safety is a condition in which there is nothing which can cause death, injury or illness, damage to/loss of equipment or property, or damage to the environment*.'

(2) The second element is meeting the necessary requirements. It means that the aircraft, or any of its parts, is designed and produced to confirm flying in safe conditions as studied and tested criteria needed.

The regulations are established by the airworthiness authorities appointed by each country. These regulations are set to promote safety by eliminating or mitigating conditions that may

cause death, injury, or damage. They are collected through the airworthiness standards, including a series of design requirements: ranging from the flight requirements (flight qualities and performance) to the strength of the structures, criteria for necessary tests, flight, good design practice, fatigue and flutter, systems, and maintenance manual content, etc.

The standards are based on the types of aircraft. Inevitably, the design of a sailplane, a big transport airplane, or a helicopter needs various rules. However, the common point is their evolution through time. [12]

Thus, a standard does not precede aeronautical progress; it does follow and sometimes accompanies it. Therefore, a good standard would not prevent aeronautical progress. [49]

Frequently, an accident analysis leads to adding some modifications. It means a progressively higher price; nevertheless, this is the price to pay to improve flight safety.

(3) Finally, when it comes to **Allowable limits,** the aircraft is designed for operation within a specific *flight envelope*, which depends mainly on speed and structural load factors. Moreover, the maximum weight of the aircraft can be established differently for various sorts of operations. The aircraft's operational conditions range from day-visual flight rule, night flight, instrumental flight, in or out of icing conditions, etc. Overriding these conditions and limits leads to accidents. [12]

3.2 Civil aviation international authority

Development of aeronautical techniques and the potential for transporting goods and people may owe to the First World War. The post-war condition required international attention to this advanced means of transport.

The negotiation on the mentioned issues took place at the Paris Conference of Peace in 1919. The discussion resulted in the establishment of an Aeronautical Commission. To achieve the objective of making aviation an instrument of peace, an International Air Convention was written and ratified by 38 states (countries). The convention included all perspectives of civil aviation; plus, an International Commission for Air Navigation was established to monitor and measure the development of civil aviation. [12]

During two World Wars, the continuous development of civil aviation in both the technical and the commercial fields was marked. Merely in six years, the Second World War did the same work as a quarter of a century regarding the development of more sophisticated military aircraft operations and significantly affected their technical aspect.

That is why, in 1944, the Government of the United States commenced conducting exploratory discussions with other allied nations. After that, invitations were sent to 55 allied and neutral states to meet in Chicago in November 1944. Fifty-two out of those states attended the meeting. The output was the Convention on International Civil Aviation which has 96 articles and a preamble.

The International Civil Aviation Organization (ICAO), on 4 April 1947, officially came into existence. Based on the invitation of the Government of Canada, Montreal was chosen as the site for its headquarters. Currently, the Contracting States are 193. [48]

3.3 Civil aviation authorities

Most countries have established institutions and authorities to guarantee the safety of flight. A couple of examples show that these organizations evolved from pre-existing institutions for marine and river navigation safety.

Historically, it is good to know that the idea and inspiration for improving the safety of navigation had nothing to do with a moral principle but an economic concern of insurance companies.

There is an accurate history regarding the 'register,' which various navigational institutions adopted. It is taken from a register related to a confident Edward Lloyd, who was the owner of a tavern located in the river port of London at the end of the 17th century. He filled the register with information on marine traffic collected through conversations with customers, including ship owners and sailors.

The information could be pertinent to ships, traffic, and, particularly, accidents involving a loss of men, goods, and ships.

After that, all similar publications were unified into the '*Lloyd's Register*' in 1833. The first register in the world obtained legal status in 1871. Subsequently, in Europe, other national registers were instituted.

As mentioned, safety plays a key role for insurance companies; the fewer accidents, the fewer indemnities to pay. Thus, the registers began to issue safety requirements for navigation.

As the operation of aircraft posed similar problems with marine traffic, the solution would be similar, the establishment of specific institutions, which was already existing for marine traffic. Even certain marine institutions took responsibility for aviation regulations and their control. Later the growth of aviation resulted in the creation of autonomous registers and national authorities dealing with aircraft and air navigation.

3.3.1 The European Aviation Safety Agency

EASA is a legal entity with autonomy in legal, administrative, and financial matters, which is an independent European Community body. This single authority with the mission of a system of air safety and environmental regulation was created by adopting a European Parliament and Council Regulation (EC), No. 1592/2002 of 15 July 2002. On 28 September 2003, its activity started [61].

3.3.1.1 Executive and regulation tasks

Following items are the primary EASA functions nowadays: [28]

i. Rulemaking: providing technical advice and drafting aviation safety legislation to the Member States and to the European Commission;
ii. Standardization programs, inspections, and training to guarantee all Member States implement a standard level of European aviation safety legislation;
iii. Aircraft, engines, and parts safety and environmental type certification;
iv. Approval of production and maintenance organizations outside the EU and aircraft design organizations worldwide;
v. Certification of organizations and personnel of aircraft operation;
vi. Certification of organizations of Air Traffic Management (ATM) and Air Navigation Services (ANS);
vii. Certification and oversight of ATC training organizations (within EASA remit), non-EU TM/ ANS organizations providing services within the EU, and pan-European service providers;
viii. Authorization of the third country (non-EU) operators;

ix. Coordination of the European Community program, Safety Assessment of Foreign Aircraft regarding the safety of foreign aircraft using Community airports;

x. Data collection, analysis, and research to improve aviation safety.

3.3.2 The Federal Aviation Administration

On May 20, 1926, the Air Commerce Act initiated the Federal government's regulation of civil aviation. This crucial point of the legislation was passed in the interest of the aviation industry. The aircraft could not achieve its full commercial potential unless the federal government took action to improve and maintain safety standards to fulfill its leaders' beliefs. The Act appointed the Secretary of Commerce responsible for issuing and enforcing air traffic rules, fostering air commerce, establishing airways, licensing pilots, operating, maintaining aids to air navigation, and certificating aircraft. In the Department of Commerce, a new Branch was established for Aeronautics and its responsibility for aviation.[62]

The Federal Aviation Act of 1958 was the result of jet airliners and a series of midair collisions. The FAA as a new independent body took place, which had broader authority to overcome aviation situations. The Act gave the FAA sole responsibility for developing and maintaining a shared civil and military system of air navigation and ATC, the responsibility that the CAA previously shared with others.[62]

The Congress of the United States authorized creating a cabinet department that would combine primary Federal transportation responsibilities in 1966. Thus, a new Department of Transportation (DOT) began its entire operations on April 1, 1967. DOT had a couple of modal organizations, including the FAA. At the same time, National Transportation Safety Board became responsible for the CAB's accident investigation. [62]

Issuing and enforcing regulations and minimum standards have been conducted by the FAA, covering manufacturing, operating, and maintaining aircraft; plus, certification of airmen and airports. [62]

3.3.2.1 Activities of Federal Aviation Administration

The safety of civil aviation is the responsibility of the FAA. Its prominent roles are as follows: [28]

a) to promote safety, regulating civil aviation.

b) developing and encouraging civil aeronautics such as new aviation technology.

c) operating and developing a system of navigation and ATC for both military and civil airplanes.

d) developing and researching civil aeronautics and the National Airspace System.

e) conducting and developing programs to control aircraft noise and other environmental effects of civil aviation;

f) regulating US commercial space transportation.

3.4 Authorities' importance

Nowadays, the EASA can perform as a powerful single authority. That is why, once EASA certifies an aircraft, this type certificate is valid for all the Member States, without further action required. It means there is a single European Agency instead of 32 national authorities. Thus, Member States are represented by the EASA. Moreover, Member States are united by and must

reflect the Agency's decisions and positions when conducting their representative roles in frameworks including the ICAO and ECAC.

The establishment of appropriate relations with non-EU members and attempt to have relationships with other international entities by specific associations, arrangements, mutual recognition agreements, and partnerships is the responsibility of the Agency. In contrast, bilateral safety agreements are legally a competence of the European Commission.

Currently, the EASA has agreed on bilateral agreements with the United States, Brazil, and Canada. Plus, it has a couple of working arrangements with non-EU states.

In this regard, the EASA and FAA are holding the tradition of an annual International Aviation Safety Conference. Since 1983 a couple of annual conferences have been hosted by the FAA and the JAA, replaced by EASA.

The subject of some conferences is related to aviation authorities and industry worldwide. They work on aircraft certification, maintenance, operations, aviation safety issues, programs, and projects. For instance, the 2015 EASA – FAA International Aviation Safety Conference on '*Global aviation safety for a global industry*' was organized in Brussel from 10th to 12th June.

The three days of the conference were articulated in eight panels of discussion followed by other introductory speeches. Here is the list of the subjects of the panels.

Panel 1: Maintenance

Panel 2: Operations (RPAS – Drones)

Panel 3: Manufacturers

Panel 4: Operations (Airline Operations)

Panel 5: Manufacturers – Adapting the Level of Involvement to the Risk

Panel 6: ATM – Future Technologies

Panel 7: Manufacturers – Supply Chain Control

Panel 8: Training – Maintaining technical proficiency.

3.5 Airworthiness Authorities' tasks

Generally, the following items are airworthiness authority tasks: [28]

- **To prescribe** airworthiness requirements and procedures.
- **To inform** the interested parties regarding the prescriptions mentioned above in different ways. The authority publishes technical regulations, technical standards, and circulars, and so on to be obtained on request or by other means.
- **To control** aeronautical design, material, manufacturing organizations, and aircraft operators to ensure that all relevant activities are complied with. It can be performed in different ways, with the proper involvement of the relevant authority.
- **To certify** aeronautical material and organizations. Legally, it is a declaration of compliance with the requirements applicable to either an aircraft or its part or a change to a type certificate and the capability of an organization.

3.6 Relations between authorities

There are some agreements between authorities to organize and harmonize their regulatory relations. Here due to the importance of certain authorities, the agreements between ICAO, EASA, FAA, and Transport Canada will be discussed.

3.6.1 EASA-ICAO agreement

On July 13, 2014, an agreement was signed between the EASA and ICAO. The subject of this agreement was “continues monitoring activities.” Some of the objectives and scope were as follow [8].

a) Practical aspects of the ICAO external audit of EASA under the USAOP
b) The interaction and coordination between ICAO and EASA regarding CMA; and
c) Other cooperation activities between EASA and ICAO

3.6.2 EASA-FAA agreement

On June 13, 2013, an agreement was signed between the United States of America and the European Union with the subject of cooperation in the regulation of civil aviation safety. The agreement requires that the FAA and the EASA develop and adopts procedures with the purpose of regulatory cooperation in civil aviation, particularly safety and environmental testing and approvals. [9]

The FAA and EASA agreed to work on the following items.

i. The functioning of this rulemaking cooperation arrangement should be reviewed.
ii. Discuss their current and future rulemaking programs, including priorities thereof and related documentation. To that end, the FAA and EASA intend to exchange on a regular basis their respective rulemaking programs and information on their implementation in accordance with Attachment I of these Guidelines.

iii. Identify rulemaking activities of common interest and corresponding working methods.

iv. Discuss possible changes in the rulemaking programs and working methods imposed by changing priorities.

v. Discuss possible contentious issues.

3.6.3 EASA – Transport Canada Civil Aviation agreement

On May 06, 2009, an agreement was signed between the EASA and Transport Canada Civil Aviation on exchange and the collection of information on the safety of aircraft which use

- EU airports,
- non-EU states airports that participate in the EU SAFA program,
- and airports of Canada. [9]

3.7 Airworthiness international and national codes

As mentioned, there are national authorities in addition to the international civil organization. Thus, ICAO is officially responsible for international civil aviation. On the other hand, national authorities are responsible for their territories [63]. However, in reality, some authorities are sufficiently powerful to influence the others, such as FAA and EASA [89]. Therefore, both international and national airworthiness codes are investigated as follows.

3.7.1 ICAO standards

One of the most complex systems interacting between human beings and machines ever created is modern aviation. Throughout the year, an airplane takes off or lands every few seconds non-stop somewhere on the earth. These flights are handled in the standard manner, whether by air traffic control, airport authorities, or pilots managing their aircraft. There are millions of

employees behind the scenes involved in manufacturing, maintenance, and monitoring the products and services in an endless cycle of flights.

Standards and Recommended Practices or SARPs are procedures and systems that are universally accepted standards. SARPs cover all operational and technical dimensions of international civil aviation, for instance, operation of aircraft, safety, personnel licensing, aerodromes, accident investigation, air traffic services, and the environment. It would be a chaotic and unsafe aviation system without SARPs.[16]

The achievement of standardization of safe, regular, and efficient air service in operation has been the primary technical task of ICAO since it was established.

International Standards and **Recommended Practices** are defined as standardization has been achieved by creating, adopting, and submitting 19 Annexes to the Convention. ICAO members agree to follow *Standards* as directives. Otherwise, any discrepancy should be notified by the member who owns it. Pursuing *Recommended practices* is favorable. To decide on the need for a standard for a specific purpose, a positive answer to the following question is necessary: 'Is it essential to apply it uniformly to all Contracting States?' Based on the Convention, the Contracting States achieve the highest practical degree of worldwide uniformity in regulations, organizing procedures concerning aircraft, airways, personnel, and auxiliary services. It will improve and facilitate air effectiveness, safety, and regularity. The 19 Annexes are described as follows:

- **Annex 1. Personnel Licensing** provides information on licensing of flight crews, air traffic controllers, and aircraft maintenance personnel, such as medical standards for air traffic controllers and flight crews. [52]

- **Annex 2. Rules of the Air** contains rules relevant to visual and flight with instrument aided.[64]
- **Annex 3. Meteorological Service for International Air Navigation** is for meteorological services for international air navigation and reporting meteorological observations from aircraft. [65]
- **Annex 4. Aeronautical Charts** contains specifications for the aeronautical charts used in international aviation.[66]
- **Annex 5. Units of Measurement used in Air and Ground Operations** lists dimensional systems used in air and ground operations. [67]
- **Annex 6. Operation of Aircraft** provides specifications to ensure a level of safety above a prescribed minimum in similar operations worldwide. [68]
- **Annex 7. Aircraft Nationality and Registration Marks** specifies requirements for the registration and identification of aircraft. [69]
- **Annex 8. Airworthiness of Aircraft** provides standard procedures for certification and inspection of aircraft. [70]
- **Annex 9. Facilitations** provides for the standardization and simplification of border-crossing formalities. [71]
- **Annex 10. Aeronautical Telecommunications** includes the following volumes. [72]
  - Volume 1 standardizes communications equipment and systems, and
  - Volume 2 standardizes communications procedures.
- **Annex 11. Air Traffic Services** covers information on establishing and operating air traffic control (ATC), flight information, and alerting services. [73]
- **Annex 12. Search and Rescue** gives information on the organization and operation of facilities and services necessary for search and rescue. [74]

- **Annex 13. Aircraft Accident and Incident Investigation** specifies uniformity in notifying, investigating, and reporting on aircraft accidents. [75]
- **Annex 14. Aerodromes** contains specifications for the design and equipment of aerodromes. [76]
- **Annex 15. Aeronautical Information Services** provides means for collecting and disseminating aeronautical information required for flight operations. [77]
- **Annex 16. Environmental Protection** includes the following volumes.[78]
  - Volume 1, specifications for aircraft noise certification, noise monitoring, and noise exposure units for land-use planning, and
  - Volume 2, specifications for aircraft engine emissions.
- **Annex 17. Security-Safeguarding International Civil Aviation against Acts of Unlawful Interference** includes means for safeguarding international civil aviation against unlawful acts of interference. [79]
- **Annex 18. The Safe Transport of Dangerous Goods by Air** provides the necessary requirements for ensuring that hazardous materials are safely transported in aircraft as well as providing a safety level protecting the aircraft and its occupants from undue risk. [80]
- **Annex 19. Safety Management**

  In 2010, the ICAO High-level Safety Conference (HLSC) initiated a new Annex for Safety Management. It contains the following items.
  - State Safety Program (SSP) framework and the eight critical elements of a safety oversight system;
  - general and business aviation activities; and
  - Retain the safety management system (SMS) requirements specific to one area of activities in individual Annexes. [32]

3.7.1.1 Standards and Recommended Practices forms

Air Navigation Bureau and its sections are responsible for seventeen out of nineteen technical annexes. Facilitation and Security annexes are under the purview of the Air Transport Bureau. The following forms are ICAO standards and other provisions.

- Standards and Recommended Practices - SARPs;
- Procedures for Air Navigation Services - PANS;
- Regional Supplementary Procedures - SUPPs; and
- Guidance Material in several formats.

“Any specification for physical characteristics, configuration, material, performance, personnel, or procedure, the uniform application of which is defined as a Standard.” [16] It is recognized as necessary for the safety or regularity of international air navigation. Furthermore, the Contracting States will conform by the Convention; on condition of impossibility of compliance, the Council must be notified based on Article 38 of the Convention.

“A Recommended Practice is any specification for physical characteristics, configuration, material, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interest of safety, regularity, or efficiency of international air navigation.” [16] The Contracting States strive to comply with the Convention. Otherwise, informing the Council of non-compliance is favorable.

“SARPs are formulated in broad terms and restricted to essential requirements. For complex systems such as communications equipment, SARPs material is constructed in two sections: core SARPs - material of a fundamental regulatory nature contained within the main body of

the Annexes, and detailed technical specifications placed either in Appendices to Annexes or in manuals." [16]

"Procedures for Air Navigation Services (or PANS) comprise operating practices and material too detailed for Standards or Recommended Practices - they often amplify the basic principles in the corresponding Standards and Recommended Practices." [16] The Contracting States strive to comply with the Convention. Otherwise, informing the Council of non-compliance is favorable.

"Regional Supplementary Procedures (or SUPPs) have application in the respective ICAO regions. SUPPs do not have the worldwide applicability of PANS." [16]

To facilitate the implementation of the SARPs and PANS and Guidance Material is published.

"Manuals provide information to supplement and/or amplify the Standards and Recommended Practices and Procedures for Air Navigation Services." [16] To facilitate implementation, they are specifically designed periodically to ensure their contents reflect updated practices and procedures.

"Circulars make available specialized information of interest to the Contracting States." [16] Circulars are generally not updated.

3.7.1.2 Annex 8. Airworthiness of aircraft

The primary purpose of Annex 8 and its concentration is a standard that defines the minimum level of airworthiness. T*he certificates of airworthiness for aircraft* are based on this annex for international recognition in accordance with Article 33 of the Convention [82-83].

Guidance material published by ICAO in this regard is Airworthiness Manual (Doc 9760) [81]. *Airworthiness Manual* is a material to guide states in uniformly establishing their national codes.

Developing its own comprehensive and detailed airworthiness code, each state has freedom, or they can adopt, select, or accept another Contracting State's code. The national code must maintain the broad standards of Annex 8 to indicate the level of airworthiness.

The content of Annex 8 [84]:

- PART I. Definitions
- PART II. Procedures for certification and continuing airworthiness
    - Chapter 1. Type Certification
    - Chapter 2. Production
    - Chapter 3. Certificate of Airworthiness
    - Chapter 4. Continuing Airworthiness of Aircraft
    - Chapter 5. Safety Management
- PART III. Large Airplanes
- PART IIIA. Airplanes over 5700 Kg for which application for certification was submitted on or after 13 June 1960 but before 2 March 2004
- PART IIIB. Airplanes over 5700 kg for which application for certification was submitted on or after 2 March 2004
- PART IV. Helicopters
- PART IVA. Helicopters for which application for certification was submitted on or after 22 March 1991 but before 13 December 2007, the Standards of this part shall

apply to helicopters intended for the carriage of passengers or cargo or mail-in international air navigation.

- PART IVB. Helicopters for which application for certification was submitted on or after 13 December 2007. Except for those Standards and Recommended Practices which specify different applicability, the Standards and Recommended Practices of this part shall apply to helicopters greater than 750 kg, maximum certificated take-off mass intended for the carriage of passengers or cargo or mail-in international air navigation.
- PART V. Small airplanes – Airplanes over 750 kg but not exceeding 5700 kg. For them, the application for certification was submitted on or after 13 December 2007. Except for those Standards and Recommended Practices, which specified different applicability, this part's standards and recommended practices shall apply to all airplanes having a maximum certificated take-off mass greater than 750 kg, but not exceeding 5700 kg intended for the carriage of passengers or cargo or mail-in international air navigation.
- PART VI. Engines – Except as noted below, the Standards of this part apply to engines of all types, used as primary propulsion units, as required in Parts IIIB, IVB, and V. The Standards of this part apply to an engine type at the time of submission of an application to the appropriate national authority for a type approval.
- PART VII. Propellers – The Standards of this part apply to all propellers, as required in Parts IIIB and V. The Standards of this part apply to a propeller at the time of submission of an application to the appropriate national authority for a type approval.[33]

Annex 13 is not directly linked to airworthiness but is capable of influencing the airworthiness requirements.

3.8 National standards

As mentioned, each Contracting State has the right to issue its standards. These standards include the requirements used to achieve their objectives which should not be less than international needs by annexes or other commitments. FAA and EASA airworthiness codes are an instance. They are for airworthiness certification of aircraft and its parts as well as relevant organizations such as design, production, and maintenance. They are in accordance with the ICAO Annexes and have an agreement with them. Thus, the certification process and criteria are not directly based on the airworthiness standards of ICAO but the national codes.

3.8.1 The Federal Aviation Administration Regulations

Title 14 of the *Code of Federal Regulations* (14 CFR) is the FAA regulations governing today's aircraft. It includes 68 regulations.

- Three volumes for *Aeronautics and Space*.
- The fourth volume about the Department of Transportation,
- and the fifth volume on NASA.

They cover the following categories:

1. Administrative
2. Airworthiness Certification
3. Airworthiness Operation

3.8.2 EASA Regulations

EASA system includes three primary levels of Regulatory material [28]:

1. The *Basic Regulation is* adopting by the European Parliament and the Council.

2. *Implementing Rules* to the Basic Regulation is adopting by the European Commission.
3. *Soft law is* adopting by EASA.

EASA develops the following three various soft laws:

- Certification Specifications (CS),
- Acceptable Means of Compliance (AMC),
- and Guidance Material (GM).

3.8.2.1.1 Initial airworthiness

On August 3, 2012, based on Commission Regulation (EU) No 748/2012, EASA established implementing rules for the airworthiness and environmental certification of aircraft. Plus, Part 21 is for 'Certification of aircraft and related products, parts and appliances, and design and production organizations.'

3.8.2.1.2 Continuing airworthiness

On November 26, 2014, based on Commission Regulation (EU) No 1321/2014, EASA established a rule on "the continuing airworthiness of aircraft and aeronautical products, parts, and appliances and the approval of organizations and personnel involved in these tasks." This Commission Regulation, updated 'Continuing Airworthiness' on the following parts:

1. Part M: Continuing Airworthiness Requirement (Annex I)
2. Part 145: Maintenance Organizations Approval (Annex II)
3. Part 66: Certifying Staff (Annex III)
4. Part 147: Training Organizations Requirements (Annex IV)

3.8.3 Requirement's applicability

The very beginning step to meet airworthiness requirements is defining the scope of work correctly and precisely in relation to the appropriate airworthiness code. There are several airworthiness codes; each includes the relevant requirements. The scope of intended work should be matched with the pre-set airworthiness standard requirements. Applicability describes the scope of work that could be matched with the concerned standard. Therefore, applicability is the essence of airworthiness requirements to consider. Thus, it is reasonable to see the applicability of a standard before taking any action. An example from EASA 21 has been provided to depict how diverse the scope of work is.

- GM 21.A.151 Terms of approval – Scope and categories

  The competent authority will issue terms of approval document(s) under 21.A.135 to identify the scope of work, the products, and/or categories for which the holder is entitled to exercise the privileges defined in 21.A.163. [34]

  The codes shown against each scope of work item are intended for use by the competent authority for purposes such as managing, administering, and filing details of approvals. It may also assist in the production and publication of a list of approval holders.

  The scope of work, the Products, Parts, or Appliances for which the POA holder is entitled to exercise the privileges defined in 21.A.163 will be described by the competent authority as follows:

  For Products:

1. General area, similar to the titles of the corresponding certification codes.
2. Type of Product, under the type-certificate.

For parts and appliances:

1. General area, showing the expertise, e.g., mechanical, metallic structure.
2. Generic type, e.g., wing, landing gear, tires.

3.9 Rulemaking process investigation

Already the appearance of authorities and their role in setting the standards are discussed. Plus, airworthiness and various international and national codes are described. Now it is time to consider the processes which develop these standards and investigate them to have a proper perspective of the contributing factors in the quality of aviation standards.

3.9.1 ICAO

As an international organization, ICAO has an incomparable role in the rulemaking process and legislation. Thus, investigation of rulemaking processes begins with the ICAO process and the relevant organizations.

3.9.1.1 Development of SARPs

Air Navigation Commission or ANC technically analyzed SARPs. The Commission may assign a specialized working group based on the nature of the proposal. The primary step to progress is meetings in the air navigation field, while correspondences play a vital role. Several meetings result in a majority of accomplishments. Through the process, they take advantage of consultative mechanisms [16].

All Contracting States have the right to participate and contribute to the air navigation meetings in an equal manner. Although international organizations may participate, they merely can observe.

ANC formed technical groups from qualified experts; ANC panels are to solve technical problems before a particular deadline that otherwise would not be appropriately solved by the established facilities of the ANC and the Secretariat.

To assist the ICAO Secretariat, Air Navigation study groups are small groups of experts provided by States and international organizations, which consult in conducting technical tasks.

Technical, economic, social, and legal problems are the responsibility of Council technical committees.

3.9.1.2 Review of SARPs' Draft

Air Navigation Commission receives the feedback of diverse groups' reports on a technical proposal for revisions to SARPs or new SARPs to conduct a preliminary review. This review is generally limited to consideration of controversial issues that require examination before the recommendations are circulated to States for comment in the opinion of the Secretariat or the Commission [16].

Air Navigation Commission submitted the original recommendations for core SARPs and any alternative proposals to the Contracting States and selected international organizations. To comment on the proposals, States typically have three months.

The comments of States and international organizations are analyzed by the Secretariat and prepares a working paper that includes the comments and the Secretariat proposals for action.

The final review of the recommendations is carried out, and the final texts of the proposed amendments to SARPs, PANS, and associated attachments are established by the Commission. The Commission presents the amendments to Annexes recommended "Report to Council by the President of the Air Navigation Commission." to the Council for adoption.

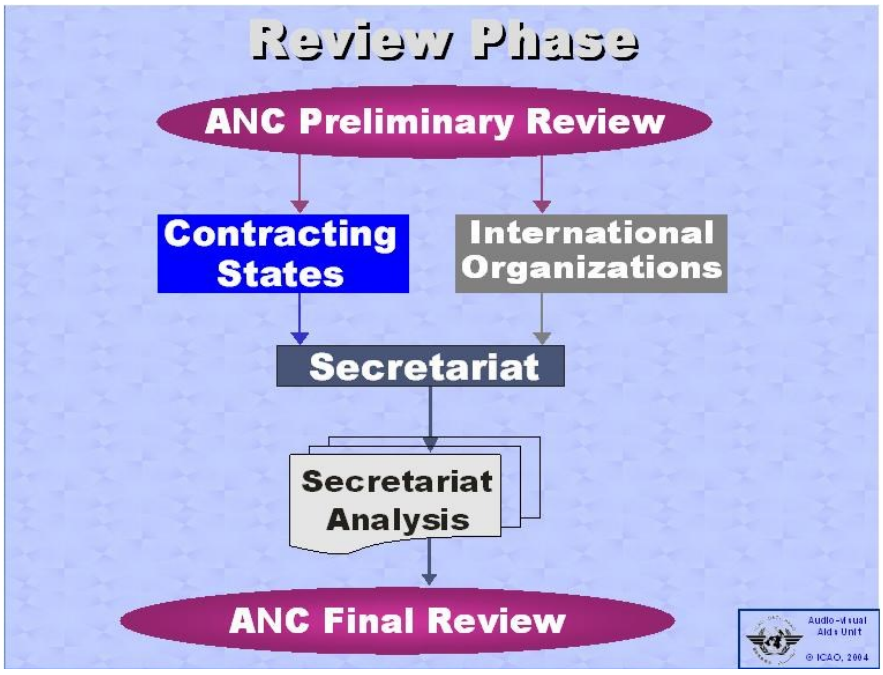


Figure 3.1 Review of Draft SARPs diagram [16]

3.9.1.3 Adoption/Publication of Annex Amendments

After reviewing the proposals of the Air Navigation Commission, on condition two-thirds of the members vote positively, the Council adopts the amendment to the Annex. "Green Edition," in two weeks of the adoption, is released to States with an explanatory letter.

The Contracting States within three months can demonstrate their disapproval of adopted amendments to SARPs. Plus, one month for preparation and transit, the Effective Date

approximately is four months after adoption by Council. There should be four months between an amendment's Effective Date and its Applicability Date. However, based on the situation, it is various. On condition a majority of States do not indicate their disapproval, the amendment put into effect on the Effective Date.

Provided there would be any differences between their national regulations, the States should notify it on the Notification Date, one month prior to the Applicability Date. The reported differences are then published in supplements to Annexes.

Immediately after the Effective Date, a letter is sent announcing that the amendment has become effective. The Secretariat takes action to issue the "Blue Edition," which is the form of the amendment suitable for incorporation in the Annex or PANS.

States must execute the amendments on the Applicability Date. On the condition, they have not notified differences. An expected applicability date yearly is set by the Council to restrict the frequency of Annex and PANS amendments.

Typically, the whole process takes two years from the Preliminary Review by the ANC to the applicability date.

ICAO’s strategic objectives are the primary document on Aviation safety. SARPs and PANS are a fundamental principle of the Chicago Convention and a foundation of ICAO’s mission and role. Further improving safety performance, States should consistently and progressively comply with SARPs and promote the execution of SARPs.

Nowadays, more than 12,000 SARPs are related to the 19 Annexes to the Convention and 5 PANS, several of which are constantly updating with the latest needs and innovations. As

mentioned, this process is structured, transparent, and multi-staged, often known as the ICAO "amendment process" or "standards-making process."

ICAO collaborates with States and industry partner organizations to deliver a coordinated, harmonized, safe, and efficient international civil aviation system. The ICAO Air Navigation Commission (ANC), through established panels of experts in diverse disciplines, works to do not leave any chances for all new or amended SARPs and PANS to be ineffective or impractical for end-users. It includes the expertise of States and international organizations to establish its technical proposals. The ICAO Secretariat supports each ANC panel. However, their Chairpersons are elected internally from the panel members.

There were 398 panel Members and 346 advisers from 61 States, which account for 31.8 percent of ICAO's 192 Member States, and 146 panel Members and 123 advisers from 35 international organizations participating in all the ANC panels in 2017.

3.9.2 FAA

As an essential national authority, FAA has an influential role in the aviation industry globally. Thus, it is crucial to identify its process of rulemaking [89, 90].

The following procedures are applicable to the issuance, amendment, and repeal of any regulation for which FAA follows public rulemaking procedures under the Administrative Procedure Act (''APA'') (5 U.S.C. 553). [22]

3.9.2.1 FAA issue rules

a) APA is the reference of the FAA for rulemaking procedures to adopt, amend, or repeal regulations. It publishes the rulemaking documents in the FEDERAL REGISTER. Otherwise, it names and distributes a copy of a rule to every person subject to it. Plus, it disseminates all documents, such as the following, to the public through the Federal Docket Management System at *http://www.regulations.gov*. [22]

   (1) An advance notice of proposed rulemaking (ANPRM).

   (2) A notice of proposed rulemaking (NPRM).

   (3) A supplemental notice of proposed rulemaking (SNPRM).

   (4) A final rule.

   (5) A final rule with a request for comments.

   (6) A direct final rule.

FAA follows the Administrative Procedure Act in case of most common sorts of rulemaking actions as follows.

a) Rules found in the Code of Federal Regulations;
b) Airworthiness directives issued under part 39 of that chapter; and
c) Airspace Designations are issued under various parts of that chapter.

The manual of the rulemaking committee contains the following information. The guidance explains how to initiate and execute the Aviation Rulemaking Committee (ARC) and Aviation Rulemaking Advisory Committee (ARAC) process. [23] **ARC charter** may contain any of the following information:

- Purpose and authority of the ARC.
- Background of the issue, including a summary of related safety data from accidents/incidents, recommendations from the National Transportation Safety Board, and other government/industry organizations.
- Historical FAA regulatory requirements, policy, and guidance.
- Relevant petitions for exemption.
- Outstanding enforcement actions.
- Objectives and Tasks of the ARC. These should be specific directions that focus on the technical and policy issues that could result in rulemaking. The ARC will use the findings from these tasks to write the recommendation report. There should be specific guidance on what to include in the recommendation report.
- Procedure outlines who the sponsor is, guidance on both the status report(s) and recommendation report, and information on reconvening the ARC after submitting the recommendation report.
- Submittal date of the recommendation report. It is best to have the submittal date earlier than the charter expiration date.
- Organization, Membership, and Administration, which describes the number of representatives chosen to be on the ARC, the participation requirements, the responsibilities of the sponsor and the co-chairs, and lobbyist guidance.
- Cost and Compensation for both the government employees and non-government representatives to work and travel for the duration of the ARC.
- Public Participation, which explains that the ARC meetings are not open to the public.
- Availability of Records, specifying FOIA requirements and costs associated, and where the public can access the charter.
- Distribution to various offices within the FAA.

- Effective Date and Duration (Typically no more than two years. The recommendation report should be submitted prior to the charter's expiration.)
- The ARC may be reinstated temporarily to assist the FAA with questions and concerns after submitting the recommendation report.

ARAC *Federal Register* tasking notice may contain any of the following information: [23]

- A detailed description of the issue.
- Background of the issue, including a summary of related safety data from accidents/incidents, recommendations from the National Transportation Safety Board, and other government/industry organizations.
- Outstanding enforcement actions.
- Historical FAA regulatory requirements, policy, and guidance.
- Relevant petitions for exemption.
- Guidance about harmonization, if it is a goal.
- Specific guidelines about the task for the working group to examine.
- Specific questions that focus on the technical and policy issues that could be addressed by rulemaking or other action.
- Initial qualitative and quantitative costs and benefits, if necessary.
- Requirement for a recommendation report, which includes documenting the majority and dissenting positions.
- Duration of the working group. Typically, a working group is established for one year. However, the length depends on the scope, magnitude, and complexity of the task.
- The urgency of the task.
- Who should receive the task: the ARAC or a subcommittee.

- If the OPR knows in advance that it will task the working group based on the recommendation report, those tasks should be included in the tasking notice to prevent delays.
- After submitting the recommendation report, the working group may be temporarily reinstated to assist the FAA with questions and concerns.

The FAA establishes an ARC to:

- Improve development of the FAA's regulations by involving members of the aviation community early in the development process.
    - Includes both industry and public concerns and opinions in the recommendation report to enhance the probability of acceptance when the FAA publishes a document.
    - Avoids placing unnecessary burdens on industry and the public because of a lack of information.
- Exchange ideas through the ARC process give the FAA additional opportunities to obtain first-hand information and insight from those parties most affected by existing and proposed regulations and other regulatory information.

A group of the aviation industry, the FAA, and public interest representatives who work together to develop and submit a recommendation report that addresses the charter's taskings is the organization of ARC.

A recommendation report describes the outcome of the research and analysis of the tasking. It contains the specific details, including:

- Summary,
- Background information,
- Research information,
- Task group assignments and findings,
- Issues because of the research and task group findings,
- Consensus, including majority and dissenting opinions, and
- Recommendations.
- The Co-Chairs lead the ARC in developing the recommendation report. The ARC should:
- Research and analyze the information they have collected.
- Actively represent their organization's viewpoints and keep management apprised of the findings.
- Should discuss, but not document, with management the overall concepts and ideas.
    - Discuss any potential concerns from the organization's standpoint.
    - Cannot share the actual recommendation report until it is submitted to the FAA.
- Take notes (suggested, but not required.)
- Identify any discussions in the recommendation report, including majority positions, dissenting positions, non-voting member positions, task group findings, and areas where the ARC cannot reach consensus.
- Mark any draft documents the FAA Co-Chair distributes for review as "DRAFT WORKING MATERIAL—NOT FOR PUBLIC RELEASE."
- Be advised on potential issues with any of the recommendations by the FAA Attorney or the FAA Economist if providing support.
- Be advised by the FAA on its position and be provided any technical or process guidance.

If the ARC is considering recommendations the FAA may not accept, the FAA Co-Chair should inform the ARC and explain why those positions would not likely be supported. This explanation should be included in the final recommendation report.

The ARAC is a formal standing advisory committee made up of representatives from:

- Advocacy groups,
- Aviation associations,
- Aviation industry,
- Interested members of the aviation community, and
- Public interest groups (to include non-profit organizations).

The FAA Administrator sponsors ARAC. The ARAC reports to the FAA Administrator, through the Associate Administrator for Aviation Safety, with information, advice, and recommendations related to aviation issues. The FAA has the sole authority to task the ARAC, which allows the FAA to work with industry and the public to improve the development of the FAA's regulations.

The ARAC's objectives are to: [23]

- Improve development of the FAA's regulations by involving interested members of the aviation community early in the development stage.
- Avoid placing unnecessary burdens on the public by providing the FAA with sufficient technical and economic information to develop well-reasoned regulatory and guidance material.

- Include the regulated industry's concerns and opinions in certain documents to reduce the probability of receiving non-supportive public comments when a document is published.
- Exchange ideas through the ARAC process give the FAA additional opportunities to obtain firsthand information and insight from those parties most affected by existing and proposed regulations.

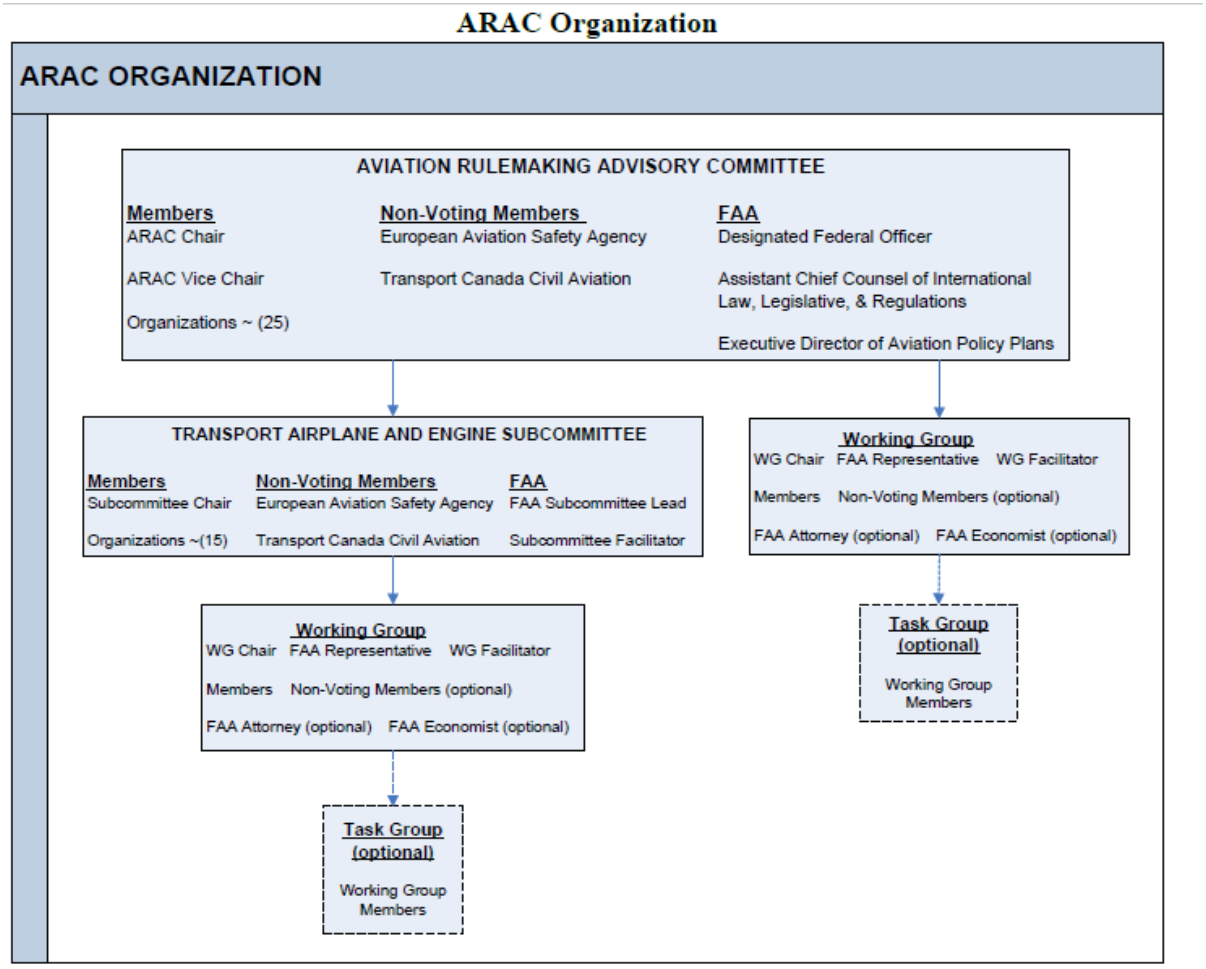


Figure 3.2 ARAC Organization chart and diagram [22]

3.9.3 EASA

As the EASA has an influential role in aviation [89,90], it is worth identifying its rulemaking process. EASA Management Board Decision number 18-2015, on December 15, 2015, prescribes the procedures for developing and issuing opinions, certification specifications, acceptable means of compliance, and guidance material by the Agency. [35]

- 'Rulemaking' means the development and issuing of rules for the implementation of the Basic Regulation.
- 'Rules' comprises the following:
  - opinions on the scope and content of the Basic Regulation and its implementing rules, consisting of a draft regulation and an explanatory memorandum;
  - certification specifications (CSs) are technical standards adopted by the Agency indicating the means to demonstrate compliance with the Basic Regulation and its implementing rules, and which can be used by organizations for certification;
  - acceptable means of compliance (AMC) are non-binding standards adopted by the Agency to illustrate the means to establish compliance with the Basic Regulation and its implementing rules; and
  - guidance material (GM) means non-binding material developed by the Agency that helps illustrate the meaning of a requirement or specification and is used to support the interpretation of the Basic Regulation, its implementing rules, and AMC.
- 'Preliminary impact assessment' (PIA) means an assessment of:
  - the need to address safety, environmental, level playing field and/or proportionality/efficiency issue, and its priority; the identified, possible alternatives

(e.g., safety promotion, focused oversight, research/studies, and/or ‘do nothing’) to rulemaking to address an existing or new issue;

- The potential safety, environmental, level playing field, or proportionality/efficiency improvement compared to the estimated cost of the proposed measure.

- ‘Regulatory impact assessment (RIA)’ means an assessment of the benefits (in terms of safety, environmental, level playing field, or proportionality/efficiency aspects) expected from the proposed rule as well as its implementation cost for national administrations and those subject to its provisions measured concerning the option not to issue a rule. The aim of the RIA shall be to improve the quality of regulations by helping ensure well-substantiated decisions and by clarifying the positive and negative safety, economic, environmental, social, or other non-safety-related impacts of a proposed rule. [35]

Once Rulemaking Program is established, these items shall be considered:

a) the objectives set out in Article 2 of the Basic Regulation;
b) the criteria set out in Article 19 of the Basic Regulation;
c) the relevant developments in European Union and international law;
d) the European Commission’s work program for legislative and non-legislative tasks;
e) the objective of harmonizing Union rules with those of the European Union’s main partners;
f) the principles of performance-based regulations;

g) identified safety hazards, risk assessment studies, and other research activities undertaken by the Agency and other organizations, including the action areas identified in the European Plan for Aviation Safety (EPAS);

h) the need to monitor the effectiveness of aviation safety and environmental protection requirements and to address any acute implementation problem as they fall within the Agency's remit;

i) the experience gained from the implementation and standardization process;

j) the need to consider the results of air accident investigations in so far as they relate to aviation safety requirements;

k) technological and scientific progress, new business models, and the need for corresponding changes to aviation safety and environmental protection requirements;

l) cross-domain issues stemming from strategic developments;

m) the needs of emerging air traffic enhancement programs from competent authorities in so far as they relate to aviation safety requirements that fall within the Agency's remit; and

n) the regular review of the rules referred to in Article 3.9 of this Decision. [35]

Regulatory impact assessment (RIA)

(1) Further to the PIA referred to in Article 3.4, a RIA shall be part of the drafting of the rules to ensure that their content is based on evidence and sound analysis and to assess the need for a performance-based approach.

(2) The RIA shall be conducted based on the principle of proportionate analysis: in-depth analysis to be performed for rulemaking projects with expected high impact and light analysis for rulemaking projects with expected lower impact.

(3) The Agency's advisory bodies and the rulemaking group members (when a rulemaking group is set up) shall support the development of the RIA by providing economic and other quantitative data.

Drafting of rules

In case of the drafting of rules, these items shall consider:

a) European Union law, and in particular the objectives and essential requirements set out in the Basic Regulation;
b) ICAO Standards and Recommended Practices (SARPs);
c) harmonization objectives with other aviation authorities and international organizations under the applicable arrangements with third parties;
d) the principles of performance-based regulations and related criteria for their implementation;
e) relevant findings and recommendations of air accident investigations;
f) existing industry standards;
g) timely implementation of the rules, taking into account translation delays;
h) compatibility with existing rules and interfaces with other ongoing rulemaking projects;
i) state of the art and best practices in aviation safety and environmental protection requirements;
j) risk assessments conducted and available data;
k) feedback from the implementation and standardization process;
l) cross-domain issues stemming from strategic, scientific, and technological developments; and
m) the outcome of the RIA being drafted, if applicable, as specified in the ToRs. [35]

Chapter 4:

Solution Approach

In this chapter, methodology, tools, and techniques are discussed. A Model to analyze the quality and reliability of requirements, the relevant diagrams, processes, sub-processes, and attributes are the main concentration of this chapter.

4.1 Systems engineering theory and methodology

A system is an integrated combination of resources like human resources, machines, and instructions that would be capable of meeting at least an intended requirement. Another necessary definition to know is system engineering. There are three as follows.

- A logical sequence of decisions and activities transforming an operational need into a description of system performance parameters and a preferred system configuration is system engineering. [17]
- "An interdisciplinary approach that encompasses the entire technical effort evolves into and verifies an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs." [18]
- An interdisciplinary, collaborative approach evolves and verifies a life-cycle balanced system solution that satisfies customer expectations and meets public acceptability. [19]

Thus, systems engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer needs.

Complex systems commonly call for a diverse appeal to technology requiring many kinds of specialists. Complex systems consist of many elements that must be organized into families, each arranged in a hierarchy. These families and elements must be assigned to engineering teams, organizations, or companies specializing in designing particular kinds of things. These elements must be designed to interplay with the others in the system and the system environment to satisfy the system's needs.

The system development process most likely to succeed has evolved from many years of experience. It involves a three-step process accomplished within an infrastructure of sound technical management. The first step in that process is to define the problem as a prerequisite to solving it. Any detailed design effort should be preceded by releasing a specification containing all of the essential characteristics and nothing else. The second step involves solving the problem defined in the specification, referred to as synthesis. This step is commonly broken into three sub-steps:

(1) design, creating an engineering design solution,
(2) procurement translating that solution into a list of suppliers of materials needed to manufacture and assemble the solution and gaining access to them, and
(3) the manufacturing of the solution. [24]

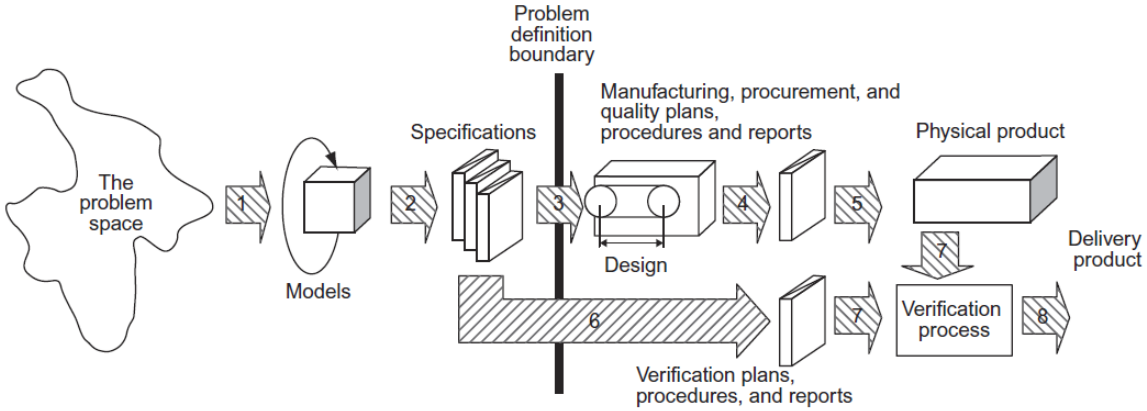


Figure 4.1 System development transformations [24]

The fact is that it is not hard to write requirements. It is hard to know what to write them about and determine appropriate numerical values to include. A requirement is an essential attribute or characteristic for a system or an element to develop a design for the item before efforts. The attribute is coupled with the attribute's value and unit's information based on a relation statement. Each requirement statement in a specification must satisfy several characteristics, including

(i) proper grammar,

(ii) appropriate use of shall, will, and other keywords, and

(iii) rigid compliance with a format.

System requirements analysis (SRA) is a structured or organized methodology for identifying an appropriate set of resources to satisfy a system need and the essential characteristics (requirements) for those resources that provide a sound basis for designing or selecting those resources. It transforms between the customer's system need and the design concept energized by the organized application of engineering talent. The basic process decomposes a customer need statement through a systematic exposition of what the system must do to satisfy that need.

The need is the ultimate system requirement from which all other requirements and the designs flow.

It shows that system engineering could be considered an acceptable option to design the system required by the competent authority to operate a business in the aviation industry, such as designing or manufacturing an aircraft. However, there are other options. The objective here is not to demonstrate that system engineering is the best choice to do that. Instead, system engineering is applied as a reasonable solution to verify the different aspects of the requirement.

Although there are some steps to take before requirement analysis based on the system engineering theory, this thesis's primary concentration is requirements analysis. Plus, the development phase of system engineering has apparent similarities with the Define and Measure phases of DMAIC, which was discussed in the previous chapter. Thus, to prevent repetition, that information does not mention for the second time.

4.2 Requirement's analysis strategies

Before elaborating on requirements analysis, there is some vital information in this regard to consider. The majority of requirements analysis projects pursue one of the four following fundamental strategies. [24]

(i) structured analysis or modeling,

(ii) cloning,

(iii) freestyle, and

(iv) question and answer.

4.2.1 Freestyle Strategy

It is possible for an experienced system engineer, familiar with the product line appropriate to the customer's need, to craft a system requirements document based on a customer need statement and minimal additional information entirely from scratch on a word processor. It is a freestyle approach since the engineer makes no obvious appeal to any structure to gain insight into the appropriate requirements.

The outcome will not always be desirable. Freestyle imposes the danger of possible incompleteness due to a lack of rigor in the analysis process. It requires a very experienced analyst to have any hope that this approach will succeed. Regardless of who does the work, the results should be scrutinized by project personnel most familiar with the customer's needs. Probably, they are not able to see their own mistakes, but anyone else may see them. So, it should always take advantage of the low cost of criticism through peer review, as the rulemaking procedures of ICAO, FAA, and EASA.

When this strategy is followed as the only requirements analysis approach on an extensive program, it can be characterized as chaos. There is a likelihood that the principal engineers responsible for the many lower-tier specifications will not effectively communicate in an organized way. The system requirements will not properly influence the requirements for lower-tier items.

4.2.2 Cloning Strategy

A program that is already established with an extensive library of specifications, however, they were created, can have a very successful requirements analysis experience without applying the structured analysis approach. Such a program has a tremendous storehouse of requirements

in the form of the many specifications on hand. While one may question the quality of that storehouse as a function of how it was obtained in the first place, it has probably withstood the test of time. These documents can be used as an inspiration for others through a process called cloning, which is a scheme for using an existing document as the basis for another. [24]

4.2.3 Question and Answer Strategy

In the third strategy, an agent demands questions from the customer about their needs and turns the answers into requirements for inclusion in top-level specifications. This process should be part of every requirement analysis activity. Thus, those who ask the questions need machinery to encourage good questions and all their interest. Plus, knowledgeable people must respond to these questions.

Q and A combined with structured analysis provides the best combination as it uses simple pictures (models) to stimulate a conversation between one party with questions and another who may have answers.

4.2.4 Structured Analysis or Modeling Strategy

Structured analysis is synonymous with the term system requirements analysis as applied in the aerospace industry. An organized and systematic environment is provided by the structured analysis strategy to decompose a significant problem into a series of smaller ones. The solution of all minor, more specialized problems results in a solution to the larger one. This strategy is followed throughout the Analysis phase of this thesis.

4.3 Requirement's analysis

Requirements analysis generally should result in a clear understanding of:

- Functions: What the system must do,
- Performance: How well the functions must be executed,
- Interfaces: the system executes in which environment, and
- Other requirements and constraints.

No matter what sort of system is intended for consideration, the principal goal is to fulfill the requirements [85]. The requirements have been divided into various categories based on where they came from, including Customer Requirements, Functional Requirements, Performance Requirements, Design Requirements, and Derived Requirements to Allocated Requirements [13].

Inevitably, the process of meeting requirements is a sophisticated subject. However, there would be no guarantee to reach a satisfactory result ultimately unless, at the first step, the requirements are investigated appropriately. In other words, if the requirements do not define correctly and adequately, there would be no possibility to fulfill them correctly. Provided that the requirement analysis has various aspects, the quality of requirements is essential before taking any further action. [39] Obviously, the quality, in this case, is a generic term that needs to be more specified to take practical action. Therefore, there is a need to be familiarized with the following definitions prior to further progress.

The requirement is any sort of needs to be satisfied. There are various requirements as below.

There are six types of requirements categories as follows. They are divided Based on each category's characteristics.

- Customer Requirements

The operational requirements which show the fundamental needs are categorized as customer requirements. Measures of effectiveness and suitability (MOE/MOS) are some instances of the expectations from the systems in the form of mission, objectives, environment, and constraints.

- Functional Requirements

The requirements that come from requirement analysis are the highest level of function for functional analysis. They are required functions, tasks, actions, or activities that must be carried out.

- Performance Requirements

The boundaries of a mission or function that must be accomplished. They can be in the form of quantity, quality, timeline, etc. When it comes to requirement analysis, performance requirements according to system life cycle factors develop among all defined functions. Plus, the certainties and importance's degree besides relations to other requirements depict.

- Design Requirements

How to build, buy, or carry out the product or processes shown in technical manuals or data packages.

- Derived Requirements

The requirements come from higher-level like for high-speed vehicles, a low weight design could be required.

- Allocated Requirements

As a result of dividing or breakdown a high-level requirement into multiple lower-level requirements.

4.4 Quality

Quality could be variously defined based on people's responsibilities in the production-marketing value chain. Furthermore, there is no end to quality which makes it an evolving definition [14]. A study in the eastern United States depicts managers' notion on quality as bellow:

- Perfection
- Consistency
- Eliminating waste
- Speed of delivery
- Compliance with policies and procedures
- Providing an excellent usable product
- Doing it right the first time
- Delighting or pleasing customers
- Total customer service and satisfaction

To some extent, all of them could be true. However, it is not practical to analyze the quality of a requirement based on these notions. There is a need for robust criteria, processes, tools, and techniques to develop a model that allows a user to systematically analyze requirements' quality and figure out the exact problem and its effect on the system.[86]

4.5 Requirements Attributes

It is essential to consider all possible quality concerns to have reliable, sufficient, and appropriate criteria for analyzing requirements. There are seven types of requirements' attributes based on which the quality of a requirement can be determined [13, 40, 47]. They almost cover every quality possibility.

1. Achievable

   A requirement is achievable when it shows a need for a solution at an affordable cost.

2. Verifiable

   The quantity of a need should be clearly defined, which permits verification. Excessive, sufficient, resistant, etc., are not acceptable.

3. Unambiguous

   A requirement should be clear and non-vague. Plus, it needs at least one meaning.

4. Complete

It must include all information needed to understand customer requirements, mission profiles, operational and maintenance needs, and other constraints like environments.

5. Need

It must not address the solution like how to meet the requirement. Instead, it should be shown in the form of need like what and why.

6. Consistent

There should be consistency between all requirements. Any sort of conflict should be avoided.

7. Hierarchy

The level of requirements should be suited for the intention and compatible with the others. Neither too detailed nor too general.

4.6 Flowchart and process

As mentioned, seven essential and comprehensive attributes are considered to analyze the requirements ranging from achievable, verifiable, unambiguous, complete, need, consistent to hierarchy. At the same time, the order and process of identifying their level of conformance with the requirements is a crucial subject to work on. Plus, there are some sub-processes and criteria to determine how each step should be taken. Eventually, the requirements will be analyzed and recognized as either acceptable or not acceptable from the quality perspective. It

enables system engineers to negotiate with requirements owners about a possible opportunity for improvements.

- The process of evaluation of the requirement's quality begins with determining conformance with the need attribute. If the requirements include the solution, it is not acceptable. Inevitably, there should be a need for a solution. In the case of a solution without a need, the need is missing. As a result, there is no further step to take.
- If not, the next step is to breakdown the requirement as much as possible to reach the lowest layer of required actions to analyze the requirement hierarchy.

Work breakdown structure (WBS) is a tool to breakdown the different levels of a project. There are many applications. However, here to identify the position of each activity in terms of hierarchy, WBS is applied.

- Once the requirement has been singled out, any pertaining predecessor should be identified. Any of them must be defined as either a new one or an existing one. Otherwise, the process can be reached the next step.
- In the case of consistency, the interface's identification is the following action to take. A requirement may have no or more than one interface.
- Provided that it has any interface, it may be internal, external, or a mixture of both. Thus, the relation between interfaces should be determined, which could be one of the following options. Conflict, redundancy, compatibility.
- While reaching redundancy means any possible action probably has been taken at the first occurrence. In the case of conflict, there is no further action to take. However, when it comes to a compatible option, the next step should be taken.

- A requirement should be verifiable. Thus, if it is not, it would be failed. Otherwise, the process reaches the result as the following diagram shows.

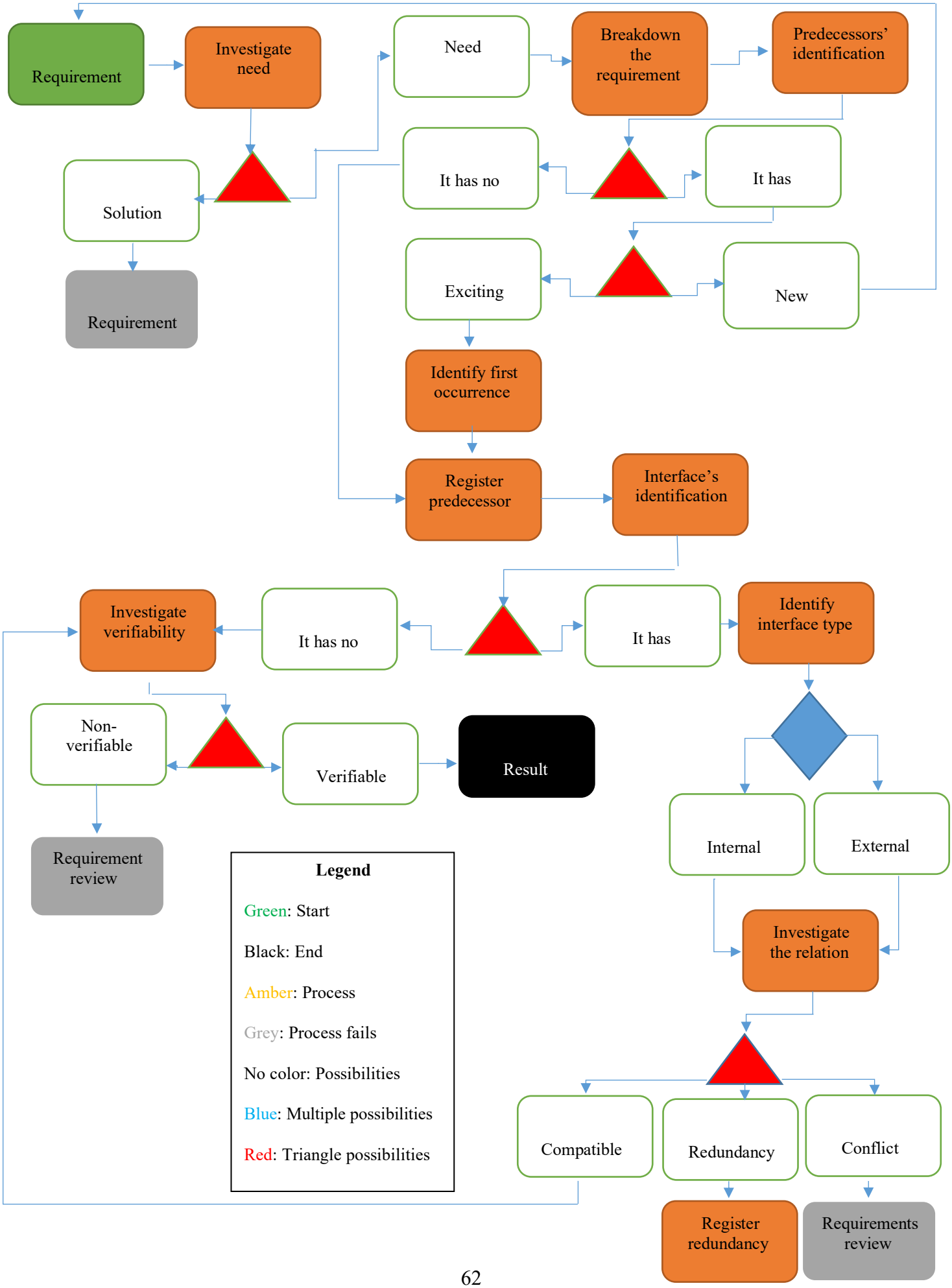


Figure 4.2 Requirement analysis diagram 1

4.7 Sub-process and criteria

Besides the primary process mentioned in the above diagram, some sub-processes need to be considered and explained as below.

- Hierarchy

The number of actions derived from a single requirement should be apparent based on the requirement breakdown results. The average number of actions would be an acceptable level of hierarchy. Either Higher or lower numbers should be registered as the higher or lower level of hierarchy.

- Verifiable

In accordance with the definition, the requirement should be measurable. Therefore, any requirement without some obvious boundaries cannot meet this criterion.

4.8 Analysis of the result

When the result comes out from the diagram depicted in figure 4.2, the next step is to analyze it. Previous steps clarified if a requirement fails to meet specific criteria, including need, hierarchy, consistency, and verifiability. However, the other criteria, like unambiguous, complete, and achievable, are more complicated. Thus, to determine the conformance of the requirement with them, more analysis is needed.

There are three possibilities for the result as follows:

1) The analysis is left incomplete

2) The analysis results in requirement review at some point

3) The analysis has reached the result

In the case of the two first options, it should be determined if the requirement is ambiguous or incomplete. Plus, it could be a mixture of both. While, if the analysis ends up with the result, it should be clarified whether the requirement is achievable.

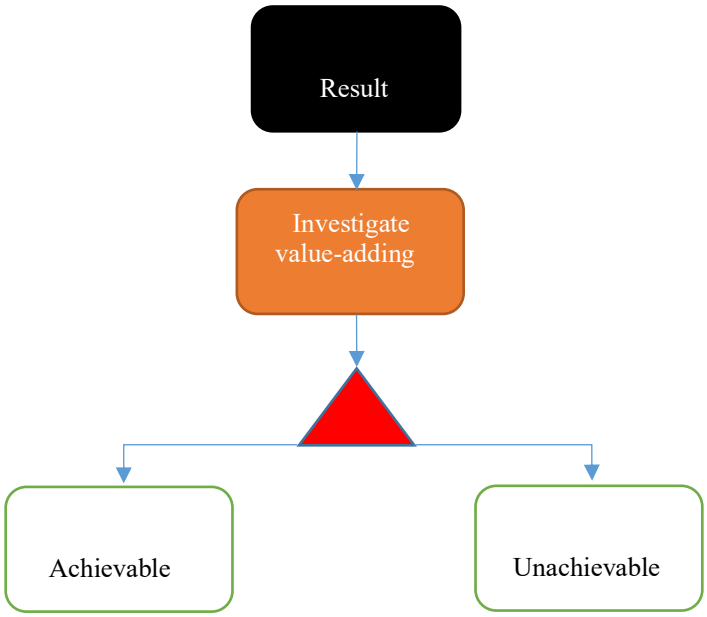


Figure 4.3 Requirement analysis diagram 2

4.9 System Affordability

System affordability means spending money not only on value-added activities but also on those activities supporting value-added activities. Their functions are required for the system. Thus, it is the correct cost of the system. While the system is not affordable to pay for non-value-added activities, which are waste and wrong cost [15].

- Value-added

What the customers desire to pay for is value-added, and anything else is non-value-added.

4.9.1 Available funds

Probably when it comes to affordability, available funds could be a critical factor to consider. However, there are at least two different approaches, in this case, the first of which is the customer approach, and the second is the administration approach. As a customer, it is mandatory to know if the required funds are available. On the other hand, as an administration, one of the concerns is the finical ability of a business applicant. Thus, available funds could not affect the concern of this thesis regarding system affordability. Instead, it is the concern for applicant affordability. [45]

4.9.2 Risk-based approach

The keyword is the affordable cost to investigate whether the requirement is achievable or not. When it comes to the affordable cost, it can be considered what would happen if the requirement were disregarded. In this scenario, the consequences of intentionally disregarding a requirement are the subject of matter. On condition either nothing happens, or the consequence is not related to value-added activities, the requirement probably is not value-added. Therefore, it is not affordable for the system to support a non-value-added activity. In doing so, the best technique is Design Failure Mode and Effect Analysis (DFMEA) [46].

4.9.3 DFMEA

Initially, the system structure is analyzed to determine the scope of the DFMEA. It results in the definition of the structure and limits of the system. Thus, a functional analysis is carried out. To do so, from various disciplines, subject matter experts build a cross-functional team. Once the function of the system has been described, various possible failure modes are determined [53].

To figure out the potential causes, DMAIC provides a couple of practical techniques, including root-cause analysis and cause-and-effect diagram [14]. The potential failure effect is determined within the identified items as the severest.

By performing tests and analysis to better understand the probability of failure, the prediction of the reliability of a product can be improved. Thus, the probability of failure may be decreased. This decrease is characterized by a detection score (PD) for each cause activity combination [54].

The DFMEA technique provides not only the results needed for affordability analysis but also the other sorts of information that are helpful in terms of reliability. However, there is no access to the factual information showing the initial aim and consequence of missing or improperly compliance with the chosen requirements. Instead, the best possible assumption has been held.

Required columns are added to the RTM excel file as shown in the following table to facilitate tracking and calculation of DFMEA analysis.

Table 4.1 DFMEA application example

Item no	Requirements	Required Outcomes (deliverables)	DFMEA							
			Potential failure mode	Potential failure effects	Severity	Potential causes	Occurrences	Current control	Detection	Risk priority No.
1	Any person may apply for a production certificate if that person holds, for the product concerned — (a) A current type certificate,	Eligibility	Revoke a Type certificate	Lost eligibility	5	Nonconformity with type design	2	Does not define	5	50
2	(b) A supplemental type certificate, or	Eligibility	Revoke a Supplemental Type certificate	Lost eligibility	5	Nonconformity with type design	2	Does not define	5	50

Based on the previous steps, the risk priority number (RPN) is calculated in this technique. It is the product of the multiplication of the severity of effect (SE), probability of failure occurrence (PFO), and probability of detection (PD). These three terms represent the three categories of contributing factors in the RPN [30]. To calculate RPN following equation is applied. [46]

$$RPN = SE \times PEO \times PD \tag{3.1}$$

Through the following table, SE, PFO, and PD levels for each failure mode are determined on a scale from 1 to 5. However, the scale of the following table could be modified based on the nature and specifications of the intended project.

Table 4.2 Failure mode levels

Titles	Level 1	Level 2	Level 3	Level 4	Level 5
Severity	Low risk to the system	Moderate risk to the system	High risk to the system	High risk of mission fail	Mission fail
Occurrences	Unlikely probable	Low probability	Moderately probable	Highly probable	Extremely probable
Detection	Extremely probable	Highly probable	Moderately probable	Low probability	Unlikely probable

4.10 Reliability

Successful deployment of a complex, high-reliability system that meets the user ‘s expectations for reliability, maintainability, and availability is dependent on the definition, execution, and monitoring of a set of interrelated tasks. The acquisition cycles depicted in figure 3.4 can span multiple months or even years.

The first step is to derive the requirements for the specific system being acquired. Following that, a set of incremental activities should be carried out to establish increasing levels of confidence. The system is designed, built, and tested to meet those requirements of the design and development phases. Completing the acquisition cycle is an approach to monitoring performance in the field to determine whether the resulting system meets or exceeds requirements over its lifetime. This information then forms a foundation for the specification of new or replacement systems. The number of test hours needed to obtain a statistically valid result is a fundamental statistical limitation for reliability acceptance tests. [25]

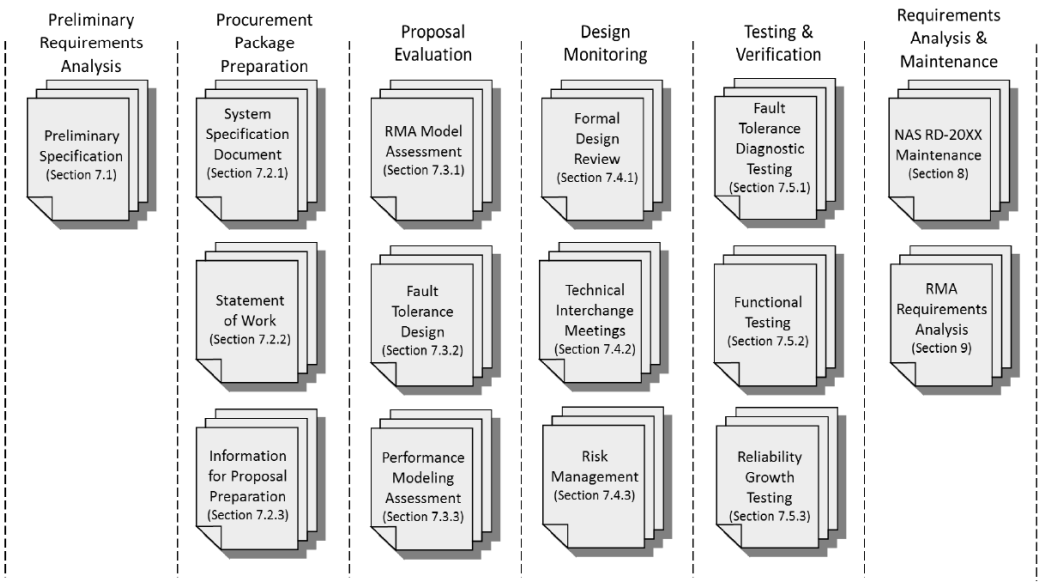


Figure 4.4 Acquisition Process Flow Diagram [25]

To the extent that reliability was a consideration, the design engineer was responsible. Safety features were either present or not in the design due to the design engineer's knowledge of what contributes to product safety. The design engineer was a generalist in a broad field, such as mechanical engineering. Systems could be designed that appealed to a relatively narrow range of engineering knowledge, such as mechanical systems or electrical systems, rather than the systems we commonly see now that include a rich mixture of mechanics, electronics, hydraulics and fluid dynamics, aerodynamics, computer software, and many other fields.

In the case of requirement analysis, there are three levels of reliability. The first level is about how reliable is the requirements to provide a system design that realizes the expectations. In other words, to what extent does the requirement guarantee that the design would meet the expectations in the best-case scenario. This step is the requirements analysis level [37].

The second one is how the design is reliable in developing a system that realizes the design's expectations, design verification. [54] The third level is how reliable the system is to achieve

the objective. Obviously, the first and second levels can impact the final result even if the system is highly reliable in the third level [41].

The third level is a well-known subject. The reliability of a system is not a new initiative to focus on in this thesis. Investigating the second level of reliability (design verification), DFMEA was applied in this thesis, but the intention was affordability. The other options are available for design verification. Even in the event of the DFMEA application, there is a need for modification based on the new objective, design verification. On the other hand, it is vital to consider a solution to predict the reliability of the first level, which can prevent adverse effects on the following levels.

4.10.1 Assumption

As quality has a direct relation with reliability. The assumption is that the same attributes affecting quality are impacting reliability as well. [29] In other words, in case of non-conformity or poor conformance with the following attributes, failure of the requirement is predictable. Thus, the following items are considered as contributing factors to investigate the reliability of a requirement. It means they can guarantee that a design or product meets the expectations in the first level [41].

The requirement conformance with the following attribute is analyzed to predict the reliability of each requirement. If the requirement is conformed with the attribute, it shows by 1. Otherwise, 0 demonstrates the result. The requirement analysis process was previously explained.

- Achievable

- Verifiable
- Unambiguous
- Complete
- Need
- Consistent
- Hierarchy

The sum of attributes conformance calculation of each requirement could not exceed 7 as there are 7 attributes. This should be divided by 7, which is the sum of the maximum possible values. The result can be between 0 and 1, which shows the prediction of the reliability of the requirement.

Although it is possible that the attributes do not have the same effect on reliability, non-conformity with them results in a failure that causes mission failure. Plus, there could be some cases that are not 0 or 1. Instead, they comply with the attributes to some extent. However, to simplify the calculation and follow this assumption's goal, this possibility is not essential. The goal of this assumption is to predict whether the reliability of a requirement is acceptable. It is not to precisely calculate the level of reliability with regards to each attribute.

In this way, each requirement is assumed as a system component, with certain restrictions. Therefore, the reliability of each requirement could be calculated as follows:

Reliability of a requirement = R

$$R_i = \sum_{j=1}^{n} x_{ij} \Big/ \sum_{j=1}^{n} \max x_{ij} \quad (3.2)$$

$x = Value\ of\ the\ requirement\ conformance\ with\ the\ intended\ attribute$

$i = Requirement$ number

$j = Attribute$

- To simply the prediction, the value of x is dedicated 0 or 1 (binary)
- In this assumption, there are 7 attributes. Thus, the value of n is 7.

If there are any interfaces between a given requirement and any other internal or external entity, it should be verified that this interface matches which kind of reliability relation including series to parallel.

Reliability block diagrams (RBDs) or predictive fault trees is to show the logic of how a failure could adversely affect the intended outcome or "mission". Generally, the segment or system reliability of n blocks are as bellow. [29]

Blocks A and B in the following Figure are "series" units. In a series unit, the failure of either component leads to system failure.

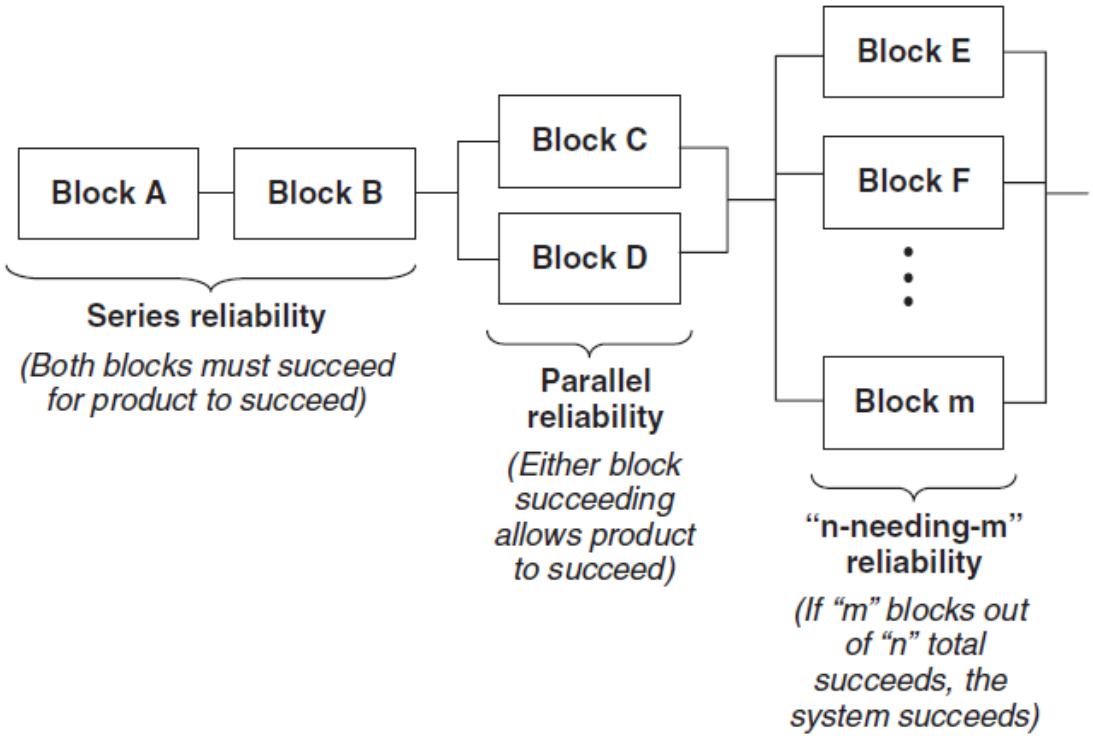


Figure 4.5 Reliability Block Diagram [29]

Provided that it could be a series segment, the reliability should be calculated as follows.

$$\text{Series segment reliability} = R_{Segment} = R_1 \times R_2 \times R_3 \times R_n \qquad (3.3)\ [29]$$

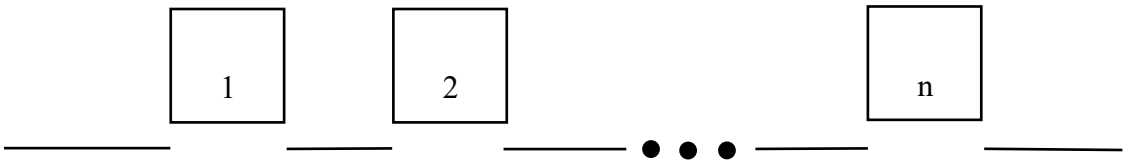


Figure 4.6 Sample of Series system

The C and D components are parallel or redundant. In case of failure of one of them, the second would support the system to succeed. It means, to fail the system, both must fail. The probability of both failing is the result of their unreliability 1−R, or in this case,

Parallel segment reliability = $R_{Segment} = 1 - [(1 - R_c) \times (1 - R_d) \times \ldots\ldots \times R_m]$ (3.4) [29]

Chapter 5:

Case Study

In this chapter, the proposed model to carry out requirements analysis is applied to CFR-14 Part-21 Subpart-G. SIPOC, DFMEA, Building block diagram, are a part of the solution. As a result, the contributing factors, Pareto charts, and the analysis results are explained in this chapter.

5.1 Data collection and Sampling

As mentioned, this work's main objective is to investigate the standards applicable to specific organizations operating in aviation industries, such as design or production organizations. Previously, it was explained which standard could apply to such organizations.

As there are many common points when it comes to production and design organizations with regards to general quality systems' requirements, one of them could cover another one, with some recognizable discrepancies. Furthermore, there are the mentioned similarities with maintenance organizations.

Due to limited resources, there is no way unless prioritize one standard related to an organization. Otherwise, the consistency of requirements will be compromised, which can adversely affect this work's result. It means requirements pertaining to the production organization were chosen instead of various standard requirements related to the diverse organizations.

As most of the aviation industry and its products are under the influence of two leading authorities, FAA and EASA, which was explained previously, one of them could be an acceptable option to be chosen.

As the framework of requirements is not the same in design organization between FAA and EASA, it cannot probably be the best option to do any further analysis between them like benchmarking. Thus, production organization is selected.

The data collecting method is clustered. The unit in a clustered sample is subgroups of the population rather than individuals. The clusters result from the deviation of the population into subgroups, which are randomly selected. All members of the chosen clusters are included in the study in single-stage cluster sampling [20]. The FAA requirements applicable to a production organization are selected through this method.

5.2 RTM

The process of identifying, documenting, and managing stakeholder needs and requirements to achieve objectives is collecting requirements. The primary merit of this process is that it supplies the basis for defining the product and the project scope and other sorts of processes, resources, and required actions [87].

A traceability matrix is a table related to the requirements in which intended information is mentioned from the base to the outcome. This tool provides an opportunity to trace that each requirement adds business value. In doing so, the relationship between the outcome of requirements and project objectives could be verified. It means eliminating the chance of missing a requirement throughout the project life cycle or its approval. Plus, it is a change management structure. It can include the following items but is not restricted to them.

- Business needs, opportunities, goals, and objectives;
- Project objectives;
- Project scope and WBS deliverables;
- Product design;
- Product development;
- Test strategy and test scenarios; and
- High-level requirements to more detailed requirements.

Attributes associated with each requirement can be recorded in the requirements traceability matrix. These attributes help to define critical information about the requirement [21].

As the definition mentioned, an RTM is drawn to organize and trace the requirements. The details and information about the RTM used through this work are as follows. It is about how to draw a table for RTM in Excel.

Table 5.1 RTM first part

Item no	Standard (source)	Code	Title	Requirements	Requirement Interface type
1					

1. On the first right column, the consecutive number of requirements is written. This number shows how many items have been collected. There is a difference between this number and how many codes have been collected since a code could include several items. There is no way unless to decompose a code into single items to make the analysis possible.

2. The second column is the source of the requirement to address and verify as it is necessary. In this work, the source is the CFR14- part21-subpart G.
3. The third one is the identification code of the requirement based on what is given by the standard.
4. The Forth column is for the title. In this case, the standard itself determines the category of the requirements. Otherwise, the title shows the requirement category.
5. After that, the requirement itself without any modification or edition is mentioned.
6. The next column belongs to the requirement interface; if there is any, it can be external, internal, or both.

Table 5.2 RTM second part

Action Sequence	Total number of actions		Precedence		Action required	Doer	Required Outcomes (deliverables)
	More than average	Less than average	Action 1	Action 2	Action required		

7. The seventh column is for the action sequence number, which shows how many series of actions belong to this requirement.
8. The following two columns show the total number of actions required by the requirement to be met. Plus, it shows if it is either more or less than the average.
9. After that, the first precedence action should be written.
10. Then, the second precedence action should be written.
11. The eleventh column belongs to action required directly by the requirements.
12. After that, Doer, who is supposed to take action, is mentioned.

13. Next to it, a deliverable (outcome) should be written.

Table 5.3 RTM third part

DFMEA							
Potential failure mode	Potential failure effects	Severity	Potential causes	Occurrences	Current control	Detection	Risk priority

14. The fourteenth column belongs to the Potential failure mode, which is usually the worst possible failure that could happen.
15. The next one is the severest consequence of the worst failure mode.
16. The next column is to determine SE (severity) number.
17. Then, potential causes should be written in the next column.
18. The eighteenth column is for occurrences probability.
19. After that, any current control needs to be mentioned.
20. Afterward, the probability of detection should be written.
21. Moreover, the Risk priority number is the last column for DFMEA purposes.

Table 5.4 RTM fourth part

Requirements analysis (Attributes)							
Result	Achievable	Verifiable	Unambiguous	Complete	Need	Consistent	Hierarchy

22. The twenty-second column belongs to the result of attribute analysis. If any of the seven attributes' analysis results in a "not acceptable" response, the final result is not acceptable. Otherwise, it would be acceptable.
23. Next to it is the column to mention the result of achievable attribute analysis.
24. Thereafter, if the requirement is verifiable, the result should be written.
25. After that, if the requirement is unambiguous, it should be mentioned.
26. The next column is where to write down the result of the "complete" attribute analysis.
27. Thereafter, if the requirement is acceptable in terms of the need, it should be noted.
28. Consistent is the following attribute. The result of the analysis should be written in this column.
29. The last attribute is the hierarchy; the analysis result should be noted in the twenty-ninth column.

Table 5.5 RTM last part

Interfaces (Relation to other requirements)						Reason of incomplete	Reason of Ambiguous
External	External	External	Internal	Internal	Internal		

30. Once interfaces are identified, if any is found, they should be categorized into external or internal. In the case of external, the thirtieth column is the place to mention the first external interface.
31. After that, the second external interface should be written.
32. The thirty-second column belongs to the third external interface.
33. Next is the place to note the first internal interface.
34. After that, a second internal interface is mentioned.
35. Moreover, the thirty-fifth column is to write down the third internal interface.
36. If the requirement is marked as incomplete, then the reason is noted in the thirty-sixth column.
37. If the requirement is noted as ambiguous, then the reason for that could be found in the last column.

Apparently, Excel software is used to facilitate working with this RTM and reduce the possibility of error. The first row of tables belongs to titles and is highlighted with various colors based on the category of the information. Plus, to ease identifying non-conformity with attributes, they are highlighted by red color. This RTM includes 65 items coming from 16

requirements codes. The method and more analysis information are explained under the analysis topic. This file, as appendix A is attached to this report.

5.3 SIPOC

SIPOC is a diagram which is for identifying Supplier, Input, Process, Output, Customer. SIPOC helps to organize the information for more efficient and practical analysis.[43] That is why this tool is applied to the current thesis to have an overview of every aspect of this work in the form of a diagram.

As the following diagram shows, ICAO is the supplier. Various types of international demands and concerns are the input of the rulemaking process. The result of the process is Annexes, SARP, and other sorts of ICAO documents, as mentioned. Finally, the customer is any member state which means any country that is a member of ICAO.

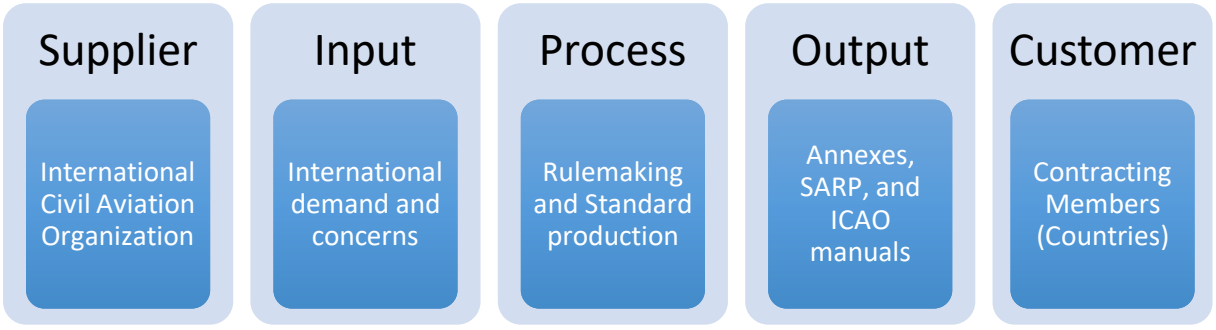


Figure 5.1 First level of SIPOC diagram

Thereafter the output of the previous layer is considered as the input of the next layer. Thus, for example, FAA, which is one of the customers of Annex 8, here is the supplier of national regulation relating to airworthiness. However, the output is not exactly the requirements of the annex, as it was explained before. Instead, all contracting states attempt to legislate a set of

regulations with regard to the annexes. Otherwise, they must inform ICAO about the discrepancies.

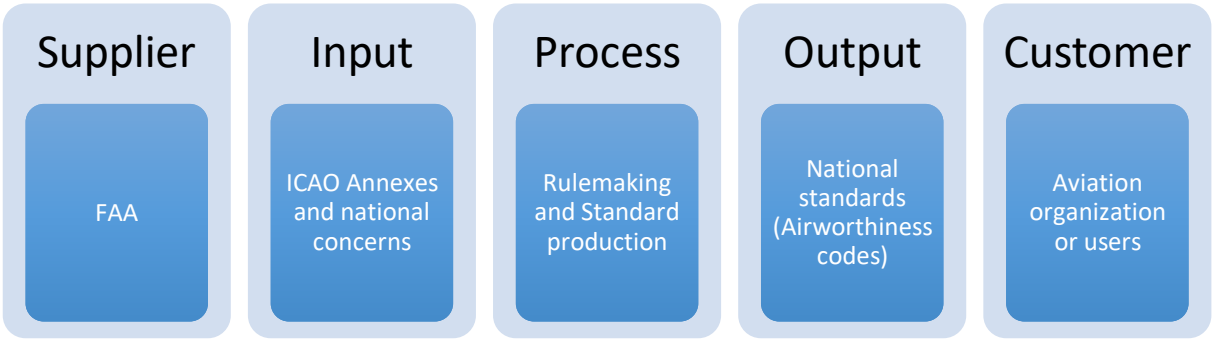


Figure 5.2 Second level of SIPOC diagram

The next layer of SIPOC is to reach a system required for an aviation organization such as a design or production organization. However, this is not identical in all cases since it is the responsibility of any aviation organization applicant to design a system that complies with the requirements, thereafter, demonstrating the confirmation to the competent authority. While among various authorities, there are some recommendations or solutions like a Means of Compliance (AMC) and Guidance Material (GM) when it comes to EASA and Advisory Circular (AC) in case of FAA. Figure 5.3 shows a diagram of the applicability of System engineering theory in this case. Previously, the diverse aspects of this solution were discussed in further detail.

The system engineering process includes three main phases, Development phasing, System engineering process, Life cycle integration.

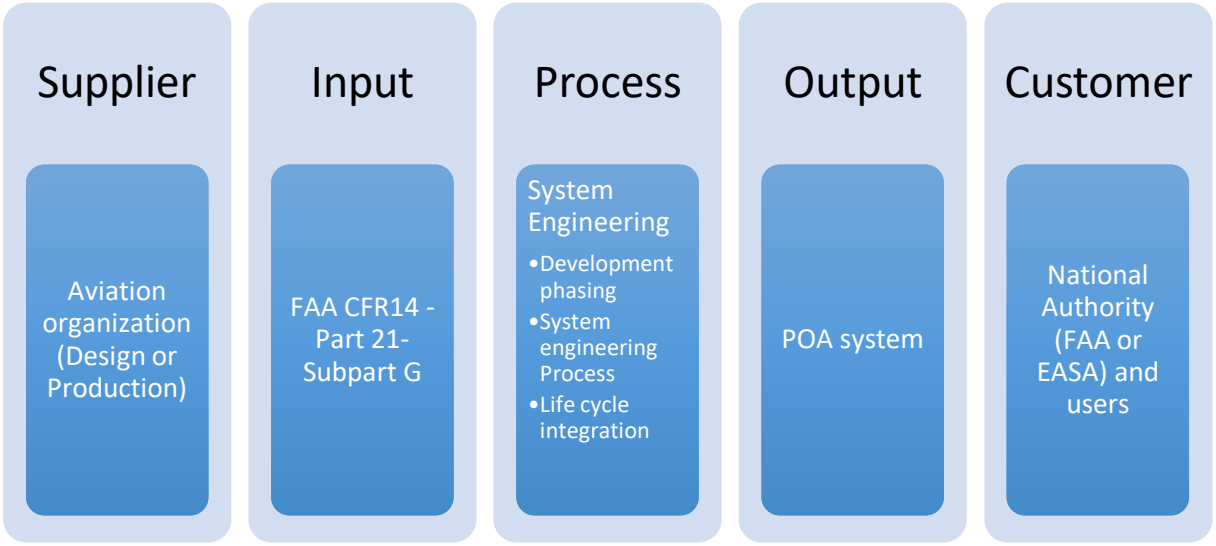


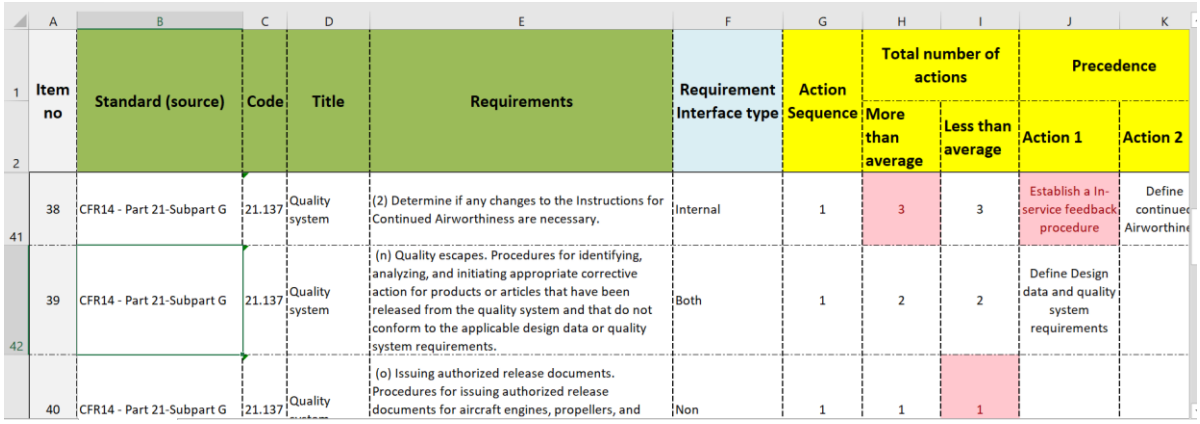
Figure 5.3 Third level of SIPOC diagram

5.4 Analysis

As this thesis's introduction, methodology, and model are elaborated, it is time to conduct the analysis.

Sixteen codes of CFR14 - Part 21-Subpart G of FAA regulation were collected as data set to apply the model proposed by this thesis for analysis. These codes decomposed to 65 requirements (items) which provide the possibility of analysis. Otherwise, due to complexity, a flawed process would be probable.

The information is entered into an RTM to trace from beginning to end. Moreover, it provides the possibility of applying other tools and conducting further investigation, as necessary. As depicted by Figures 5.4 to 5.7 from Appendix A, the RTM has thirty-seven columns, any of which shows specific information explained previously.



Item no	Standard (source)	Code	Title	Requirements	Requirement Interface type	Action Sequence	Total number of actions		Precedence	
							More than average	Less than average	Action 1	Action 2
38	CFR14 - Part 21-Subpart G	21.137	Quality system	(2) Determine if any changes to the Instructions for Continued Airworthiness are necessary.	Internal	1	3	3	Establish a In-service feedback procedure	Define continue Airworthin
39	CFR14 - Part 21-Subpart G	21.137	Quality system	(n) Quality escapes. Procedures for identifying, analyzing, and initiating appropriate corrective action for products or articles that have been released from the quality system and that do not conform to the applicable design data or quality system requirements.	Both	1	2	2	Define Design data and quality system requirements	
40	CFR14 - Part 21-Subpart G	21.137	Quality	(o) Issuing authorized release documents. Procedures for issuing authorized release documents for aircraft engines, propellers, and	Non	1	1	1		

Figure 5.4 Requirement's analysis example- the first part

As the data is entered, it is identifiable if the requirement has any internal or external interface. If there would be any, it should be clarified that there is no conflict between interfaces. If there is no possibility of verifying their relations, it is considered a non-conformity since there is a potential conflict. Any identified interfaces should be noted on the columns dedicated to this type of information.

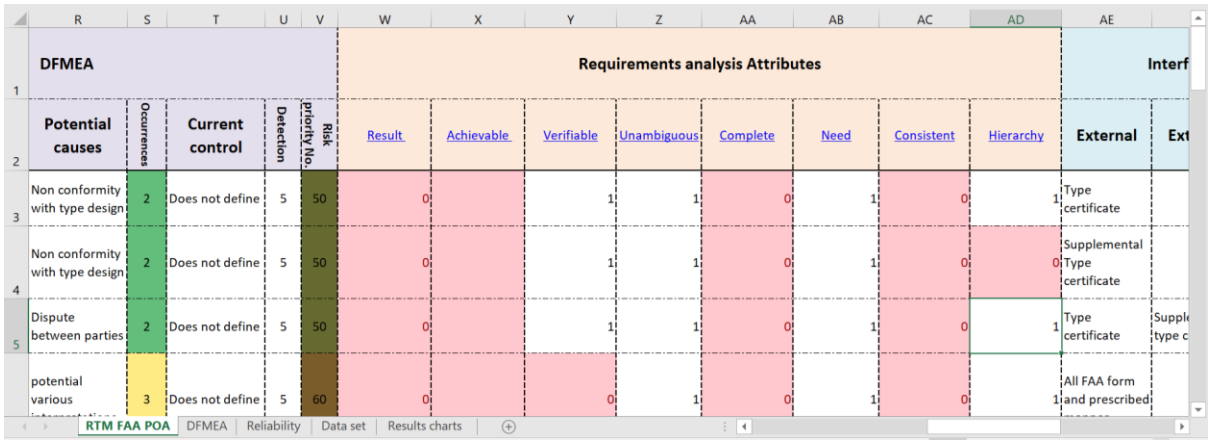
The following step to take is to breakdown the required actions to meet the requirements. If there is any sequential, it should be considered. If there is any repeated action, it should be noted. In this thesis, these actions are highlighted with red color. Plus, some requirements need more than three actions to be met. Thus, the action sequence shows how many series of actions are needed to meet the requirement.

	F	G	H	I	J	K	L	M	N	O	P	Q	R	
1	Requirement Interface type	Action Sequence	Total number of actions		Precedence		Action required	Doer	Required Outcomes (deliverables)	DFMEA				
2			More than average	Less than average	Action 1	Action 2	Action required			Potential failure mode	Potential failure effects	Severity	Potential causes	Occurrence
3	External	1	2	2	Gain a Type Certificate		Hold a current Type certificate	Applicant	Eligibility	Revoke a Type certificate	Lost eligibility	5	Non conformity with type design	
4	External	1	3	3	Gain a Type Certificate	Gain a Supplemental type certificate	Hold a Supplemental Type certificate	Applicant	Eligibility	Revoke a Supplemental Type certificate	Lost eligibility	5	Non conformity with type design	
5	External	1	2	2	Gain a Type Certificate		Reach a licensing agreement	Applicant	Eligibility	Revoke the licensing agreement	Lost eligibility	5	Dispute between parties	
6	Both	1	2	2	Collect information prescribed by the FAA		Apply for a production certificate	Applicant	Application for a production certificate	Information could be collected insufficiently	Compliance with the requirement is not forecastable	4	potential various interpretations	

Figure 5.5 Requirement's analysis example- the second part

After that, the number of actions is counted and mentioned. There are two columns to make it easy and more understandable. The average of actions required by the requirements shows the hierarchy level of requirements. If any requirement needs more or fewer actions than the hierarchy level, it is highlighted in red.

Furthermore, the intended doer is identified. Plus, the requirement's deliverable (outcome) is determined. The deliverable is vital to determine the potential failure mode and its effect. The potential failure mode is the worst occurrence, and the effect is the severest one accordingly. Plus, causes and probability of detection are mentioned, and related calculations based on the DFMEA technique are conducted.

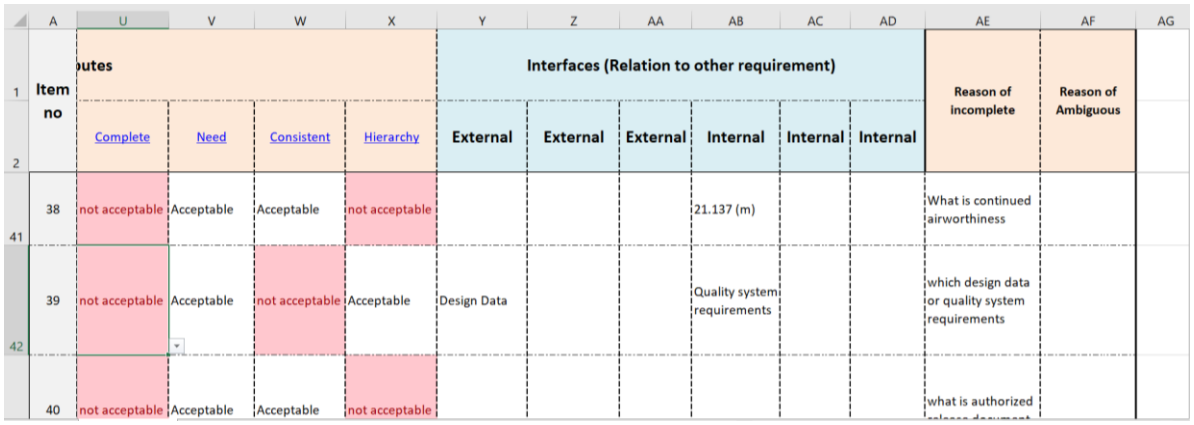


	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	
1	DFMEA					Requirements analysis Attributes								Interf	
2	Potential causes	Occurrences	Current control	Detection	priority No. Risk	Result	Achievable	Verifiable	Unambiguous	Complete	Need	Consistent	Hierarchy	External	Ext
3	Non conformity with type design	2	Does not define	5	50	0		1	1	0	1	0	1	Type certificate	
4	Non conformity with type design	2	Does not define	5	50	0		1	1	0	1	0	0	Supplemental Type certificate	
5	Dispute between parties	2	Does not define	5	50	0		1	1	0	1	0	1	Type certificate	Suppl type c
	potential various	3	Does not define	5	60	0		0	1	0	1	0	1	All FAA form and prescribed	

RTM FAA POA | DFMEA | Reliability | Data set | Results charts

Figure 5.6 Requirement's analysis example- the third part

The next step is to determine the conformity of requirements with the attributes based on the analysis methodology mentioned before. If a requirement fails to meet an attribute according to the processes and sub-processes previously explained, it needs an improvement to become accepted. Thus, the requirement is not acceptable.



	A	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1	Item no	utes				Interfaces (Relation to other requirement)						Reason of incomplete	Reason of Ambiguous	
2		Complete	Need	Consistent	Hierarchy	External	External	External	Internal	Internal	Internal			
41	38	not acceptable	Acceptable	Acceptable	not acceptable				21.137 (m)			What is continued airworthiness		
42	39	not acceptable	Acceptable	not acceptable	Acceptable	Design Data			Quality system requirements			which design data or quality system requirements		
	40	not acceptable	Acceptable	Acceptable	not acceptable							what is authorized		

Figure 5.7 Requirement's analysis example- the last part

Furthermore, supplementary information, such as the internal or external interfaces or why the requirement is incomplete or ambiguous, is provided based on the analysis in Appendix A.

5.5 Analysis' results

As the analysis is carried out, its results need to be considered. Sixty items out of sixty-five were found unacceptable due to various reasons. It means almost 92% of 16 CFR-14 Part 21 sub-Part G codes are unacceptable and need to be improved. Further details on various aspects of this analysis and results are provided as follows.

5.5.1 Contributing factors

The following Pareto chart shows the most influential factors contributing to reaching the analysis result [88]. It shows that thirty-seven items are found unacceptable regarding completeness, which is the most significant non-conformity among this data set. The next problem is with Hierarchy. There are thirty-three non-conformities with regard to this attribute. More than 80 % of total issues are caused by non-conformities with the two mentioned attributes.

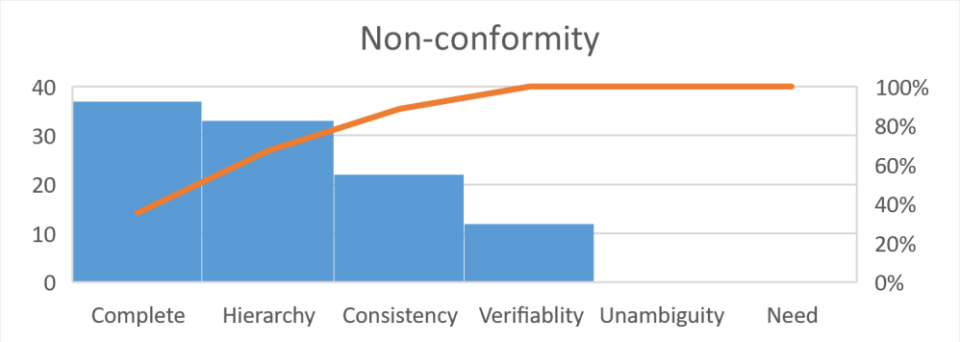


Figure 5.8 Non-conformities Pareto chart

While consistency-related issues are twenty-two, and verifiability non-conformities (NC) are twelve to take the following places. In terms of need or unambiguity, no NC is founded.

As there is no access to the initial goal of each requirement, when it comes to potential failure mode and its effect, the apparent option is taken into account. Regarding Achievability, all five items are acceptable with no other NC. It means there is no problem with this attribute.

Nineteen items are found problematic with three non-conformities. Plus, eleven items are not acceptable with regard to two non-conformities. Even, there is an item with four non-conformities.

As the nature of a requirement needs to be acceptable from all aspects of the seven attributes, it is crucial to conform to all attributes. Although most of NC is due to the complete attribute, improving a requirement merely regarding this attribute would not make it acceptable if it has more than one non-conformity. Therefore, the mixtures of non-conformities need to be considered.

There are thirteen mixtures of non-conformities. The following Pareto chart shows more information on the mixtures.

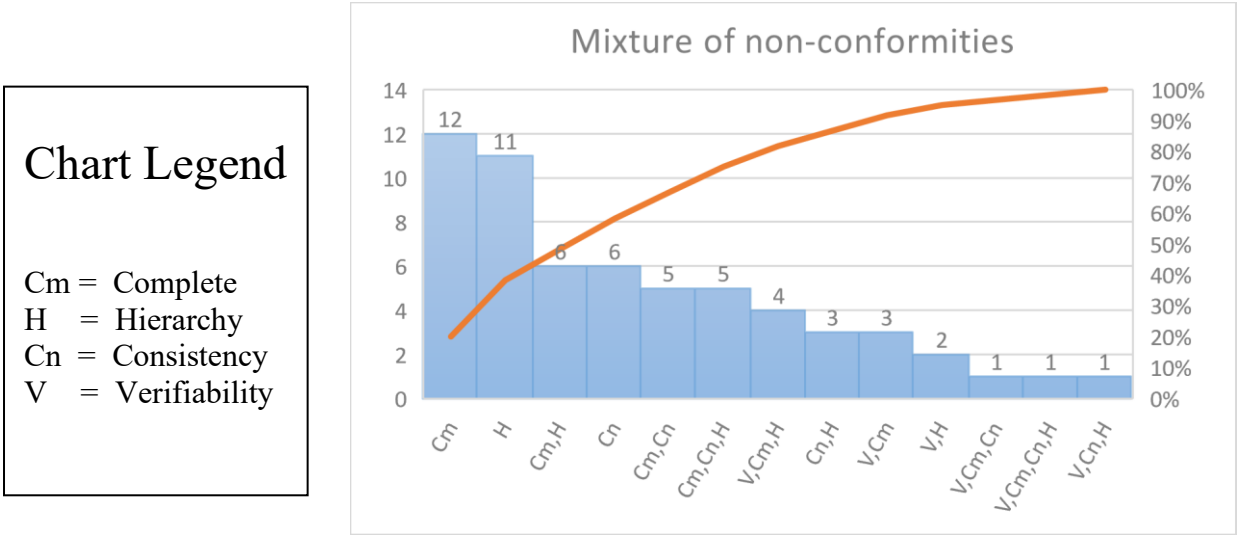


Figure 5.9 Mixtures of non-conformities Pareto chart

As the Pareto chart shows, twelve items merely encounter completeness (Cm) problems. The second problematic issue is a hierarchy (H) that is solely responsible for eleven items. The first mixture is complete-hierarchy (Cm, H) which accounts for six items. Thereafter, Consistency (Cn) with the same number is found. Besides, the mixture of complete-consistency (Cm, Cn) and complete-consistency-hierarchy (Cm, Cn, H) each account for five items. The last mixture to reach 80% of the problematic issues is verifiable-complete-hierarchy (v, Cm, H) which is the reason for four unacceptable items.

5.5.2 Interfaces

Through the requirements analysis, all internal and external interfaces of requirements have been identified and registered in the RTM. However, to facilitate and further use of this vital data, for instance, to identify each segment of the system and the relations of components within them, the following diagram shows the interfaces of CFR-14-part 21 subpart G with internal and external entities.

It is a building block diagram visualizing system interaction at a high level which permits system engineers to separate requirements analysis from system design and start system-level design before finishing component-level designs.[44]

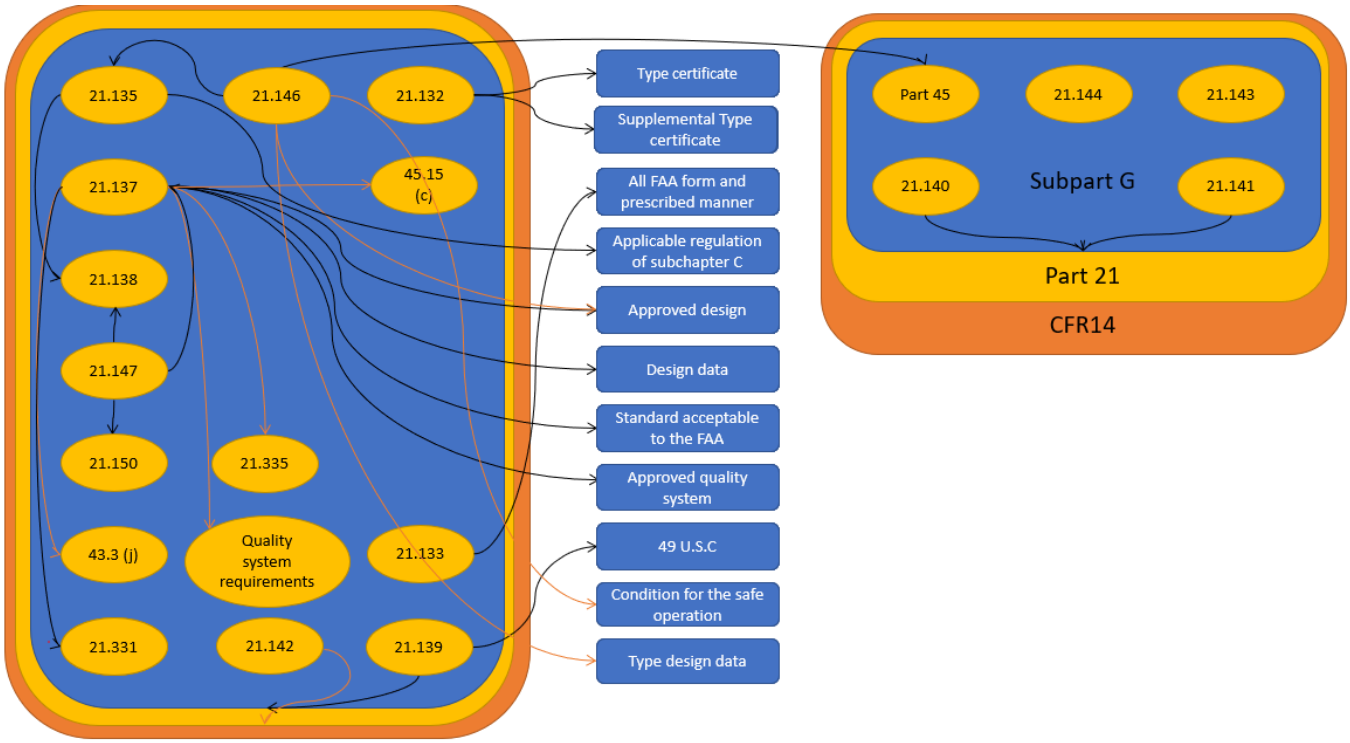


Figure 5.10 Building Block diagram

5.5.3 DFMEA

As a result of the application of DFMEA on the CFR-14 part21 subpart G requirements, the risk priority number is depicted below. The following graph has two axes, the vertical one is for RPN, and the horizontal axis is for requirements which shows the maximum RPN is more than 120, while the minimum is 30. Plus, there are a couple of requirements with RPN between 40 and 60. Moreover, two requirements are found with 100 RPN.

Obviously, based on the priority number of the requirements, they should be reviewed to mitigate the risk. However, there is a need to determine which RPN number could be tolerated. [38]

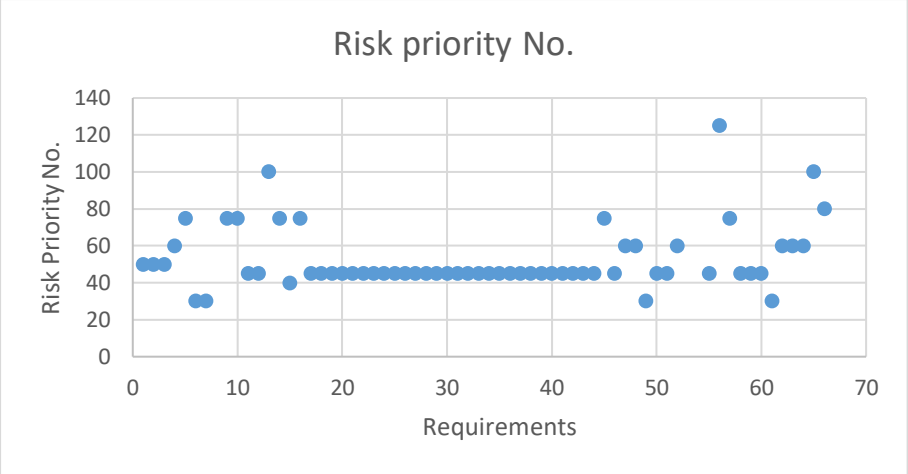


Figure 5.11 Risk Priority Number

Figure 5.12 shows contributing factors to the RPN number. There are three contributing factors to calculating RPN, which are severity, occurrences, and detection. Each factor has a different level. The vertical axis, in this case, shows the level of contributing factors, which is on the scale of 1 to 5, whereas the other axis shows the number of requirements. Due to the lack of any particular measurement for detection, all requirements are found with the highest level, which is 5. However, most other factors are in level 3 based on the analysis results.

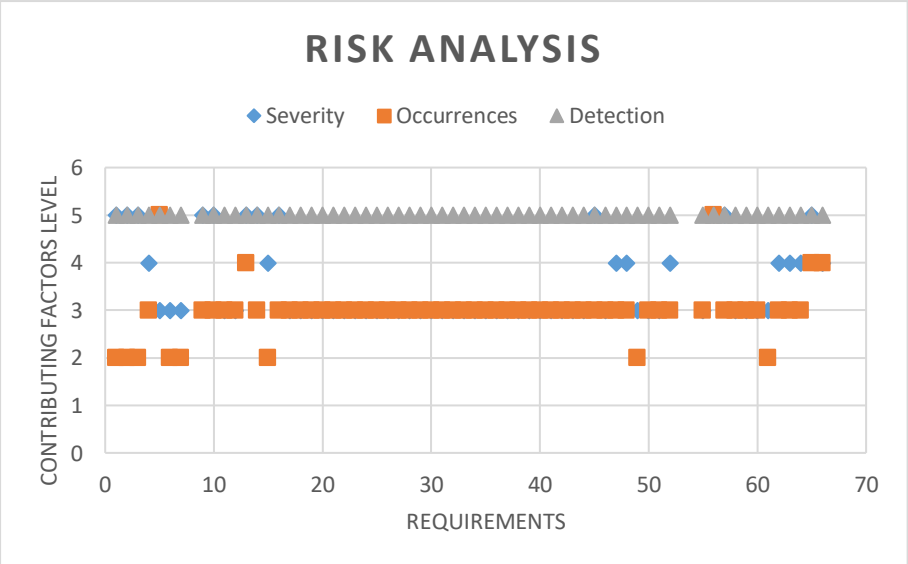


Figure 5.12 Risk analysis

The last graph has three axes, a combination of two previous graphs to show the contributing factors to RPN. The left vertical axis shows the level of contributing factors, and the right one shows RPN. Requirements are horizontal axis.

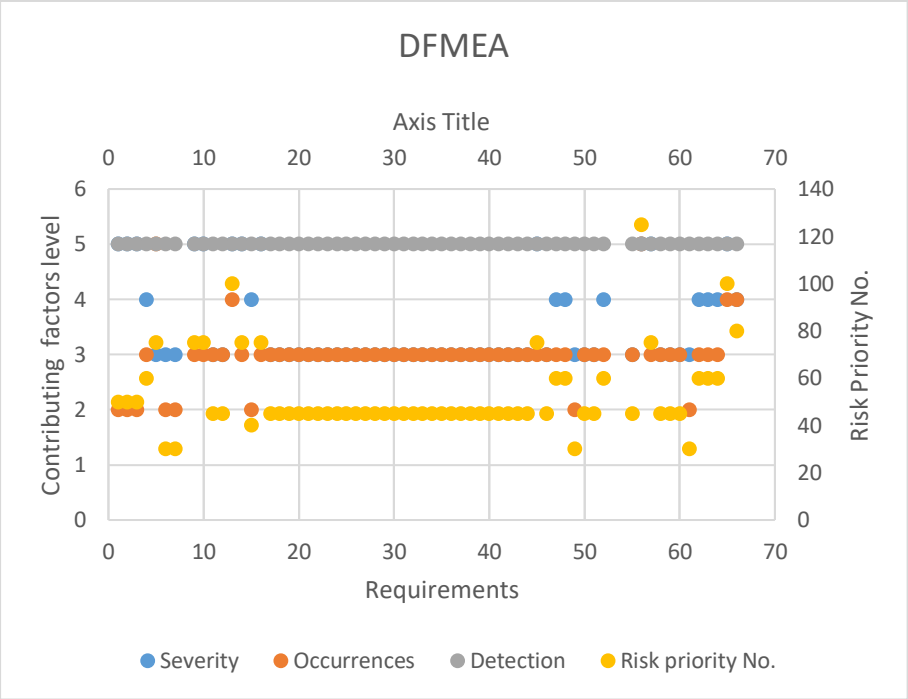


Figure 5.13 DFMEA results

5.5.4 Reliability

Based on the reliability assumption, the reliability of the requirements has been predicted. An example depicts by the following figure. However, as the building block diagram shows, many requirements have external interfaces with unknown reliability.

	A	B	C	D	E	F	G	H	I
1	Index	Achievable	Verifiable	Unambiguous	Complete	Need	Consistent	Hierarchy	Result
2	1		1	1	0	1	0	1	0.571428571
3	2		1	1	0	1	0	0	0.428571429
4	3		1	1	0	1	0	1	0.571428571
5	4		0	1	0	1	0	1	0.428571429
6	5		1	1	1	1	1	0	0.714285714
7	6		1	1	0	1	1	0	0.571428571
8	7		1	1	0	1	1	0	0.571428571
9	8								0
10	9		0	1	0	1	1	0	0.428571429
11	10		1	1	0	1	1	0	0.571428571
12	11		1	1	0	1	1	0	0.571428571
13	12	1	1	1	1	1	1	1	1
14	13		1	1	1	1	1	0	0.714285714
15	14		1	1	1	1	0	0	0.571428571

Figure 5.14 Example of prediction of the reliability of a requirement

- The index number is similar to the requirement number in the RTM

Once the reliability of each requirement has been predicted, each segment is identified based on the building block diagram. After that, in accordance with the equation's numbers (3.3) and (3.4), the reliability of each segment is calculated. The following table shows an example of a calculation of the reliability of four segments. These are the segments formed as a result of analysis of interfaces of CFR-14 part 21 subpart-G requirements.

Table 5.6 Segment reliability calculations example

Item No.	Component Identification	Reliability	CI	R	CI	R	Segment reliability
1	21.132	0.57	Type certificate	x			$.58\,x$
2	21.132	0.43	Supplemental Type certificate	y			$.43\,y$
3	21.132	0.57	Type certificate	x	Supplemental type certificate	y	$.58\,xy$
4	21.133	0.43	All FAA forms and prescribed manner	x_1	All FAA form and prescribed manner	y_1	$.43\,x_1y_1$

The following table shows which variant belongs to which entity's reliability.

Table 5.7 Reliability variants of CFR-14 part-21 subpart-G

Type certificate	x	Supplemental type certificate	y
All FAA forms and prescribed manner	x_1	All FAA forms and prescribed manner	y_1
Applicable regulation of subchapter C	x_2	Standard acceptable to the FAA	y_2
Approved design	x_3	Type certificated product	y_3
Design data	x_4	Approved quality system	y_4
Quality system requirements	x_5	Condition for the safe operation	y_5
43.3 (j)	x_6	part 45	y_6
Type design data	x_7	49 U.S.C	y_7
this part (part21)	x_8	This subchapter	y_8
45.15 (c)	x_9	this subpart	y_9
21.331	z		

Chapter 6:

Conclusions and future work

The literature review shows a great concern regarding various sorts of requirements when it comes to organizations related to specific aviation products and services, such as design and production. Literature review shows some attempts to integrate a system or optimize it according to similarities and discrepancies between the requirements.

The mentioned requirements belong to international and national aviation organizations and authorities, including ICAO, FAA, EASA, and Transport Canada. The main concentration of these requirements is airworthiness, and this term is directly related to aviation organizations, like design and production. Although mentioned authorities reached some agreements to work on their regulation from diverse views, they have their own policy in terms of rulemaking.

The studies showed that the national authorities consider international regulation and standards. However, they have their own way of meeting them and setting their further regulation and standards. There are various sorts of regulations and standards internationally and nationally. The Chicago Convention and its annexes, particularly Annex 8, and SARP are reviewed in this case.

As an effective method, system and requirement engineering was chosen to evaluate the quality of the requirements. Several strategies to conduct requirements analysis were discussed. As a result, the best of them, the structured strategy was followed to take further steps. There are a

couple of other actions to take when it comes to system engineering methodology. However, the central concern of this thesis is the requirements' analysis.

Thus, requirement analysis was conducted to investigate whether the requirements were acceptable or not. No matter how well-designed the system is, there is no guarantee that a system may meet the requirements and the final result would be satisfactory unless the requirements are well-defined.

Studies showed seven essential attributes are defined as the most comprehensive criteria to evaluate the quality of requirements, including complete, hierarchy, need, unambiguity, consistency, verifiability, and achievability.

Diagrams, processes, and sub-processes are defined and developed to provide a model that turns this theory into practical work. This detailed solution allows applying an engineering response to this problem instead of a freestyle strategy of requirement analysis.

A requirement traceability matrix is formed to organize and trace the requirements from beginning to end. This Excel file contains all information pertaining to requirements ranging from WBS to requirements analysis elements.

The SIPOC diagram showed that national requirements such as CFR-14-part 21 subpart G should be met to approve a system for a production organization in the aviation industry based on the United States regulations. Thus, because of the influential role of FAA in the aviation industry, the data set, collected from CFR-14 Part 21 subpart G, was transferred to an RTM. Sixteen national codes were decomposed into sixty-five items, which provided a more understandable and logical analysis.

Thereafter, analysis was conducted. Based on the developed model, the data set was analyzed, and the details on each item and its results were mentioned in the RTM. The analysis consisted of various steps and some sub-processes, including WBS and DFME.

According to the analysis results, 92% of sixty-five items are not acceptable, including sixty items. It shows an opportunity for improvement to reach an acceptable level of quality when it comes to this code of regulation.

The analysis also provides further details on the contributing factors. It shows that 80% of unacceptable requirements do not meet two attributes: complete and hierarchy. In other words, they do not have sufficient and clear information to identify correctly the action required. Plus, they are either too general or too detailed when it comes to hierarchy.

On the other hand, the mixture of non-conformities with attributes as an essential subject was investigated. Thus, nineteen items have two non-conformities. Plus, the analysis resulted in finding eleven items with more than three non-conformities.

There are thirteen various mixtures. However, twelve items merely encounter incompleteness problems. The second problematic issue is the hierarchy that is solely responsible for eleven items. The first mixture is complete-hierarchy which accounts for six items. Thereafter, Consistency with the same number is founded. The mixtures of complete-consistency and complete-consistency-hierarchy account for five items. The last mixture to reach 80% of the problematic issues is verifiable-complete-hierarchy which causes four unacceptable items.

Certain similarities are found comparing these two different approaches, mixtures, and single non-conformity with attributes. Complete and hierarchy are the most crucial factors to improve the quality of this code of regulation. Consistency and verifiability are the next ones.

Meanwhile, interfaces of the requirements with all internal and external entities were investigated. This investigation results in a building block diagram showing how the requirements depend on the other requirements and standards. Plus, it depicts how complicated they are to be met.

Reliability-wise, it is possible to take advantage of the results of DFMEA, which was applied for affordability, to verify a design of the system meeting the requirements. On the other hand, an assumption is introduced to predict the requirements' reliability.

According to the provided evidence, the model to analyze the requirements works properly and renders all required technical details. It gives the opportunity to accurately identify the problem and how it affects the goal and other related issues.

In addition, based on the analysis result, CFR-14 Part 21 subpart G needs a plan of improvement. This plan should include the improvement of the process of rulemaking as well. As reviewed, the rulemaking process is based on committees and the experts' point of view, which potentially increases the risk of various human errors, plus a lack of robust criteria to assess the quality of input, process, and output. In other words, the rulemaking processes need a structured requirement analysis strategy and model.

To proceed with other steps of system engineering and provide the possibility of an integrated system, there is a need to analyze the other requirements and verify if they are acceptable. This integrated system covers EASA, FAA, and Transport Canada requirements altogether.

The model proposed by this thesis provides the possibility to systematically approach the requirement analysis and prevent problematic requirements by improving the process of rulemaking. Besides, this improvement avails a predictable condition for active or potential investors in the aviation industry.

This conclusion may raise the question of how the aviation industry works nowadays if the requirements are more than ninety percent unacceptable in the case of the POA requirements of the FAA.

The answer is that other materials previously studied like Advisory circulars, help the competent authorities to verify the implementation of these requirements. The experience, knowledge, and wisdom probably assist both sides (applicant and authority) to have a better idea about expectations. Furthermore, there are some powerful companies in this industry that have been working for many years. These companies are considered another useful resource.

However, when it comes to a beginner, the process depends on stakeholders and unpredictable factors.

Based on the analysis results, what is probable is the possibility of rework, errors, improper system design, and consequently, improper system implementation. They are all barriers to investment and innovations.

6.1 Research contributions

This thesis contributed to producing various layers of SIPOC diagram and collecting pertaining information, beginning with international standards, and ending in national codes. This diagram provides a more detailed view of how the rulemaking process in the aviation industry develops, and the results apply to those who desire to work in this industry. However, this is the beginning of innovation. In other words, it is inspiring to follow the main goals.

As the rulemaking process was studied, it became apparent that typically this process is based on experts' points of view. Obviously, the possibility of human errors was considerable, mainly due to the lack of robust quality criteria. In comparison, the requirements are vital as the foundation and criteria for pertinent activities.

It means the quality of the activities is based on the defined requirements, while the quality of the requirements itself has not been assessed through a systematic approach. System engineering introduces requirement analysis to solve this problem. However, the implementation of this theory was still highly dependent on the experts' point of view.

As a significant contribution, this thesis provides a model of requirement analysis based on the structured strategy. The criteria were defined practically. Diagram, process, sub-process, and techniques were either developed or organized to investigate the conformance of requirements with the criteria.

Applying this model means that there is a strong possibility of accurately evaluating the quality of any sort of requirements for any project. Plus, it shows a specific and root cause of the problem if the requirement is unacceptable. Thus, rapidly the requirements could be analyzed

and improved to become acceptable. Furthermore, in a novel way to measure system affordability, the application of DFMEA is proposed.

Moreover, this thesis provides the opportunity for the requirements analysis process automation, reducing the probability of human errors even more. This contribution could increase the effectiveness of the standards for both implementation and evaluation simultaneously.

Lastly, the application of this model on an aviation standard shows there is a need for systematic improvement of aviation standards.

6.2 Research limitations

As this thesis is about aviation standards' requirements analysis, the ideal case would be to directly access the requirements problems from the industry and authorities or cooperate with an authority or a company involved in implementing the standards.

Although several times have attempted to contact the national authorities like Transport Canada, no response has been received. As clarified, this subject is a legislative concern related directly to a specific section of governments pertaining to aviation rulemaking, competent authority.

Thus, cooperating with an authority, preferably FAA, EASA, and Transport Canada, could be a gamechanger to achieve the highest level of accuracy and precision. On the other hand, it could allow performing Improve and Control phases of DMAIC methodology in an actual situation. However, there was no such opportunity.

6.3 Future work and recommendations

It is interesting that although there are some papers related to this subject, there is no previous work with the same approach. Most of the previous work concentrated on how to implement the standard instead of the standards themselves. It means they ignored that the initial steps like requirements analysis or a structured requirements analysis.

The distribution of this thesis to the requirements analysis provides a versatile tool. This tool could be applied to various subjects ranging from purchasing a cup of coffee to defining and realizing a complicated aerospace project.

There are diverse aspects of its effects on industries, like how much it could save resources by preventing reworks. Working on these advantages could encourage the user to consider this sort of improvement more seriously.

On the other hand, an integrated system that can meet various standards is achievable if the aviation authorities accept these improvements. Thus, it can reduce conflict and repetition in the systems and different sorts of their extra cost accordingly.

Indeed, the quality of aviation standards itself is a significant subject of matter. Whereas the quality of the rulemaking process even is more important. Now that it can be a quality assurance consideration that can continuously improve the quality of aviation rulemaking.

As concisely mentioned, thanks to the availability of all details of requirements analysis, automation, and data mining or AI algorithm development is possible. Considering the volume of aviation standards, it is probably a practical solution to evaluate all of them.

Plus, benchmarking FAA with EASA or Transport Canada standards could be helpful in terms of designing an integrated system. However, this subject was already covered by the available papers.

Moreover, if a system will be established to monitor the effects of aviation standards' requirements on all stakeholders, including the industry, customer, environment, etc., there would be an opportunity to assess how a modification or improvement is effective. Plus, where is the most critical area to consider and other important information will be available.

As the building block diagram shows, a couple of other standards have interfaces with this one. Evaluating them both for quality and reliability is necessary to have a more accurate and reliable analysis result.

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Appendix A

Item no	Standard (source)	Code	Title	Requirements	Requirement Interface type	Action Sequence	Total number of actions		Precedence		Action required	Doer	Required Outcomes (deliverables)	DFMEA							Requirements analysis Attributes								Interfaces (Relation to other requirements)						Reason of incomplete	Reason of Ambiguous	Total Number of NC	Combination of NC
							More than average	Less than average	Action 1	Action 2	Action required			Potential failure mode	Potential failure effects	Severity	Potential causes	Occurrences	Current control	Detection	Risk priority No.	Result	Achievable	Verifiable	Unambiguous	Complete	Need	Consistent	Hierarchy	External	External	External	Internal	Internal	Internal				
1	CFR14 - Part 21-Subpart G	21.132	Eligibility.	Any person may apply for a production certificate if that person holds, for the product concerned—(a) A current type certificate,	External	1	2	2	Gain a Type Certificate		Hold a current Type certificate	Applicant	Eligibility	Revoke a Type certificate	Lost eligibility	5	Non conformity with type design	2	Does not define	5	50	0		1	1	0	1	0	1	Type certificate						What kind of type certificate.		2	Cm, Cn
2	CFR14 - Part 21-Subpart G	21.132	Eligibility.	(b) A supplemental type certificate, or	External	1	3	3	Gain a Type Certificate	Gain a Supplemental type certificate	Hold a Supplemental Type certificate	Applicant	Eligibility	Revoke a Supplemental Type certificate	Lost eligibility	5	Non conformity with type design	2	Does not define	5	50	0		1	1	0	1	0	0	Supplemental Type certificate						What kind of Supplemental type certificate.		3	Cm, Cn,H
3	CFR14 - Part 21-Subpart G	21.132	Eligibility.	(c) Rights to the benefits of that type certificate or suppl	External	1	2	2	Gain a Type Certificate		Reach a licensing agreement	Applicant	Eligibility	Revoke the licensing agreement	Lost eligibility	5	Dispute between parties	2	Does not define	5	50	0		1	1	0	1	0	1	Type certificate	Supplemental type certificate					What kind of agreement		2	Cm, Cn

				emental type certificate under a licensing agreement																																			
4	CFR14 - Part 21-Subpart G	21.133	Application	Each applicant must apply for a production certificate in a form and manner prescribed by the FAA.	Both	1	2	2	Collect information prescribed by the FAA		Apply for a production certificate	Applicant	Application for a production certificate	Information could be collected insufficiently	Compliance with the requirement is not forecastable	4	potential various interpretations	3	Does not define	5	60	0		0	1	0	1	0	1	All FAA form and prescribed manner			All FAA form and prescribed manner			What kind of form and prescribed manner		3	V,Cm,Cn
5	CFR14 - Part 21-Subpart G	21.135	Organization.	(a) Each applicant for or holder of a production certificate must provide the FAA with a document — (1) Describing how its organization will ensure compliance with the provisions of this subpart;	Non	1	1	1			Produce a Compliance checklist	Applicant	Compliance checklist	Missing an item	Time-consuming compliance verification process	3	lack of a system design	5	Does not define	5	75	0		1	1	1	1	1	0									1	H
6	CFR14 - Part 21-Subpart G	21.135	Organization.	(2) Describing assigned responsibilities,	Non	1	3	3	Define responsibilities	Define Human resources	Assigned responsibilities	Applicant	List of assigned responsibilities	Missing a responsibility	Unknown In charge of responsibility	3	lack of a system design	2	Does not define	5	30	0		1	1	0	1	1	0							Which responsibilities		2	Cm, H

7	CFR14 - Part 21- Subpart G	21.135	Organization.	delegated authorities,	Non	1	3	3	Assigned responsibilities	Define authorities	Distribute Authorities	Applicant	List of delegated authorities	Improper Authorities	Unknown Delegated an authority	3	lack of a system design	2	Does not define	5	30	0		1	1	0	1	1	0							Which authorities		2	Cm, H
8	CFR14 - Part 21- Subpart G	21.135	Organization.	and the functional relationship of those responsible for quality to management and other organizational components; and	Non	1			Identify quality responsible person	Define management	Define other organizational components	Applicant									0																	0	
		21.135	Organization.		Non	2	6	6	Define other organizational components	Define functional relationships	Identify required functional relationship	Applicant	List of Functional relations of quality personnel with the other	Missing a functional relationship	Miscommunication between quality personnel and others	5	improper organization	3	Does not define	5	75	0		0	1	0	1	1	0							Which other component of organization + which functional relationship		3	V,Cm,H
11	CFR14 - Part 21- Subpart G	21.135	Organization.	(3) Identifying an accountable manager.	Non	1	3	3	Assigned responsibilities	Define criteria to assign an accountable manager	Identify an accountable manager	Applicant	List of accountable manager	Assigned an unacceptable accountable manager	Incompetent accountable manager	5	lack of competency	3	Does not define	5	75	0		1	1	0	1	1	0							What are the criteria to assign an accountable manager		2	Cm, H
12	CFR14 - Part 21- Subpart G	21.135	Organization.	(b) The accountable manager specified in paragraph (a) of this section must be responsible within the applicant's or	Internal	1	3	3	Identify an accountable manager	Define the responsibilities	Assigned responsibilities	Applicant	List of responsibilities	Missing a responsibility	Failure to respond to responsibility	3	lack of a system design	3	Does not define	5	45	0		1	1	0	1	1	0				21.135 part a			Responsible of what		2	Cm, H

				production approval holder's organization for,																																			
13	CFR14 - Part 21- Subpart G	21.135	Organization.	and have authority over, all production operations conducted under this part.	Non	1	2	2	Distribute Authorities		Assign Authorities	Applicant	List of authorities	Missing an authority	Failure to respond to accountable manager	3	lack of a system design	3	Does not define	5	45	1	1	1	1	1	1	1	1									0	
14	CFR14 - Part 21- Subpart G	21.135	Organization.	The accountable manager must confirm that the procedures described in the quality manual required by § 21.138 are in place and that the production approval holder satisfies the requirements of the applicable regulations of subchapter C, Aircraft.	Internal	1	3	3	Define procedures described by 21.138	Establish a quality manual	Verify quality manual to confirm the requirement	Accountable manager	Verification of Quality manual	Non-conformance with the requirements	Failure to confirm the procedures are in place	5	lack of systematic approaches	4	Does not define	5	100	0		1	1	1	1	1	0				21.138					1	H

		2.1.135	Organization.		External	2	3	3	Verify the required procedures are in place	Identify the requirement of regulation subchapter C	verify quality manual to confirm the requirement	Accountable manager	Confirmation of requirements	Non-conformance with the requirements	Failure to confirm the manual satisfies the requirements	5	lack of a system design	3	Does not define	5	75	0		1	1	1	1	0	0	Applicable regulation of subchapter C								2	Cn,H
15	CFR14 - Part 21- Subpart G	2.1.135	Organization.	The accountable manager must serve as the primary contact with the FAA.	Non	1	1	1			Serve primary contact to FAA	Accountable manager	Contact point to FAA	A non-desirable contact	miscommunication between FAA and accountable manager	4	lack of systematic approaches	2	Does not define	5	40	0		1	1	1	1	1	0									1	H
16	CFR14 - Part 21- Subpart G	2.1.137	Quality system	Each applicant for or holder of a production certificate must establish and describe in writing a quality system that ensures that each product and article conforms to its approved design and is in a condition for safe operation.	External	1	3	3	Gain Approved design	Define safe operation condition	Design a quality system	Applicant	A established quality system	Non-conformance with the requirements	Failure to confirm the requirements	5	lack of systematic approaches	3	Does not define	5	75	0		1	1	1	1	0	0	Approved design								2	Cn,H

		21.137	Quality system			2	2	2	Design a quality system		Verify a Quality system to confirm the condition	Applicant	Written confirmation of quality system	Discrepancies between Quality system and safe operation	Failure to safe operation	3	lack of systematic approaches	3	Does not define	5	45	0		1	1	1	1	0	1	Approved design								1	Cn
17	CFR14 - Part 21- Subpart G	21.137	Quality system	This quality system must include: (a) Design data control. Procedures for controlling design data and subsequent changes to ensure that only current, correct, and approved data is used.	External	1	2	2	Define Design data		Establish a design data control procedure	Applicant	Design data control procedure	Defective procedure	Improper design data control	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	0	1	Design data								1	Cn
18	CFR14 - Part 21- Subpart G	21.137	Quality system	(b) Document control. Procedures for controlling quality system documents and data and subsequent changes to ensure that only curre	Non	1	1	1			Establish a document control procedure	Applicant	Document control procedure	Defective procedure	Improper document control	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H

				nt, correct, and approved documents and data are used.																																			
19	CFR14 - Part 21- Subpart G	21.137	Quality system	(c) Supplier control. Procedures that— (1) Ensure that each supplier-provided product, article, or service conforms to the production approval holder's requirements; and	Non	1	2	2	Define production approval holder's requirements		Establish a supplier control procedure	Applicant	Supplier control procedure	Defective procedure	Improper Supplier control	3	Improper system design	3	Does not define	5	45	1	1	1	1	1	1	1	1									0	
20	CFR14 - Part 21- Subpart G	21.137	Quality system	(2) Establish a supplier-reporting process for products, articles, or services that have been released from or provided by the supplier and subsequently found not to	Non	1	2	2	Define production approval holder's requirements		Establish a Supplier reporting process	Applicant	Supplier reporting process	Defective process	Improper Supplier reporting process	3	Improper system design	3	Does not define	5	45	1	1	1	1	1	1	1	1									0	

				conform to the production approval holder's requirements.																																			
21	CFR14 - Part 21- Subpart G	21.137	Quality system	(d) Manufacturing process control. Procedures for controlling manufacturing processes to ensure that each product and article conforms to its approved design.	External	1	2	2	Define Approved design		Establish a manufacturing process control procedure	Applicant	Manufacturing process control procedure	Defective procedure	Improper manufacturing process control	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	0	1	Approved design								1	Cn
22	CFR14 - Part 21- Subpart G	21.137	Quality system	(e) Inspecting and testing. Procedures for inspections and tests used to ensure that each product and article conforms to its approved design.	External	1	2	2	Define Approved design		Establish an inspecting and testing procedure	Applicant	Inspecting and testing procedure	Defective procedure	Improper inspecting and testing	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	0	1	Approved design								1	Cn

23	CFR14 - Part 21-Subpart G	21.137	Quality system	These procedures must include the following, as applicable: (1) A flight test of each aircraft produced unless that aircraft will be exported as an unassembled aircraft.	Internal	1	2	2	Establish an inspecting and testing procedure		Modify Inspecting and testing procedures	Applicant	Modified Inspecting and testing procedure	Defective procedure	Improper inspecting and testing	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				21.137 e			What kind of flight test		1	Cm
24	CFR14 - Part 21-Subpart G	21.137	Quality system	(2) A functional test of each aircraft engine and each propeller produced.	Internal	1	2	2	Establish an inspecting and testing procedure		Modify Inspecting and testing procedures	Applicant	Modified Inspecting and testing procedure	Defective procedure	Improper inspecting and testing	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				21.137 e			What kind of functional test		1	Cm
25	CFR14 - Part 21-Subpart G	21.137	Quality system	(f) Inspection, measuring, and test equipment control. Procedures to ensure calibration and control of all inspection, measuring, and test equipment used in determining confo	External	1	2	2	Gain Approved design		Establish an Inspection, measuring, and test equipment control procedure	Applicant	Inspection, measuring, and test equipment control procedure	Defective procedure	Improper Inspection, measuring, and test equipment control	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	1	Standard acceptable to the FAA	Approved design					Which standard is acceptable		2	Cm, Cn

				rmity of each product and article to its approved design. Each calibration standard must be traceable to a standard acceptable to the FAA.																																			
26	CFR14 - Part 21-Subpart G	21.137	Quality system	(g) Inspection and test status. Procedures for documenting the inspection and test status of products and articles supplied or manufactured to the approved design.	External	1	2	2	Gain Approved design		Establish an Inspection and test status	Applicant	Inspection and test status Procedure	Defective procedure	Improper Inspection and test status	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	0	1	Approved design								1	Cn
27	CFR14 - Part 21-Subpart G	21.137	Quality system	(h) Nonconforming product and article control.	Non	1	1	1			Establish a nonconforming product and article control procedure	Applicant	Nonconforming product and article control procedure	Defective procedure	Improper nonconforming product and article control	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H

28	CFR14 - Part 21- Subpart G	21.137	Quality system	(1) Procedures to ensure that only products or articles that conform to their approved design are installed on a type-certificated product.	Both	1	3	3	Define Approved design	Define Type-certificated product	Modify nonconforming product and article control procedure	Applicant	Modified nonconforming product and article control procedure	Defective procedure	Improper nonconforming product and article control procedure	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	0	Approved design	Type certificated product		21.137 h			What product are type-certificated		3	Cm, Cn,H
29	CFR14 - Part 21- Subpart G	21.137	Quality system	These procedures must provide for the identification, documentation, evaluation, segregation, and disposition of nonconforming products and articles. Only authorized individuals may make disposition determinations.	Internal	1	3	3	Establish a nonconforming product and article control procedure	Define Authorized individuals	Modify nonconforming product and article control procedure	Applicant	Modified nonconforming product and article control procedure	Unauthorized individuals determinations	Nonconforming product and article usage	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	0				21.137 h			What are the criteria of authorized individuals		2	Cm, H

30	CFR14 - Part 21- Subpart G	21.137	Quality system	(2) Procedures to ensure that discarded articles are rendered unusable.	Internal	1	2	2	Establish a nonconforming product and article control procedure		Modify nonconforming product and article control procedure	Applicant	Modified nonconforming product and article control procedure	Defective procedure	Nonconforming product and article usage	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				21.137 h			What are the discarded articles		1	Cm
31	CFR14 - Part 21- Subpart G	21.137	Quality system	(i) Corrective and preventive actions. Procedures for implementing corrective and preventive actions to eliminate the causes of an actual or potential nonconformity to the approved design or noncompliance with the approved quality system.	External	1	3	3	Gain Approved design	Gain an approved quality system	Establish a corrective and preventive action procedure	Applicant	Corrective and preventive action procedure	Defective procedure	Improper corrective and preventive actions	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	0	Approved design	Approved quality system					which quality system is approved		3	Cm, Cn,H
32	CFR14 - Part 21- Subpart G	21.137	Quality system	(j) Handling and storage. Procedures to prevent damage and deterioration of each product and	Non	1	1	1			Establish a Handling and storage Procedure	Applicant	Handling and storage procedure	Defective procedure	Improper handling and storage	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H

				article during handling, storage, preservation, and packaging																																			
33	CFR14 - Part 21- Subpart G	21.137	Quality system	(k) Control of quality records. Procedures for identifying, storing, protecting, retrieving, and retaining quality records.	Non	1	1	1			Establish a Control and quality records procedure	Applicant	Control of quality records procedure	Defective procedure	Improper Control of quality records procedure	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H
34	CFR14 - Part 21- Subpart G	21.137	Quality system	A production approval holder must retain these records for at least 5 years for the products and articles manufactured under the approval and at least 10 years for critical components identified under § 45.15	Internal	1	2	2	Identify critical components		Modify Control of quality records procedures	Applicant	Modified control of quality records procedure	Defective procedure	Insufficient retain of the required records	3	Lack of system updating	3	Does not define	5	45	0		1	1	0	1	1	1				45.15 (c)			What are the critical components		1	Cm

				(c) of this chapter.																																			
35	CFR14 - Part 21- Subpart G	21.137	Quality system	(l) Internal audits. Procedures for planning, conducting, and documenting internal audits to ensure compliance with the approved quality system. The procedures must include reporting results of internal audits to the manager responsible for implementing corrective and preventive actions.	External	1	3	3	Define Approved Quality system	Identify the manager responsible for implementing corrective and preventive actions	Establish an Internal audits procedure	Applicant	Internal audits procedure	Defective procedure	Improper internal audits	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	0	Approved quality system						What is approved quality system		3	Cm, Cn,H

36	CFR14 - Part 21- Subpart G	21.137	Quality system	(m) In-service feed back. Procedures for receiving and processing feed back on in-service failures, malfunctions, and defects. These procedures must include a process for assisting the design approval holder to—	Non	1	1	1			Establish a In-service feed back procedure	Applicant	In-service feed back procedure	Defective procedure	Improper In-service feedback	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H
37	CFR14 - Part 21- Subpart G	21.137	Quality system	(1) Address any in-service problem involving design changes; and	Internal	1	2	2	Establish a In-service feed back procedure		Modify In-service feed back procedures	Applicant	Modified In-service feed back procedure	Defective procedure	Missing a problem involving design changes	3	Lack of system updating	3	Does not define	5	45	1	1	1	1	1	1	1	1				21.137 (m)						
38	CFR14 - Part 21- Subpart G	21.137	Quality system	(2) Determine if any changes to the Instructions for Continued Airworthiness are necessary.	Internal	1	3	3	Establish a In-service feed back procedure	Define continued Airworthiness	Modify In-service feed back procedures	Applicant	Modified In-service feed back procedure	Defective procedure	Missing an item related to continued airworthiness	3	Lack of system updating	3	Does not define	5	45	0		0	1	0	1	1	0				21.137 (m)			What is continued airworthiness		3	V,Cm,H

39	CFR14 - Part 21- Subpart G	21.137	Quality system	(n) Quality escapes. Procedures for identifying, analyzing, and initiating appropriate corrective action for products or articles that have been released from the quality system and that do not conform to the applicable design data or quality system requirements.	Both	1	2	2	Define Design data and quality system requirements		Establish a quality escapes procedure	Applicant	Quality escapes procedure	Defective procedure	Improper quality escapes	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	1	Design Data			Quality system requirements			which design data or quality system requirements		2	Cm, Cn
40	CFR14 - Part 21- Subpart G	21.137	Quality system	(o) Issuing authorized release documents. Procedures for issuing authorized release documents for aircraft engines, propellers	Non	1	1	1			Establish an Issuing authorized release documents procedure	Applicant	Issuing authorized release documents procedure	Defective procedure	Improper Issuing authorized release documents	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	0							what is authorized release document		2	Cm, H

				, and articles if the production approval holder intends to issue those documents.																																			
41	CFR14 - Part 21- Subpart G	21.137	Quality system	These procedures must provide for the selection, appointment, training, management, and removal of individuals authorized by the production approval holder to issue authorized release documents.	Internal	1	2	2	Establish an Issuing authorized release documents procedure		Modify Issuing authorized release documents procedures	Applicant	Modified Issuing authorized release documents procedure	Defective procedure	Improper Issuing authorized release documents	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				21.137			what is authorized release document		1	Cm
42	CFR14 - Part 21- Subpart G	21.137	Quality system	Authorized release documents may be issued for new aircraft engines, propellers, and articles manufactured by the	Internal	1	2	2	Define § 43.3(j) of this chapter		Modify Issuing authorized release documents procedures	Applicant	Modified Issuing authorized release documents procedure	Defective procedure	Improper Issuing authorized release documents	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				43.3 (j)			what is authorized release document		1	Cm

				production approval holder; and for used aircraft engines, propellers, and articles when rebuilt, or altered, in accordance with § 43.3(j) of this chapter.																																			
43	CFR14 - Part 21-Subpart G	21.137	Quality system	When a production approval holder issues an authorized release document for the purpose of export, the production approval holder must comply with the procedures applicable to the export of new and used aircraft engines, propellers	Internal	1	2	2	Define articles specified in § 21.331 and the responsibilities of exporters specified in § 21.335.		Modify Issuing authorized release documents procedures	Applicant	Modified Issuing authorized release documents procedure	Defective procedure	Improper Issuing authorized release documents	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1				21.331	21.335		what is authorized release document		1	Cm

				, and articles specified in § 21.331 and the responsibilities of exporters specified in § 21.335.																																			
44	CFR14 - Part 21- Subpart G	21.138	Quality manual	Each applicant for or holder of a production certificate must provide a manual describing its quality system to the FAA for approval. The manual must be in the English language and retrievable in a form acceptable to the FAA.	Non	1	2	2	Define Quality system manual		Establish a Quality system manual	Applicant	Quality system manual	Unacceptable to the FAA	Failure to proceed	5	lack of systematic approaches	3	Does not define	5	75	0		0	1	0	1	1	1							What is acceptable form to the FAA		2	V,Cm

45	CFR14 - Part 21- Subpart G	21.139	Location of or change to manufacturing facilities.	(a) An applicant may obtain a production certificate for manufacturing facilities located outside of the United States if the FAA finds no undue burden in administering the applicable requirements of Title 49 U.S.C. and this subchapter.	Both	1	2	2	Define requirements of Title 49 U.S.C. and this subchapter.		Obtain a Production Certificate	Applicant	Production certificate	Inability to obtain Production certificate	Failure to obtain production certificate	3	lack of a system design	3	Does not define	5	45	0		1	1	1	1	0	1	49 U.S.C			this subchapter					1	Cn
46	CFR14 - Part 21- Subpart G	21.139	Location of or change to manufacturing facilities.	(b) The production certificate holder must obtain FAA approval before making any changes to the location of any of its manufacturing facilities.	Non	1	2	2	Define changes to the location of manufacturing facilities		Request an approval	Applicant	FAA approval	unacceptable changes	Inability to obtain approval of FAA	4	lack of system updating	3	Does not define	5	60	1	1	1	1	1	1	1	1									0	

47	CFR14 - Part 21- Subpart G	21.139	Location of or change to manufacturing facilities.	(c) The production certificate holder must immediately notify the FAA, in writing, of any change to the manufacturing facilities that may affect the inspection, conformity, or airworthiness of its product or article.	Non	1	2	2	Define inspection, conformity, or airworthiness of its product or article		Notify FAA any changes to manufacturing facilities	Applicant	Written Notification	Improper notification	Adverse effect on inspection, conformity, or airworthiness of its product or article	4	lack of competency	3	Does not define	5	60	0		0	1	0	1	1	1							What may affect the inspection, conformity, or airworthiness of its product or article		2	V,Cm
48	CFR14 - Part 21- Subpart G	21.140	Inspections and tests.	Each applicant for or holder of a production certificate must allow the FAA to inspect its quality system, facilities, technical data, and any manufactured products or articles and witness any tests,	Internal	1	1	1			Issue Inspection permits	Applicant	Inspections	misconducting inspection	unverifiable inspection result	3	System mismanagement	2	Does not define	5	30	0		0	1	0	1	0	0				This subchapter			what is necessary to determine compliance with this subchapter		4	V,Cm,Cn,H

				including any inspections or tests at a supplier facility, necessary to determine compliance with this subchapter.																																			
49	CFR14 - Part 21- Subpart G	21.141	Issuance	The FAA issues a production certificate after finding that the applicant complies with the requirements of this subpart.	Internal	1	2	2	Finding compliance with the requirements of this subpart		Issue a production certificate	FAA	Certificate	not finding compliance with the requirements of this subpart	not issue a production certificate	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	1				this subpart			How to find the compliance with the requirements of this subpart		2	Cm, Cn
50	CFR14 - Part 21- Subpart G	21.142	Production limitation record.	The FAA issues a production limitation record as part of a production certificate. The record lists the type certificate number and model of every product that the productio	Non	1	1	1			Issue a production limitation record	FAA	A record	Improper information	Improper record	3	Improper system design	3	Does not define	5	45	0		1	1	1	1	1	0									1	H

				n certificate holder is authorized to manufacture,																																			
51	CFR14 - Part 21- Subpart G	21.142	Production limitation record.	and identifies every interface component that the production certificate holder is authorized to manufacture and install under this part.	Internal	1	1	1			Identify interface component	FAA	Authorization to manufacture	Improper identification of interface component	Unauthorized manufacturing	4	Improper system design	3	Does not define	5	60	0		1	1	1	1	0	0				this part					2	Cn,H
52	CFR14 - Part 21- Subpart G	21.143	Duration.	A production certificate is effective until surrendered, suspended, revoked, or the FAA otherwise establishes a termination date.	Non	1	1	1				FAA	Effective production certificate								0	0		1	1	1	1	1	0									1	H
53	CFR14 - Part 21- Subpart G	21.144	Transferability	The holder of a production certificate may not transfer the production	Non	1	1	1			Not transfer production certificate	Applicant	Hold production certificate								0	0		1	1	1	1	1	0									1	H

				n certificate.																																			
55	CFR14 - Part 21- Subpart G	21.146	Responsibility of holder	The holder of a production certificate must — (a) Amend the document required by § 21.135 as necessary to reflect changes in the organization and provide these amendments to the FAA.	Internal	1	3	3	Amend the required document	Reflect changes in the organization	Provide these amendments to the FAA	Applicant	Amended documents	Improper amending	Improper amendment	3	Improper system design	3	Does not define	5	45	0		0	1	1	1	1	0				21.135					2	V,H
56	CFR14 - Part 21- Subpart G	21.146	Responsibility of holder	(b) Maintain the quality system in compliance with the data and procedures approved for the production certificate;	Non	1	2	2	Identify data and procedures approved for production certificate		Maintain quality system in compliance with the requirements	Applicant	Maintained quality system	Improper identification of data and procedures approved for the production certificate	Improper maintenance of quality system	5	Lack of maintenance system	5	Does not define	5	125	0		1	1	0	1	1	1							what does maintain mean		1	Cm

57	CFR14 - Part 21- Subpart G	21.146	Responsibility of holder	(c) Ensure that each completed product or article for which a production certificate has been issued, including primary category aircraft assembled under a production certificate by another person from a kit provided by the holder of the production certificate, presented for airworthiness certification or approval conforms to its approved design and is in a condition for safe operation;	External	1	3	3	Define Approved design	Define the condition for safe operation	Ensure conformance with the requirements	Applicant	Conformance with approved design and in condition for safe operation	Improper conformance with the requirements	A dangerous situation like accident happens	5	Improper system design	3	Does not define	5	75	0		0	1	1	1	0	0	Approved design	Condition for the safe operation							3	V,Cn,H

58	CFR14 - Part 21- Subpart G	21.146	Responsibility of holder	(d) Mark the product or article for which a certificate or approval has been issued. Marking must be in accordance with part 45 of this chapter, including any critical parts;	External	1	3	3	Identify product or article has a certificate or approval	Define marking requirements	Mark the required product or article	Applicant	Marked approved or certified product or article	Improper marking	Inability to identify required product or article	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	0	0	part 45						Which product or article needs approval or certificate		3	Cm, Cn,H
59	CFR14 - Part 21- Subpart G	21.146	Responsibility of holder	(e) Identify any portion of the product or article (e.g., sub-assemblies, component parts, or replacement articles) that leave the manufacturer's facility as FAA approved with the manufacturer's part number and name, trade	Non	1	2	2	Define FAA approved manufacturer's identification		Identify any portion of product or article required	Applicant	Identification of any portion of the product or article required	Improper identification of any portion of the product or article required	Inability to identify any portion of the product or article required	3	Improper system design	3	Does not define	5	45	0		1	1	0	1	1	1							Which product or article leave the manufacturer's facility as FAA approved		1	Cm

				mark, symbol, or other FAA approved manufacturer's identification;																																			
60	CFR14 - Part 21-Subpart G	21.146	Responsibility of holder	(f) Have access to type design data necessary to determine conformity and airworthiness for each product and article produced under the production certificate;	External	1	3	3	Define type design data	Determine conformity and airworthiness for each product and article	Have access to type design data	Applicant	Access to type design data	Improper access to type design data	nonconformity with type design data and airworthiness	3	Improper system design	3	Does not define	5	45	0		0	1	1	1	1	0	Type design data								2	V,H
61	CFR14 - Part 21-Subpart G	21.146	Responsibility of holder	(g) Retain its production certificate and make it available to the FAA upon request; and	Non	1	2	2	Retain a production Certificate		Make it available to the FAA	Applicant	Availability of production certificate	Improper retain the production certificate	Unavailability to FAA	3	system mismanagement	2	Does not define	5	30	0		1	1	0	1	1	1							In which condition retain		1	Cm
62	CFR14 - Part 21-Subpart G	21.146	Responsibility of holder	(h) Make available to the FAA information regarding all deleg	Non	1	3	3	Define all delegation of authority to suppliers	Define information required by FAA	Make the information available to the FAA	Applicant	Availability of the required information on the FAA	Collecting improper information	Unavailability of required information to the FAA	4	system mismanagement	3	Does not define	5	60	0		0	1	0	1	1	0							Which type of information		3	V,Cm,H

				ation of authority to suppliers.																																			
63	CFR14 - Part 21- Subpart G	21.147	Amendment of production certificates	(a) A holder of a production certificate must apply for an amendment to a production certificate in a form and manner prescribed by the FAA. production certificate to add a type certificate or model, or both, must comply with §§ 21.137, 21.138, and 21.150. (c)	Internal	1	2	2	Define 21.137, 21.138, and 21.150 (c) requirements		Apply for an amendment to a production	Applicant	Amendment to a production certificate	Failure to apply properly for the amendment	Lack of amendment to production certificate	4	Lack of system updating	3	Does not define	5	60	0		1	1	0	1	1	1				21.137	21.138	21.150 (c)	What is the form and manner prescribed by FAA		1	Cm

		21.147	Amendment of production certificates	An applicant may apply to amend its production limitation record to allow the manufacture and installation of an interface component, provided — (1) The applicant owns or has a license to use the design and installation data for the interface component and makes that data available to the FAA upon request; (2) The applicant manufactures the interface component; (3) The applicant's product conforms to its approved	Non		2	2	Define the conditions and limitations		Apply to amend production limitation record	Applicant	Amendment to production limitation record	Failure to meet the requirements	lack of amendment to production limitation record	4	Lack of system updating	3	Does not define	5	60	0		0	1	0	1	1	1							What other conditions and limitations the FAA consider necessary		2	V,Cm

				type design and the interface component conforms to its approved type design; (4) The assembled product with the installed interface component is in a condition for safe operation; and (5) The applicant complies with any other conditions and limitations the FAA considers necessary.																																			
64	CFR14 - Part 21- Subpart G	21.150	Changes in quality system.	After the issuance of a production certificate — (a) Each change to the quality system is subject to review by the FAA; and	Non	1	3	3	Gain production certificate	Change to quality system	Review changes	FAA	Review on changes	Improper changes	inacceptable changes	5	Improper system design	4	Does not define	5	100	0		0	1	0	1	1	0							What kind of change or review		3	V,Cm,H

65	CFR14 - Part 21- Subpart G	21.150	Changes in quality system.	(b) The holder of a production certificate must immediately notify the FAA, in writing, of any change that may affect the inspection, conformity, or airworthiness of its product or article.	Non	1	2	2		Define required changes	Notify FAA	Applicant	Written Notification	Notify the FAA with delay	inacceptable changes	4	system mismanagement	4	Does not define	5	80	0		1	1	0	1	1	1							In what context and extent may affect inspection, conformity, or airworthiness of product or article		1	Cm
Report	Total number of code	16			Average number of action	1.04615385	20	13	Plus/minus 20%						NA items						0	60	5 items are AC	12	0	37	0	22	33										

Appendix B

Item No.	Component Identification	Reliability	CI	R	CI	R	CI	R	Segment reliability
1	21.132	0.57	Type certificate	x					0.58x
2	21.132	0.43	Supplemental Type certificate	y					0.43y
3	21.132	0.57	Type certificate	x	Supplemental type certificate	y			0.58xy
4	21.133	0.43	All FAA form and prescribed manner	x1	All FAA form and prescribed manner	y1			0.43x1y1
5	21.135	0.71							0.71
6	21.135	0.57							0.57
7	21.135	0.57							0.57
8	21.135	0.00							0.43
9	21.135	0.43							0.43
10	21.135	0.57							0.57
11	21.135	0.57	21.135 part a	0.57					0.33
12	21.135	1.00							1
13	21.135	0.71	21.138	0.57					0.41
14	21.135	0.57	Applicable regulation of subchapter C	x2					
15	21.135	0.71							0.71
16	21.137	0.57	Approved design	x3					
17	21.137	0.71	Approved design	x3					
18	21.137	0.71	Design data	x4					

19	21.137	0.71							0.71
20	21.137	1.00							1
21	21.137	1.00							1
22	21.137	0.71	Approved design	x3					
23	21.137	0.71	Approved design	x3					
24	21.137	0.71	21.137 e	0.71					0.51
25	21.137	0.71	21.137 e	0.71					0.51
26	21.137	0.57	Standard acceptable to the FAA	y2	Approved design	x3			
27	21.137	0.71	Approved design	x3					
28	21.137	0.71							0.71
29	21.137	0.43	Approved design	x3	Type certificated product	y3	21.137 h		
30	21.137	0.57	21.137 h	0.43					0.24
31	21.137	0.71	21.137 h	0.43					0.31
32	21.137	0.43	Approved design	x3	Approved quality system	y4			
33	21.137	0.71							0.71
34	21.137	0.71							0.71
35	21.137	0.71	45.15 (c)	x9					
36	21.137	0.43	Approved quality system	y4					
37	21.137	0.71							0.71
38	21.137	1.00	21.137 (m)	1.00					1.00
39	21.137	0.43	21.137 (m)	1.00					0.43
40	21.137	0.57	Design Data	x4	Quality system requirements	x5			
41	21.137	0.57							0.57

42	21.137	0.71	21.137	0.57					0.41
43	21.137	0.71	43.3 (j)						
44	21.137	0.71	21.331		21.335				
45	21.138	0.57							0.57
46	21.139	0.71	49 U.S.C	y7	this subchapter	y8			
47	21.139	1.00							1
48	21.139	0.57							0.57
49	21.140	0.29							0.29
50	21.141	0.57	This subchapter	y8					
51	21.142	0.71	this subpart	y9					
52	21.142	0.57							0.57
53	21.143	0.71	this part	x8					
54	21.144	0.71							0.71
55	21.146	0.57							0.57
56	21.146	0.71	21.135	0.01					0.01
57	21.146	0.43	Approved design	x3	Condition for the safe operation	y5			
58	21.146	0.43	part 45	y6					
59	21.146	0.71							0.71
60	21.146	0.57	Type design data	x7					
61	21.146	0.71							0.71
62	21.146	0.43							0.43
63	21.147	0.71	21.137	0.57	21.138	0.714286	21.150 (c)	0.714286	0.21
64	21.147	0.57							0.57
65	21.150	0.43							0.43
66	21.150	0.71							0.71