A FUZZY QUALITY FUNCTION DEPLOYMENT BASED APPROACH FOR QUALITY MANAGEMENT MATURITY MEASUREMENT

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LIST OF SYMBOLS

A	: Average
AA	: Above Average
AHP	: Analytic Hierarchy Process
AIWH	: Absolute Importance Weight of Enabler (HOW)
AIWW	: Absolute Importance Weight of Target (WHAT)
AS	: Aerospace Standards
BA	: Below Average
CMM	: Capability Maturity Model
CMS	: Current Maturity Score of Target (WHAT)
CS	: Current Score of Enabler (HOW)
CQA	: China Quality Award
CTQMS	: Current Total Quality Maturity Score
E	: Excellent
EFQM	: European Foundation of Quality Management
HOQ	: House of Quality
IP	: Interrelationship Power
ISO	: International Standardization Organization
M	: Moderate
MMM	: Maturity Measurement Model
MMS	: Maximum Possible Maturity Score of Target (WHAT)
MS	: Maximum Possible Score of Enabler (HOW)
MTQMS	: Maximum Possible Total Quality Maturity Score
P	: Poor
PDCA	: Plan – Do – Check – Act
RIWH	: Relative Importance Weight of Enabler (HOW)
RIWW	: Relative Importance Weight of Target (WHAT)
S	: Strong
SJV	: Sum of Judgment Values of Answers In Response To Questions
QFD	: Quality Function Deployment
QMM	: Quality Management Maturity
QMMM	: Quality Management Maturity Measurement
QMMI	: Quality Management Maturity Index
QMR	: Quality Management Review
QMS	: Quality Management System
UAV	: Unmanned Air Vehicle
VP	: Very Poor
VS	: Very Strong

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ABSTRACT

A quality management system (QMS) ensures that the activities carried out in the organizations are conducted in line with the pre-determined objectives. AS9100D quality management standard is the guideline document for establishing and operating the QMS in the aviation industry. After establishing a QMS, improvement needs arise later in the process. The effectiveness, performance, and maturity of this system should be measured to identify the issues that require improvement within the organization.

This study aims to develop a quality management maturity measurement (QMMM) model suitable for an aviation organization. The quality function deployment (QFD) method is employed by determining the targets (WHATs) that the organization desires to accomplish and the enablers (HOWs) which are required for achieving determined targets. Additionally, as part of the measurement model, a set of questions grouped according to HOWs and to be answered by experts are prepared.

After that, the relationship between WHATs and HOWs and the correlation between each HOWs are established by collecting data from expert judgments as linguistic variables. These linguistic variables which are demonstrated as fuzzy triangular numbers during fuzzy operations enable experts to be more flexible about their judgment. So, they can determine their decisions more naturally and accurately. Eventually, using relationship and correlation values with experts' answers, the maturity index for the organization's QMS is obtained. A case study that is performed in an aviation organization is also demonstrated in this study.

ÖZET

Kalite yönetim sistemi, kuruluşlarda yürütülen faaliyetlerin önceden belirlenmiş hedefler doğrultusunda yürütülmesini sağlar. AS9100D kalite yönetim standardı, havacılık endüstrisinde kalite yönetim sistemlerinin kurulması ve işletilmesi için kılavuz bir dokümandır. Kalite yönetim sistemi kurulduktan sonra, sürecin ilerleyen aşamalarında iyileştirme ihtiyaçları ortaya çıkar. Kuruluş içinde iyileştirilmesi gereken konuları belirlemek için kalite yönetim sisteminin etkinliği, performansı ve olgunluğu ölçülmelidir.

Bu çalışmada, havacılık sektöründe faaliyet gösteren bir organizasyonun kalite yönetim sistemine uygun olacak şekilde kalite yönetimi olgunluk ölçüm modeli geliştirilmesi amaçlanmıştır. Kuruluşun başarmak istediği hedefleri (NE) ve belirlenen hedeflere ulaşmak için gerekli olan etkinleştiricileri (NASIL) belirlemek için kalite fonksiyon yayılım kullanılmıştır. Ek olarak, ölçüm modeli kapsamında etkinleştiricilere (NASIL) göre gruplandırılmış ve uzmanlar tarafından yanıtlanması gereken bir dizi soru hazırlanmıştır.

Daha sonra, dilsel değişken olaran uzmanlardan elde edilen görüşler ile her bir hedef ve etkinleştirici arasında ilişki matrisi, her bir etkinleştiricinin kendi arasında ise korelasyon matrisi oluşturulmuştur. Bulanık işlemler sırasında, bulanık üçgensl sayılar olarak ifade edilen bu dilsel değişkenler, uzmanların yargılarında daha esnek olmalarını sağlayarak, kararlarını daha doğal ve doğru bir şekilde belirlemesine olanak sağlamıştır. Sonuç olarak, uzmanların sorulara verdikleri cevaplar ile ilişki ve korelasyon matrislerindeki değerler kullanılarak, organizasyonun kalite yönetimi olgunluğu için olgunluk indeksi elde edilmektedir. Bu çalışma kapsamında önerilen modelin sayısal uygulaması havacılık alanında faaliyet gösteren bir organizasyonda gerçekleştirilmiştir.

1. INTRODUCTION

With the contributions of industrial innovations in the modern world, more than one organization has started to operate in almost every sector. This situation has led to composing an inevitable competitive environment and then organizations have to increase the quality of products and services provided to their customers. In a developing competitive environment, organizations somehow have to determine the ways and methods called strategies for ensuring their sustainability, attaining a competitive advantage, using their resource effectively and efficiently, and ultimately achieving their goals and objectives. The concept of strategy defines the exact point of how much the organization pays attention to reach its goals and how the organization will achieve them. A strategy determines the framework of action plans that the organization can perform. Having a strategy can increase organizational effectiveness and efficiency and allows organizations to be more proactive. The concept of the strategy includes the concept of vision that defines the position in which an organization wants to be in the future, its future goals, and objectives. Having a vision statement can improve the ability of leadership function of top-level management in an organization, can aid to create organizational culture, and can maintain the focus. The concept of strategy also includes the concept of mission that defines the main purposes of an organization's existence, its responsibilities, the approaches the organization use to achieve its goals and objectives, so ultimately who the organization is and what the organization carries out in currently. One of the most important benefits of having a mission statement is to increase employee engagement and encourage them to work effectively together to help the organization to achieve its goals. Strategic management is the whole process of planning, implementing, and evaluating strategies, vision, and mission statements to make an organization more competitive globally. It is very important for the sustainability perspective to implement all planned strategies within the scope of strategic management with a quality perspective.

The (QMS) enables organizations to carry out their activities according to the mission and vision statements that are determined in line with the strategies and then makes it possible to evaluate all results according to strategies, goals, and objectives. As part of the whole system, organizations establish QMS that ensure compliance to quality standards adopted by organizations in their processes because growing importance of providing a better quality of products and services. The QMS that includes those quality standards has come into view as a methodology to enhance the improvement of organizations' sustainability.

1.1 Quality Management System

A QMS is a comprehensive management approach that establishes and documents processes and determines their sequence/interactions, manages and allocates resources to related activities, defines and determines responsibilities and authorities, reviews and evaluates the processes and results, and finally ensures continuous improvement activities. A QMS enables organizations to provide and maintain an acceptable and consistent level of quality of their products and services by monitoring and controlling the processes and other organizational activities. A QMS helps to coordinate and to direct organizational activities for satisfying customers' and regulatory requirements and enhance its effectiveness in a sustainable structure. Before establishing a QMS, an organization should identify its mission and vision statements along with its strategies. Therefore, the adoption of a QMS is a strategic decision for an organization. These concepts directly affect the content and boundaries of the QMS structure. One of the most important reasons for the emergence of the concept of strategy is the global competitive environment. Strategy is the means and methods to be used to achieve long-term goals and objectives under uncertainty. Organizations define goals and objectives in accordance with the strategies. Since the resources to be used to achieve these goals are limited, it is very important to determine appropriate strategies. The QMS is used to determine the requirements of processes and services to achieve these goals and objectives most effectively. As part of the QMS, the term quality assurance means focusing on providing confidence that quality requirements are fulfilled.

Quality assurance consists of plans and requirements that an organization developed and consists of activities that assure compliance with these plans and requirements to obtain customer satisfaction.

The implementation of a QMS starts with the understanding of the needs and expectations of the stakeholders and proceeds with the determination of processes that the organization will perform to achieve its goals and objectives and the determination of the sequence/interactions of these processes, then plans and procedures should be prepared as documented information appropriately. After that, the realization of the planned activities should be performed. During this stage, allocation of resources to the processes is an important activity to improve effectiveness and efficiency. Review activities are required as a result of the process realization, and during these reviews, the gaps between objectives and current status are evaluated. As a result of review activities, improvement necessities are determined and actions are taken to improve processes. Some of the significant benefits of having a QMS in an organization are; the establishment of a structural culture of quality, effective management of the processes, efficient use of resources, better understanding of customer requirements, better engagement of employees, and commitment to applying continuous improvement.

Standards such as ISO 9001:2015 Quality Management Systems - Requirements and AS 9100D Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations are the guidelines for the establishment of the QMS. Having a certificate of these standards indicates that it provides a certain level of quality and plans, implements, measures, evaluates its processes to meet customer requirements, and takes improvement actions when necessary. Since this study was performed in an aviation organization, AS 9100D Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations is considered and detailed in the next sections.

1.2 AS9100D Quality Management System Standard

AS9100D Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations standard is formed to establish a QMS in an organization that carries out design, development, and production activities in the aviation industry. This international standard specifies requirements for a QMS when an organization: needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements. AS9100D quality management standard covers all requirements stated in ISO 9001:2015 quality management standard. In addition to these requirements, AS9100D includes specific requirements related to aviation, space, and defense organizations in areas such as configuration management, safety, design and development, and counterfeit part management.

This international standard encourages the process approach that integrates the Plan-Do-Check-Act (PDCA) cycle and risk-based thinking methodology. PDCA cycle can be used for evaluating whole processes included in the standard. PDCA cycle includes 4 different components. Plan means creating quality objectives and processes required to provide intended results. Do means performing everything that has been considered during the planning stage. Check is likely one of the most important phases of the cycle, in this step actual results are measured per planned quality requirements. In the step of the act, in case there is a difference between planned quality requirements and actual results, the necessary actions are taken to eliminate this difference. Risk-based thinking is an essential part of this international standard for operating an effective QMS. Risk-based thinking encourages organizations to identify, evaluate and manage risks during the phases of establishing and operating processes, control points, and improvement needs in a QMS. In this international standard, QMS requirements are stated in different sections.

In section 4: requirements regarding the definition and determination of the context of the organization, understanding of the needs of the stakeholders/customers, and requirements for the planning of QMS processes, are stated.

In section 5: requirements for top-level management leadership, the status of establishment of a quality policy, and determination of organizational roles, responsibilities, and authorities are stated.

In section 6: requirements related to the planning of risk and opportunity activities, quality objectives, and change management process are included.

In section 7: requirements characterized by the planning of human resources and infrastructure resources, planning of environment where processes will be realized, planning of resources that will be used in monitoring activities, and planning of capturing and managing the organizational knowledge are stated. Furthermore, requirements consisting of the planning of improvement of the individuals' competency, and planning of improvement of the individuals' awareness about processes, planning of communication ways, and planning of management of documented information process are stated as well.

In section 8: requirements regarding operational risk management, configuration management, the safety of products, and counterfeit part usage are stated. Moreover, planning of the design and development processes that include management of requirements, inputs, outputs, and changes are stated. Eventually, requirements related to the planning of management of externally provided products and services, planning of validation and verification activities, planning post-delivery activities, and planning of control of nonconforming outputs are included in this section.

In section 9: requirements about the planning of analysis and evaluation activities, and planning of audit activities are stated. In addition to that, requirements for the planning of quality management reviews (QMR), determination of QMR inputs, and planning of management of QMR outputs are included.

In section 10: requirements regarding the planning of continuous improvement activities and planning of management of nonconformity and corrective action activities are stated.

Once an organization implements all requirements of the AS9100D quality management standard successfully, the status of compliance to these requirements is audited and evaluated by accredited organizations. After successful completion of the audit and evaluation process, the organization obtains an AS9100D certificate. Having this certificate indicates that the organization provides a certain level of quality and plans, implements, measures, evaluates its processes to meet customer requirements, and takes improvement actions when necessary. After establishing a QMS, improvement needs arise later in the process. The effectiveness, performance, and maturity of the QMS should be measured to identify the issues that require improvement within the organization.

1.3 Quality Management Maturity Measurement

With regard to quality management practices in the organization, maturity relates to the adoption level of dedicated quality management practices and tools. Maturity measurement of the QMS for an organization is important from a sustainability perspective. Organizations that aim for sustainability should always improve their QMS maturity level. The QMS maturity assessment intends to evaluate the ability of the organization both to determine relevant processes needed for creating valuable outputs and to manage these processes effectively. Additionally, in the scope of the QMS maturity measurement, the ability of the organization both to review its processes and to improve them by taking necessary actions are evaluated. Measurement of quality management maturity (QMM) is performed by an organization for measuring how mature their processes and systems are and for determining how well these processes and systems are embedded in their culture. Properly applied QMMM can be a key driver for improvement opportunities by determining deficiencies in the organization. When the organization gets a higher level of maturity in the QMS, it will make significant progress on the excellence path. The QMS can be at different levels from different points of view. A review of the gaps can help top management in planning and prioritizing the improvement and/or innovation activities needed to move to a higher level of maturity.

A maturity model is a self-assessment tool for measuring the maturity of the QMS. The QMM grid that includes different types of maturity levels was introduced by Crosby (Crosby, 1979). Different types of models can be used for measuring QMS maturity (Krzemień and Wolniak, 2011). The effectiveness of the maturity measurement is directly based on the model used. Therefore, during the development of the maturity model and determination of the evaluation criteria, the requirements of the organization should be taken into consideration.

In this study, a maturity measurement model (MMM) is developed for an organization that has established a QMS as per AS9100D. This model is developed according to the AS9100D quality management system standard and the organization's requirements and integrates fuzzy QFD methodology into it. Therefore, the contributions of this study are to develop a MMM suitable for the aviation industry particularly and to enable experts to be more flexible in their judgment utilizing fuzzy QFD processes. The other objective of this study is to determine the dimensions that affect the maturity of the QMS and create an opportunity for improvement activities in an aviation organization.

The study is organized according to the following sequence. In section 2, a review of the literature is given. In section 3, how the model structure and methodology are established is explained. In section 4, a case study applied in an aviation organization is represented. After evaluation of results is given in section 5, suggestions for future research are described in section 6.

2. LITERATURE REVIEW

There were studies in the literature about maturity measurements. Dewi and Suhardi (2014), conducted a maturity assessment in information quality management activities by using the capability maturity model (CMM). They used 5 different maturity levels in their model and benefited from the survey method during the assessment process. Xiuxia and Zhongwen (2007), introduced a maturity model for the assessment of information quality in their study. They developed a model that had 5 different maturity levels based on 4 different dimensions. In each dimension, necessary activities required for the assessment of the maturity level were determined. For the assessment, a questionnaire was prepared and the proposed model was applied by them to an organization located in China.

Domingues et al. (2016), used a model for the assessment of the maturity of an integrated management system which is composed of the QMS, environmental management system, and occupational health and safety management system. In their model framework, six different maturity levels were introduced. They determined the requirement set that was necessary to satisfy each maturity level. Ormazabal et al. (2017), developed a MMM that includes six different maturity levels for environmental management in their study. In each of these maturity levels, requirements that are necessary to meet the level were determined. The proposed model was applied in organizations located in different countries such as Spain, Italy, and United Kingdom.

In a different study, Novokmet and Rogošiæ, (2017) evaluated the QMS maturity effects on financial areas for a long-range period. The model structure used in their study was developed by the principles of the ISO 9001 QMS standard. During data collection, they used the survey method.

They applied the proposed MMM in organizations located in Croatia. All data collected were analyzed by using statistical methods and the effects of the QMS maturity on financial dimensions were evaluated.

Shah et al. (2009), conducted a maturity measurement for risk management activities in a manufacturing organization that has design and development processes. They proposed a model that has six different maturity levels of Capability Maturity Model Integration. Four different dimensions were evaluated in their maturity model and for the assessment, a questionnaire was prepared. Eventually, an application of this proposed model was demonstrated.

Witek-Crabb (2016), in her study, proposed a MMM based on the structure of CMM and this model had 5 different maturity levels. She evaluated the maturity of strategic management activities by considering two different dimensions. Under these two different dimensions, she determined 8 different factors and under these factors, there were 32 questions. The proposed model was applied by her in the 150 different organizations that were classified according to their total number of employees and located in Poland. Then, statistical methods were used by her to analyze the data collected. Van Laar et al. (2020), developed a MMM for knowledge management activities at U.S. Army headquarters. In their model, there were 4 different dimensions and under these dimensions, there were 42 different factors. The assessment of the knowledge management maturity study was conducted in 11 different U.S. Army headquarters. The collected data were analyzed with the usage of the analysis of variance method. Sohrabi and Fallah (2017), worked on the effects of the quality level of services and innovation on knowledge management maturity in another study. They determined eight different key indicators that affect the maturity of knowledge management. Apart from that, 4 key indicators that affect the innovation activities and 3 different key indicators that affect the quality of services were determined by them. For data collection, a questionnaire method was used. They used statistical methods for analyzing the data collected. Then, they evaluated the relationship between the key indicators determined for knowledge management maturity, innovation, and the quality of services.

Söderberg and Bengtsson (2010), introduced a maturity model for the assessment of supply chain management activities in 15 different organizations that work in the metal, steel, manufacturing, and service industries in Sweeden. In their study, 5 different performance metrics were determined in terms of supply chain management, and a questionnaire was prepared to collect data. The maturity was calculated as a result of answers to the prepared questions and then, according to the results, 15 different organizations were demonstrated on a scale of 5 different maturity levels. Cubo et al. (2021), developed a MMM for supply chain quality management. The maturity model proposed by them had 5 different maturity levels, 5 different key maturity indicators, and 100 different evaluation criteria. During the assessment, each criterion was scored from 1 to 5 and the total maturity score was calculated accordingly.

There were some other studies regarding the maturity measurement of the QMS. These studies were applied in different types of industries.

Teguh et al. (2020), indicated that the maturity of QMS was one of the most important performance measures throughout the organization for achieving the desired targets. In their study, they developed MMM to measure the performance of the QMS in the manufacturing industry by introducing factors that had a relationship with this system. The designed MMM had four levels and each of these levels was established based on different types of factors. They only explained the development framework of an MMM for QMS in their study. However, how this maturity model was applied or numerical example was not included. Tita and Christina (2012), pointed out that assessing the maturity of QMS enabled organizations to monitor and evaluate all processes and allowed an increasing level of effectiveness of those processes that contribute to overall quality. They used two maturity models similar to each other in terms of structure but different in terms of content. The first model used was CMM and the second one was a model established in accordance with ISO 9004. They did not represent the application of these proposed models in their study.

Halima et al. (2017), performed a QMMM in libraries. For measuring the maturity of the QMS in libraries, they considered different types of variables such as “leadership”, “human resource management”, “customer focus”, “process management”, and “performance management”. They used surveys and interviews as tools to obtain quantitative data. As a result, the QMM of fifteen different university libraries was evaluated and results were demonstrated on a scale from Level 0 to Level 5 maturity. Wilson (2015), used the maturity model as a tool for evaluating the maturity of QMS of the libraries. Under eight different factors, he evaluated 41 different variables in his study. He preferred to use question-based interviews with related groups to obtain appropriate data. The MMM used in his paper had five different maturity levels such as “ad hoc”, “repeatable”, “defined”, “managed” and “continuous”. Finally, an example application of the proposed methodology was given in his study.

Wolniak (2019), focused on a study that searched the level of the maturity of organizations’ QMS established as per requirements stated in ISO 9001 quality management standard. He proposed different types of factors such as “customer orientation”, “leadership”, “commitment of the people”, “process approach”, and “evidence-based decision making” in his study. For the establishment of the MMM framework, he used the ISO 9004 guideline document. After the establishment of the MMM, approximately 3000 organizations in Poland were chosen and questionnaires were sent to them. Results were calculated via statistical methods and were demonstrated on a five-point maturity scale. Ligarski (2017), made assessments for organizations with the employment of over 250 people in the Polish market. In his study, the maturity of the QMS based on ISO 9001 quality management standard was assessed by using a questionnaire-based measurement model established as per ISO 9004, ISO 10004, and the Polish Quality Award measurement model. Each measurement model had different types of evaluation criteria. He demonstrated and shared the results of the measurements in his study and he stated that every organization which has the intention of being sustainable should perform this type of measurement periodically.

Ehsan et al. (2019), conducted QMMM studies in hospitals. For obtaining data from hospitals, they opted for using question-based interviews with related groups. They determined 46 different variables that could affect the maturity of QMS under nine different factors. After answers were gathered from experts, statistical methods were used to analyze those data. Results were demonstrated as a QMS index and this index was quantitative. However, scaled maturity levels were not used in the scope of this study.

In their work, Glogovac et al. (2020), proposed the usage of Industry 4.0 to increase organizations' effectiveness and performance. They considered ISO 9004 guideline as a basis for the establishment of MMM that was used as a tool for the assessment of QMS. A questionnaire was prepared to gather information from organizations in related industries. Gathered data were analyzed by using confirmatory factor analysis. Besides, verification of the proposed model was also included in their study.

Xiaofen (2013), performed a maturity study for QMS of organizations located in Shanghai. He developed a MMM based on criteria using "Crosby's Evaluation Model of Quality Management Maturity" and ISO 9004:2009 guideline. As a result of the measurement study, an index that demonstrates maturity was obtained. For the proper demonstration of maturity results, he designed a formulation for this index in his study. For obtaining data from organizations, surveys including 50 different questions under fifteen different factors were performed with related groups. These fifteen different factors were divided into three sub-levels. Results were analyzed by using statistical methods and demonstrated on five-scaled maturity levels.

Makhanya et al. (1990), indicated that factors such as "customer satisfaction", "process management", "strategic alignment", "continuous improvement", and "information management" could be used in the process of measurement of QMS maturity. There were 5 different maturity levels deployed in their study. After related factors were determined, they mainly focused on research methodology regarding QMMM studies issued in literature.

Shrayner and Yashchenko (2019), introduced different types of maturity models that can be used for the measurement of QMS in the high-tech industry. For this, they created and used a systematic literature review procedure based on specific search and selection criteria.

Some studies integrated QFD into performance measurement and maturity measurement studies. Digehsara et.al. (2018), used a structure that was a combination of the European Foundation of Quality Management (EFQM) model and the QFD method for measuring the performance of the project management system. EFQM model consisted of different types of elements that can affect the performance of the QMS and the QFD methodology was used for collecting information from experts. To obtain experts' opinions, the questionnaire was prepared and experts were asked to answer them. They formulated relationships through the usage of the QFD methodology, and then they obtained numerical-based results accordingly. Hence, deficiencies that need improvements could be determined and prioritized in their study.

Yun and Zhongchun (2009), benefited from the QFD methodology for engineering project performance evaluation. They used the QFD method for specifying necessary performance indicators and their weights. Furthermore, a multi-stage model of the house of quality was established so that at the beginning, customer needs were turned into first-class indicators, and then these first-class indicators were converted to second-class performance indicators. After the proposed model structure was described, a numeric example was given to demonstrate how this model works.

Lee and Arditi (2003), developed a QFD-based tool used for measuring the service quality of design-build organizations. They named customer needs and expectations called the voice of the customers as service factors and they obtained these factors from construction owners through a questionnaire-based method. After the importance weights of service factors were determined, relationship values between elements of QMS established in these organizations and service factors were assigned by experts as well.

Then, an index that represents the performance of QMS was calculated by using these weights and relationship values. They used this index to rank more than one design-build organization in terms of satisfaction level of customer needs and expectations.

Liu and Xu (2006), used QFD as a tool for both identifying the dimensions that had a significant effect on the QMS and measuring the maturity. They developed a multi-phased QFD model structure was developed. China Quality Award (CQA) criteria were chosen as a basis for the MMM and different numbers of criteria were set under each level of indicators. To ensure an appropriate transition from one phase to another, they developed formulations. The result of the calculations was demonstrated as a quality score at the end.

Bashir (2016), used the QFD technique as a tool for assessing the maturity of total quality management activities conducted in a university. In the early phases of his study, initially, customer requirements were gathered from students and markets, then technical requirements were established by employees of the university in response to customer requirements. After the relationship between customer requirements and technical requirements was developed, the importance weight of each customer requirement was calculated. Finally, improvement areas that could affect customer satisfaction were determined.

Zhang and Cheng (2012), developed a QFD tool for the assessment of QMS established by contractors. They determined seven different engineering quality factors as customer requirements and eight different QMS factors as technical requirements. Then, formulations were set to establish the relationship between engineering quality factors and QMS requirements. They verified the proposed model with a case study and they demonstrated the final results of calculations as an index that symbolize the performance of QMS.

Deveci et al. (2019), assessed the service quality of public bus transportation by using the QFD methodology.

In their study, data from passengers who use public buses were gathered by surveys as the voice of customers, then the design requirements regarding this service were determined in response to customer requirements. After the determination of related requirements, weights of these requirements and relationship values between these were calculated. Finally, it was determined which design requirements should be improved to increase customer satisfaction regarding public bus transportation service quality.

There were other studies that used the QFD technique. Raziei et al. (2018), integrated the servqual and QFD methodology for assessing the service quality in hospitals, and Hamzah et al. (2019), used these techniques for assessing the total quality management in universities. Additionally, Kudryavtsev et al.(2014), benefited from the QFD to establish an aligned business architecture that considers shareholders' concerns and customer requirements, and Jagdev et al. (1997), used the QFD as a performance measurement tool in business process re-engineering. Andronikidis et al. (2009), integrated the analytic hierarchy process (AHP), analytic network process, and QFD techniques into service quality management activities. In another study, Awasthi et al. (2018), introduced and integrated the AHP and QFD techniques to improve logistic service quality to be able to increase customer satisfaction. Jaqin et al. (2020) conducted a study by using the QFD principles for analyzing the quality performance of an automotive company to solve quality problems that affect the rate of quality performance indicator. Rathore et al. (2015), developed a QFD-based structure as a performance measurement tool for after-sales service activities in the automotive industry. Dwivedi et al. (2018), integrated balanced scorecard applications and a QFD model to assess and evaluate the performance of an agriculture organization. Matook and Indulska (2009) developed a QFD-based methodology for increasing the quality of the process reference model.

There were some QFD studies applied in the aviation industry. Filippova (2019), used the QFD method used as a tool for risk management activities in the design and development process of unmanned aircraft vehicles (UAV) by creating a relationship between design requirements called as the voice customer and technical characteristics.

Dmitriev and Mitroshkina (2019), used the QFD approach in the design and development process of UAVs to understand the customer and the related stakeholders' requirements and to establish a relationship between these requirements and the technical specification of UAVs. Palmer et al. (2013), developed a QFD-based approach for the analysis of requirements of propulsion system design and development activities and to establish the relationships between design requirements and technical requirements.

Additionally, the criticality of the functions determined as a result of failure mode and effects analysis was evaluated by using the QFD in her study. Chen et al. (2014), proposed a model that is a combination of AHP and QFD techniques to evaluate the importance of safety factors in the aviation industry. In their study, the QFD was used to establish a relationship between the safety factors and functions that were needed to be realized. Younus and Iqbal (2011) used the QFD technique to establish a relationship between the customer requirements and service quality factors in an organization that performs maintenance, repair, and overhaul activities in the aviation industry.

There were also some other studies that include fuzzy QFD applications. Yenradee and Akkawuttiwanich (2018), integrated fuzzy and QFD methods for measuring the supply chain performance. Dursun and Karsak (2013) used these techniques as a framework for supplier selection. Vinodh and Chintha (2011), integrated fuzzy logic and QFD methods to both enable sustainability in the manufacturing industry and to deal with uncertainty caused by subjective judgments. Dat et al. (2015), developed a fuzzy QFD-based model for market segment evaluation and selection. Alptekin and Alptekin (2018), provided a solution by using fuzzy logic and QFD method integration for diversifying cloud products. Efe (2019), pointed out that a fuzzy cognitive map-based QFD approach could be used for dishwasher machine selection. In another study, Tian et al. (2018), used a multi-phase QFD-based methodology on a fuzzy multi-criteria decision-making process for performance evaluation.

Considering all of the above literature survey results given, until now, it has been observed that there has been no research regarding the establishment of the MMM for QMS established in the aviation industry.

3. METHODOLOGY

The aim of this study is to develop a fuzzy QFD-based maturity model for the assessment of the QMS. Therefore, fuzzy logic and the QFD technique are used and integrated. The following subsections describe the concepts of the QFD technique and fuzzy logic methodology according to the usage pattern in this study. Eventually, the structure of the proposed MMM is described in this section.

3.1 Quality Function Deployment

The QFD is a tool and comprehensive methodological approach that is used to determine the customer requirements and to transform these requirements to the technical specifications of the final output. The QFD method is usually preferred by the design and manufacturing organizations to establish a relationship between the requirements of the customers and the detailed design of the products. The QFD was introduced by Yoji Akao in Japan and defined by its creator (Yoji, 1990) as an approach that was used in the design and development phases to satisfy the stakeholders by understanding their requirements and transforming these requirements into the design characteristics. The QFD also can be used as a decision-making technique by weighting or prioritizing the customer requirements or the technical specifications (Matook and Indulska, 2009).

Yoji (2014), stated in his study that there were dimensions that create the concept of quality, and QFD techniques can be used to establish overall control of them. QFD methodology provides a defined set of matrices utilized to facilitate this progression. One of these matrices called as house of quality (HOQ) is used to demonstrate the relationship between the customer requirements and the technical specifications (Dai and

Blackhurst, 2012). The visual demonstration of the house quality can be in the following figure.

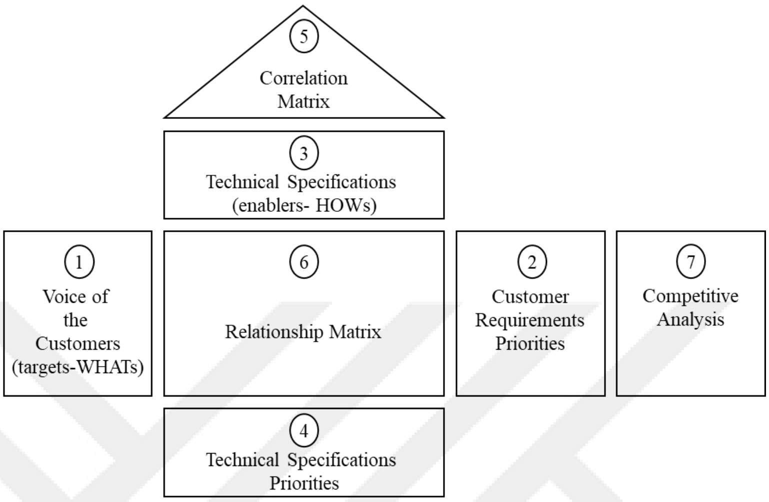

Figure 3. 1: The General Representation of the House of Quality

The house of quality is a kind of scheme that provides the means for inter-functional planning and communications. Descriptions of the areas in the house of quality are as follows.

(2) Customer Requirements Priorities: To understand the degree of the importance of the needs and expectations of the customers, prioritization is applied to them. Then, resource allocation is realized accordingly. This prioritization can be applied by using qualitative and quantitative analysis methods (Na et al., 2012).

3) Technical Specifications (enablers-HOWs): That part of the house of quality is named as ceiling and includes the technical specifications that are required to satisfy the customer requirements to increase the satisfaction. These technical specifications are used as inputs in the QFD process. Technical specifications may be derived from standards that are specifically generated for the products or services (Chan and Wu, 1998).

(4) Technical Specifications Priorities: To understand the degree of contribution of the technical specifications to the satisfaction level of the customer requirements, prioritization is applied. This prioritization can be applied by using qualitative and quantitative analysis methods (Na et al., 2012).

(5) Correlation Matrix: This is called as the roof of the house of quality matrices. This matrix demonstrates the degree of correlation established between the technical specifications.

(6) Relationship Matrix: This is called the body of the house of quality matrices. This matrix represents the relationship between the customer requirements that are desired to be achieved and the technical specifications that are required for accomplishing the requirements of the customers.

(7) Competitive Analysis: The competitive analysis may be performed in the QFD process to determine and understand the strengths and weaknesses of the organizations against the other organizations that produce the same products or services in the industry. This area of the house of quality is not planned to use in the scope of this study.

3.2 Fuzzy Quality Function Deployment

In this study, the QFD method is used to determine targets (WHATs) and enablers (HOWs) that will be used in the MMM. The QFD is also used both to weight and prioritize the targets (WHATs) and enablers (HOWs) and establish interrelationship power matrices between them. Additionally, the correlation matrices are established between enablers (HOWs) by using QFD.

During the both weighting the targets (WHATs) and establishment of interrelationship power matrices and the correlation matrices experts have stated their opinions as linguistic variables. Fuzzy logic is integrated into QFD method at this phase of the study.

In this study, expert opinions that stated as linguistic variables are represented by using triangular fuzzy membership function. The triangular membership function is one of the most widely accepted and used membership function in fuzzy logic. The triangle which fuzzifies the input can be defined by three parameters where X_1 and X_3 define the base and X_2 defines the height of the triangle.

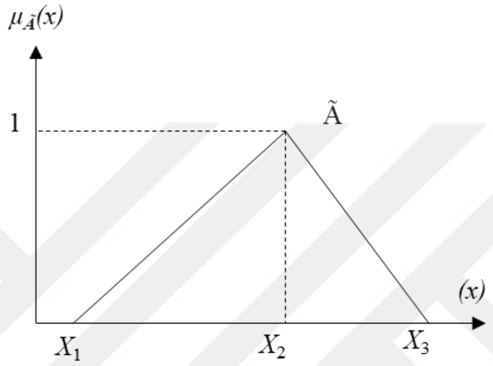

Figure 3. 2: Triangular Fuzzy Membership Function

In Figure 3.2, the X dimension means the input and the Y dimension demonstrates the corresponding fuzzy value in the fuzzy set. In the case of input x is equal to X_2 (x=X_2) which means x takes the maximum membership value in the fuzzy set ($\mu_{\tilde{A}}(x)$=1), and if x is not greater than X_1 ($x \leq X_1$) and/or is not less than X_3 ($x \geq X_3$), that means x takes the minimum membership value in the fuzzy set ($\mu_{\tilde{A}}(x)$=0). If an input x is selected between X_1 and X_2 then x takes a membership value between 0 and 1, and if an input x is selected between X_2 and X_3, then x takes a membership value between 0 and 1 as well.

The technique of assigning a system's numerical input to fuzzy sets with some degree of membership is known as fuzzification. The inverse concept of fuzzification is known as defuzzification. Defuzzification is a process of calculating a unique crisp number from the aggregated fuzzy set (Masoum and Fuchs, 2015). For the defuzzification process, the centroid method is the one that will be used in this study after max aggregation is applied to the fuzzy set.

Aggregation operations are the operations that are used to obtain a unique single fuzzy set by integrating more than one fuzzy set. The max aggregation takes the maximum part of each fuzzy set in the integration into consideration to establish a unique single fuzzy set.

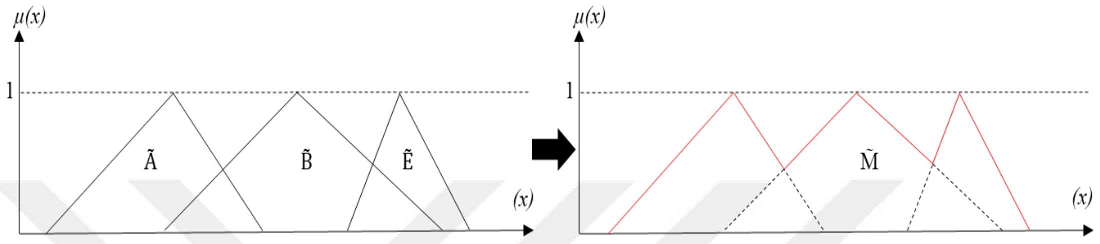

Figure 3. 3: The Max Aggregation on Fuzzy Sets

On the left side of Figure 3.4, it is seen that there are 3 different fuzzcy sets. These fuzzy sets are representations of triangular fuzzy membership functions and these are intersected with each other. On the right side of Figure 3.4, a representation of a final fuzzy set after the max aggregation is applied can be seen via the red line. After the max aggregation operation, the dotted lines in Figure 3.4 are not used to determine the boundaries of the fuzzy sets.

In the centroid defuzzification method, the center of gravity of the given fuzzy set is calculated and the result is represented as a unique crisp value. The centroid (x^*) of the given fuzzy set is calculated in accordance with Equation (3.1).

In this equation, x_i demonstrates the inputs, and $\mu(x_i)$ demonstrates the corresponding fuzzy values (Mercorelli, 2018).

$$(x^*) = \frac{\sum_i \mu(x_i) * (x_i)}{\sum_i \mu(x_i)} \tag{3.1}$$

The visual demonstration of the centroid in a fuzzy set can be seen in the following figure.

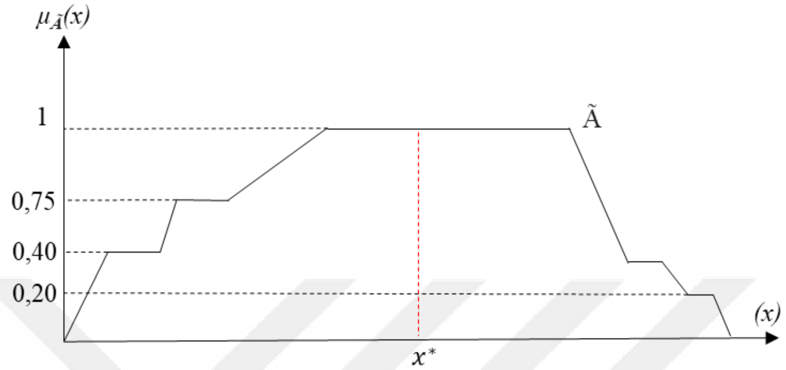

Figure 3. 4: The Visual Representation of Centroid In A Fuzzy Set

After establishment of interrelationship power matrices and the correlation matrices by using experts' opinions the relationship matrix is calculated bu multiplication of interrelationship power matrix and correlation matrix. Then, importance weight of enablers (HOWs) are calculated by using the importance weight of targets (WHATs) and the relationship matrix values.

As part of the MMM, a set of questions grouped according to HOWs are answered by experts based on linguistic variables and triangular fuzzy membership function is used to represent them. Then, max aggretation and centroid defuzzfication are applied those data. Eventually, using relationship and correlation values with experts' answers, the quality management maturity index for the organization's QMS is obtained. Detailed steps of MMM can be seen in section 4.

4. PROPOSED MODEL

Maturity model developed in this study is requested by the top-level management of the design and development project of the aviation organization. Maturity of the project is taken into consideration during development of the maturity model. This maturity model covers design and development phases of the project and these phases have milestones such as alternative system review, system requiremets review, system functions review, preliminary design review and critical design review. Consequently, prototype manufacturing and serial manufacturing phases are not considered during establishment of the MMM in this study. Because, when the manufacturing activities are started, in the structure of the MMM, some of the targets (WHATs) and some of the enablers (HOWs) are needed to be evolved in accordance with requirement of manufacturing activities.

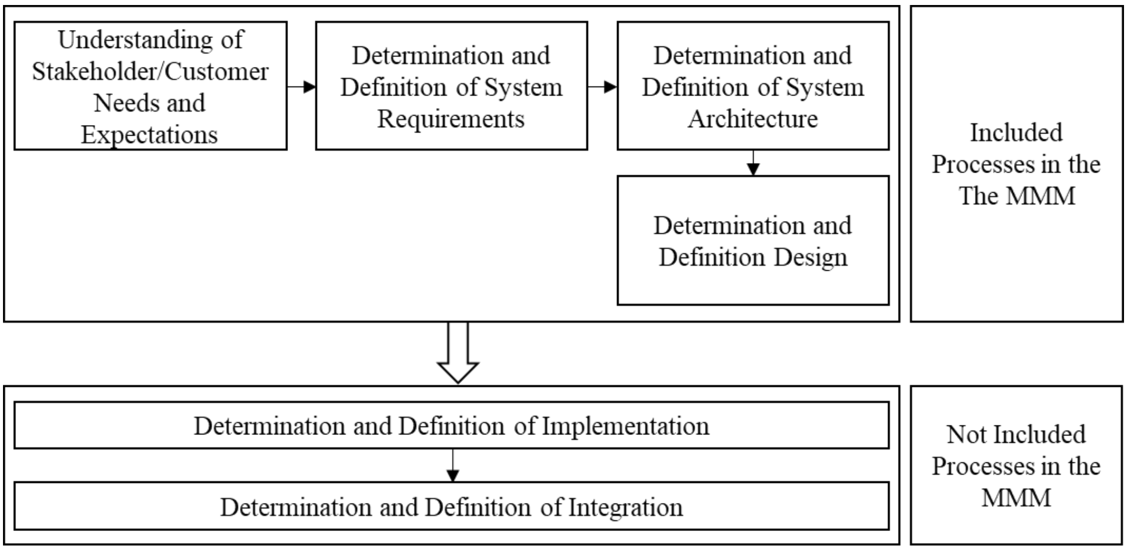

Figure 4. 1: The Included and Not Included Processes in the MMM

According to Figure 4.1, undertanding of stakeholder/customer needs and expectations, determination and definition of system requirements, determination and definition of system architecture and determination and definition of desing processes are included in the framework of the MMM. Determination and definition of implementation, determination and definition of integration processes are the following processes of the design activities. Therefore, these processes are not included in the framework of the MMM.

Within the proposed MMM, the targets (WHATs) and the enablers (HOWs) are determined. These targets and enablers are determined in accordance with AS9100D sections and organization own requirements. For example, audit management target and QMR target are determined in response to section 9 of the AS9100D and continuous improvement target is determined in response to section 10 of AS9100D. Besides, quality policy enabler is determined in response to section 5 of A9100D and quality objective enabler is determined in response to section 6 of the AS9100D.

Additionally, the levels that represent the maturity of the QMS are determined as well. Detailed descriptions of these targets (WHATs), enablers (HOWs), and the maturity levels are given in the following subsections.

4.1 Targets (WHATs)

Targets (WHATs) indicate the goals and objectives that the organization desires to accomplish for the successful operation of QMS. Detailed descriptions of targets (WHATs) that will be used in this study are given in the following subsections.

4.1.1 Management System Target

A management system is a comprehensive approach that covers high-level quality management activities used to ensure the sustainable success of an organization.

The boundaries and context of an organization are determined by the scope of the management system. A higher level of complexity in an organization requires more effective and efficient, systematic processes to achieve desired goals. One of the most important benefits of having a structured management system is the increased ability to produce sustainable and improved products and services, thereby enhanced customer and stakeholder satisfaction. This item will measure how an organization matures its QMS.

4.1.2 Resource Management Target

Basically, resource management is the planning, providing, and allocating of resources to the processes for ensuring the sustainable success of an organization. Organizations include different types of resources to establish and maintain the operability of their QMS. How an organization obtains and sustains its resources will be measured through resource management. In the resource management activities; human resources who will perform processes, external providers from which an organization provides products or services for its own processes, infrastructures that are needed for sustainable operation of the organization's processes, and organizational knowledge that is a significant resource for an organization throughout its life cycle activities are considered. Effective resource management has a significant impact on the success of overall quality management directly.

4.1.3 Planning Management Target

Essentially, planning activities are the fundamental components of each management system. It means that a plan is always necessary for any other managerial function in an organization. Planning management is related to determining what kind of activities are needed to be performed by organizations to achieve the desired objectives. Efficient planning management activities allow organizations to determine objectives properly, decreasing uncertainty, preventing waste of resources, and effective decision-making processes.

4.1.4 Audit Management Target

In terms of quality perspective, an audit is an activity whose purpose is to determine and evaluate the degree of compliance of an organization to its procedures or national/international standards or regulations that are used to meet requirements of products or services. Audits are one of the best tools for determining the areas which have deficiencies and need improvements. Therefore, the management of audits requires attention. The more organization have a high level of maturity in audit management the more benefits will increase.

4.1.5 Quality Management Review Target

Top-level management in organizations monitors and controls the results of the processes. QMR is one of the best tools to monitor and control the results and determine the gaps between goals and the current status. As a result, management reviews can be the most important opportunity for improvement activities. The content of the QMR and actions which will be taken as a result of the review will affect the maturity of a QMS.

4.1.6 Continuous Improvement Target

Continuous improvement management enables an organization to establish an efficient and effective improvement process. The concept of continuous improvement interacts and collaborates with other concepts of QMS in an organization and it can be stated that the continuous improvement process is a never-ending process. Being able to apply continuous improvement philosophy is one of the fundamental purposes why organizations try to establish a QMS structure.

4.1.7 Process Management Target

Process management enables organizations to use processes for creating valuable outputs from inputs. Thus, to maintain efficiency and effectiveness, management of processes is required as part of an established QMS.

Effective process management allows organizations to increase overall efficiency, and employee engagement and promotes a culture of continuous improvement.

4.2 Enablers (HOWs)

Enablers (HOWs) indicate the means or tools which are required for achieving determined targets. Detailed descriptions of targets (WHATs) that will be used in this study are given in the following subsections.

4.2.1 Quality Policy Enabler

A quality policy is a statement that describes an organization's mission, vision, and strategic direction. It is a fundamental requirement of a QMS. A quality policy is prepared and declared by top-level management in an organization. In the scope of the quality policy, commitment to continuous improvement and applicable statutory/regulatory requirements, degree of understanding, availability to related parties, and communication the status within the organization will be evaluated.

4.2.2 Quality Objective Enabler

Objective means result to be achieved. The quality objective is an objective that is related to quality activities. Quality objectives are determined at a top level in organizations. In the quality objectives enabler, consistency with the quality policy, the status of monitoring and communicating within the organization, the status of being measurable, the status of taking applicable requirements into consideration, the status of being relevant to the conformity of products/services will be evaluated.

4.2.3 Document Management Enabler

Document management identifies the process of how an organization manages documentation in its own processes.

In document management enabler; the determination of rules regarding document management, the determination of document management processes, the status of usage of document management tools, and the status of compliance to document management rules will be evaluated.

4.2.4 Authorization Management Enabler

Authorization is the process of giving someone or other organization permission to perform necessary activities within or outside of the organization. The authorization has significant importance in the design and development processes in the aviation industry. In authorization management enabler, the status of authorization in the document management tool, the status of determination of rules for different types of authorization roles, and the status of compliance to authorization rules will be evaluated.

4.2.5 Change Management Enabler

Change is a natural part of processes and organizations. At a point in the throughout the life cycle of the project change may be required. Roles and responsibilities, steps of the processes, and even the design of products/services may be changed. These change activities should be managed in a controlled manner. In the scope of the change management, the status of the definition of the change management process, the status of hierarchy, authority, membership structure of the configuration control board, and the status of compliance to change management process/rules will be evaluated.

4.2.6 Human Resource Enabler

Human resources are one of the most important resources to realize processes in the organization. Human resource management means a comprehensive approach to employees who are involved in the organization. Effective human resource management makes organizations competitive globally.

In human resource management enabler, human resource planning activities, determination of necessary human resources to realize the processes, availability of job descriptions and the status of role assignment to individuals, the definition of organizational responsibilities, definition of required skillsets based on job descriptions, availability of role-based trainings, availability of refreshment trainings for skills and competencies, performance evaluation activities will be evaluated.

4.2.7 External Provider Enabler

External providers are the organizations that provide products/services to other organizations. Management of external providers directly affects the organization's processes. In the external providers management enabler, determination of system subcontractors and contractual the status of these subcontractors, the status of subcontractors' evaluation process, document management regarding subcontractor activities, and authorization management regarding subcontractor activities will be evaluated.

4.2.8 Infrastructures Enabler

Infrastructures are the resources as important as human resources to realize processes in the organization. In infrastructure management enabler, determination of building infrastructure needs, determination of software/hardware needs, and the status of the review of infrastructures will be evaluated.

4.2.9 Organizational Knowledge Enabler

Organizational knowledge is the specialized knowledge, derived either from cumulative experience throughout its own processes or from the individual experience of its members. This knowledge can be used to achieve the organization's goals, whether explicitly or implicitly. Gathering and managing organizational knowledge affect the performance of the organization.

In organizational knowledge management enabler, the availability of an established system for capturing information internally or externally, the status of evaluation of captured information will be evaluated.

4.2.10 General (Planning) Enabler

Considering the project maturity, planning of activities, planning of resources, and planning of project schedule are considered. General (planning) enabler evaluates, planning of organization structure, planning of work breakdown structure, and planning of dictionary statements.

4.2.11 Risk/Opportunity Planning Enabler

The planning of risks is one of the fundamental requirements of the QMS standards. Risk planning is used to identify potential problems that can cause trouble for the design and development project. Opportunity planning is used to identify potential values, achievements, especially in technology areas. Proper risk planning can reduce the uncertainty of conditions that can cause problems. In the scope of the risk and opportunity planning management, definitions of risk and opportunity management process within the organizations, the status of control plans (mitigation and contingency) for highly critical risks, the status of compliance to risk and opportunity management rules, and the status of risk and opportunity review will be evaluated.

4.2.12 Contractual Data Documentation Planning Enabler

Contractual data documents are the documents required by the contract signed with the owner of the project that is who will benefit from the outputs of the project. Types of contractual data documents are determined and defined in the project contract. In the contractual data documents planning enabler, the status of preparation and submission of these documents in accordance with the project schedule, the status of these documents of compliance to applicable statutory and regulatory standards determined in the main contract, acceptance status of these documents by the customer will be evaluated.

4.2.13 Project Review and Monitoring Planning Enabler

Project review and monitoring are used to determine the gaps between goals and the current status of the project. Project review activities are required by the customer as per contract and globally accepted project monitoring methods are applied in the project. In the scope of the project review and monitoring planning, planning of formal reviews such as alternative system review, system requirement review, system function review, preliminary design review and realization of these formal reviews per the project schedule, planning and analysis of critical activities in the project schedule and earned value planning and analysis activities will be evaluated.

4.2.14 Audit Scope Enabler

Scope of audit defines the range of content, activities and the time that will be consumed. Proper determination of audit scope increases the effectiveness of audit activities. Audit scope enabler evalutes, the status of audit scope being conformance to the organization's internal procedures and requirements, applicable statutory or regulatory requirements, and status of documentation of audit plans.

4.2.15 Audit Team Enabler

An audit is always performed by an audit team. The audit team consists of an audit team leader, audit team members, and observers (if needed). Bringing proper team members together as an audit team in accordance with pre-defined audit scope directly affects the quality of audit activities. In audit team enabler, availability of audit team in an organization, availability, and status of competency evaluation of audit team members in accordance with the required skill set and availability and status of audit team members' evaluation after an audit is performed will be evaluated.

4.2.16 Audit Schedule Enabler

In order to increase the effectiveness of audit activities, planning should be performed appropriately. Performing audits at an ideal point of time during the life cycle of the project affects the quality of ongoing activities. In the audit schedule enabler, proper determination of audit time intervals, availability of audit schedule, status of compliance to planned audit schedule and documentation of audit schedule will be evaluated.

4.2.17 Audit Results Enabler

In order to benefit from audits, results of these activities should be managed in a controlled manner. Status of documentation of audit results as an evidence of implementation of scheduled audits, status of reporting of results to relevant management level and relevant responsibles and determination of corrective and preventive actions as results of the audits will be evaluated.

4.2.18 General (QMR) Enabler

Performing QMRs is one of the fundamental requirements of the QMS standards. In that manner, QMR should be performed throughout the organization. In the scope of general QMR activities planning of reviews and documentation of this planning, the status of compliance to planned review interval, and status of recording of review meeting attendance will be evaluated.

4.2.19 Inputs (QMR) Enabler

Determination of inputs appropriately, directly affects the effectiveness of QMR. Inputs (QMR) enabler evaluates, evaluation of status of actions from previously performed reviews, the status of evaluation of performance and effectiveness of QMS, the status of evaluation of nonconformities and corrective actions, status of evaluation of process monitoring results, status of evaluation of audits performed.

4.2.20 Outputs (QMR) Enabler

As a result of the QMR, outputs are created. Especially, these outputs are considered as the key driver for future improvement activities. Outputs (QMR) enabler evaluates, the status of documentation of QMR, determination of action items after QMR, the status of closing determined action items, the status of stakeholder feedback about the effectiveness of QMR, and status of stakeholder feedback about confidence for established QMS in the organization.

4.2.21 General (Continuous Improvement) Enabler

Continuous improvement management activities are encouraged by the quality management standards. Planning improvement activities will increase the effectiveness of processes in the organizations. In general continuous improvement activities, status of encouragement of people by senior management to participate and contribute to improvement activities, availability of documented information that describes how to apply continuous improvement process in the organizations, status of compliance to the related procedure regarding the application of continuous improvement, the status of the sufficiency of awareness of individuals about continuous improvement in the organization, status of the contribution of individuals regarding improvement activities in the organization, determination, and documentation of lessons learned will be evaluated.

4.2.22 Nonconformity/Corrective Action Enabler

Nonconformities and corrective actions are usually created as results of audit activities. With proper management of nonconformities and corrective actions, improvement opportunities may be created. In nonconformity and corrective action management, the availability of documented information that describes how this process will be managed, status of how responsible people are informed about nonconformities, status of reviewing and analyzing of nonconformities by related people, availability of timescale for corrective actions and status of conformance to determined timescales, status of evidence of corrective actions taken in response to nonconformities, availability of timescale for root cause analysis for nonconformities and status of conformance to determined timescale will be evaluated.

4.2.23 General (Process Management) Enabler

Process management is one of the fundamental activities required by the QMS standards. In the scope of the general process management activities, determination of processes needed for achieving the project objectives, availability of systematic definition and demonstration of sequences/interactions of processes, status of documentation of functional processes and status of the level of understanding of process owners, availability of process improvements as a result of user's implementation will be evaluated.

4.2.24 Process Measurement Enabler

In order to increase the effectiveness of the processes, measurements should be performed properly. Process measurement enabler evaluates, status of definition and documentation of process measurement activities, determination and definition of what will be measured, determination of the exact point of time for process measurement activities, determination of measurement criteria and determination of ways of evaluations of process measurement results will be evaluated.

4.3 Maturity Levels

A maturity level is described as a exact point where the organization is in the path of excellence of the QMS. The maturity level of an aviation organization is determined as a result of assessment by using the proposed MMM in this study. The MMM proposes 5 different maturity levels.

These maturity levels are determined in accordance with the organization's own requirements. The maturity level of the QMS in an organization is determined according to the quality management maturity index (QMMI) calculated as a result of measurement process. Descriptions of these maturity levels are as follows.

Understanding: at this phase of maturity of the QMS an organization has not started to apply the requirements of the quality management standards. Determination and explanation of processes are barely in place. Successful operation of the QMS is heavily based on the experience of employees.

Incomplete Deployment: at this phase of maturity, all requirements of the QMS are understood. The organization has determined and explained most of the processes. Necessary resources are planned and the processes have started to be performed. Monitoring and control of the processes are not in place. Successful operation of the QMS is still based on the experience of employees in some areas.

Complete Deployment: the organization has almost determined all the processes and their sequences. Monitoring and control of the processes have just started. Results of the processes are just started to evaluate. Nonconformities that can be created as a result of processes are managed. Improvement activities are in the initiation phase. Successful operation of the QMS is based on the experience of employees insignificantly.

Performing: the organization has monitored and controlled its processes effectively and efficiently. Improvement activities for the processes are performed. Organizational knowledge about the know-how of the processes are just started to be obtained. Benchmarking: this is the highest level in this maturity model. The applications in the QMS of an organization that is at benchmarking maturity level are role models for other organizations.

4.4 Steps of the Proposed Model

This study aims to develop a quality management MMM model suitable for an aviation company. This MMM is developed for an organization that has established a QMS per AS9100D. Requirements of AS9100D quality management standard and the organization's own requirements are taken into consideration during the development of this maturity model.

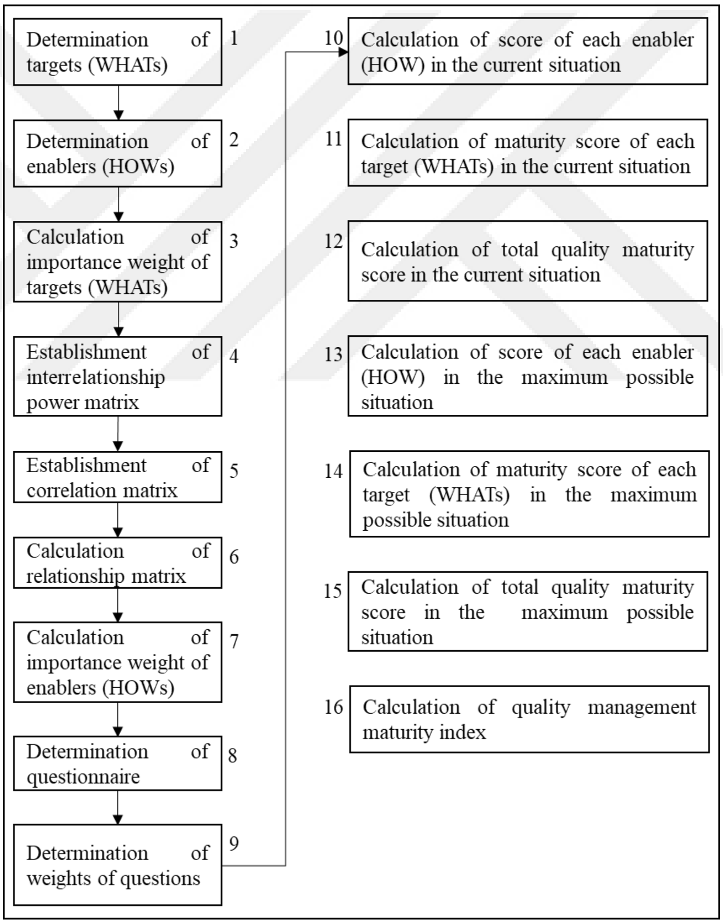

Figure 4. 2: Development Process of The MMM

The development process of this MMM can be in Figure 4.2 A detailed descriptions of each step of the development process are as following.

Step 1 – determination of the targets (WHATs): targets (WHATs) are obtained by conducting a group brainstorming technique with the participation of seven different experts who have sufficient experience in the aviation industry. There are 7 different targets (WHATs) categories determined in accordance with AS9100D quality management standard requirements and the organization's necessities. These targets (WHATs) demonstrate the goals that the organization desire to accomplish in the established QMS. Targets (WHATs) that will be used in the proposed MMM can be seen in Table 4.1. Detailed descriptions of each target are given in Section 4.1. In the following parts of this study, targets (WHATs) are demonstrated as a combination of the letter "T" and numbers. For example, "T1" means management system target, "T2" means resource mangement target, "T3" means planning management target.

Table 4. 1: Targets (WHATs) in the Proposed Maturity Model

No	Name of the Target (WHAT)
1	Management System (T1)
2	Resource Management (T2)
3	Planning Management (T3)
4	Audit Management (T4)
5	QMR (T5)
6	Continuous Improvement Management (T6)
7	Process Management (T7)

Step 2 – determination of the enablers (HOWs): enablers (HOWs) are obtained in a similar way to the determination of targets (WHATs) by conducting a group brainstorming technique with the same experts. There are 24 different enablers (HOWs) categories determined in accordance with AS9100D quality management standard requirements and the organization's necessities. These enablers (HOWs) are required for achieving determined targets (WHATs) in the established QMS. Enablers (HOWs) that will be used in the proposed MMM can be seen in Table 4.2. Detailed descriptions of each target are given in Section 4.2. In the following parts of this study, enablers (HOWs) are demonstrated as a combination of the letter "E" and numbers.

For example, “E1” means quality policy enabler, “E2” means quality objectives enabler, “E3” document management enabler.

Table 4. 2: Enablers (HOWs) in the Proposed Maturity Model

No	Name of the Enabler (HOW)	No	Name of the Enabler (HOW)
1	Quality Policy (E1)	13	Project Review and Monitoring Planning (E13)
2	Quality Objectives (E2)	14	Audit Scope (E14)
3	Document Management (E3)	15	Audit Team (E15)
4	Authorization Management (E4)	16	Audit Schedule (E16)
5	Change Management (E5)	17	Audit Results (E17)
6	Human Resources (E6)	18	General (QMR) (E18)
7	External Providers (E7)	19	Inputs (QMR) (E19)
8	Infrastructures (E8)	20	Outputs (QMR) (E20)
9	Organizational Knowledge (E9)	21	General (Continuous Improvement) (E21)
10	General (Planning) (E10)	22	Nonconformity/Corrective Action (E22)
11	Risk/Opportunity Planning (E12)	23	General (Process Management) (E23)
12	Contractual Data Documentation Planning (E12)	24	Process Measurement (E24)

Step 3 – calculation of the importance weight of targets (WHATs): to calculate the importance weights of the targets (WHATs), firstly, experts have stated their opinions based on 5-scaled linguistic variables which are increasingly sequenced as "not important (NI)", "slightly important (SI)", "moderately important (MI)", "important (I)", "very important (VI)". Then, max aggregation and centroid defuzzification are applied to inputs to obtain crisp values as outputs. These outputs are the relative importance weights. Later, these relative importance weights are normalized and absolute importance weights are obtained in accordance with Equation (4.1).

$$AIWW_w = \frac{RIWW_w}{\sum_{w=1}^{TW} RIWW_w} \tag{4.1}$$

In this equation; $AIWW_w$ means the absolute importance weight of the w^{th} target (WHAT), $RIWW_w$ means the relative importance weight of the w^{th} target (WHAT) and TW means the total number of targets (WHATs).

Step 4 – establishment of the interrelationship power (IP) matrix: the interrelationship power matrix is established between targets (WHATs) and enablers (HOWs) in accordance with experts' opinions that is based on 5-scaled linguistic variables. These linguistic variables are in increasing sequence as "very poor (VP)", "poor (P)", "moderate(M)", "strong (S)", "very strong (VS)". Then, max aggregation and centroid defuzzification are applied to inputs to obtain crisp values. As a result of this establishment, IP_{wh} values that represent the interrelationship power between w^{th} target (WHAT) and h^{th} enabler (HOW) is determined in the interrelationship matrix ([IP]).

Step 5 – establishment of the correlation (C) matrix: the correlation matrix is established between enablers (HOWs) in accordance with experts' opinions. Experts have stated their opinions based on 5-scaled linguistic variables which are increasingly sequenced as "very poor (VP)", "poor (P)", "moderate(M)", "strong (S)", "very strong (VS)". Then, max aggregation and centroid defuzzification are applied to inputs to obtain crisp values as outputs. As a result of this establishment, C_{he} values that represent the correlation between h^{th} enabler (HOW) and e^{th} enabler (HOW) is determined in the correlation matrix.

Step 6 – calculation of relationship (R) matrix: the relationship matrix is calculated between each target (WHAT) and enabler (HOW) by multiplication of the interrelationship power matrix [IP] and the correlation matrix [C] according to Equation (4.2) (Zhang and Cheng, 2012)

$$[R] = [IP]_{(w)*(h)} * [C]_{(h)*(e)} \tag{4.2}$$

As a result of this step, R_{wh} values that represent the relationship between w^{th} target (WHAT) and h^{th} enabler (HOW) is calculated in the relationship matrix.

Step 7 – calculation of the importance weight of enablers (HOWs): to calculate the importance weights of the enablers (HOWs), the absolute importance weights of the targets (WHATs) and the relationship matrix values are used according to Equation (4.3). These calculated weights are the relative values. Later, these relative importance weights are normalized and absolute importance weights are obtained in accordance with Equation (4.1) by using related importance weights for enablers (HOWs) in this equation. As a result, $RIWH_h$ values that represent the relative importance weight of the h^{th} enabler (HOW) and $AIWH_h$ values that represent the the absolute importance weight of the h^{th} enabler (HOW) are obtained. In Equation (4.3), TH means the total number of enablers (HOWs).

$$RIWH_h = \sum_{w=1}^{TW} AIWW_w * R_{wh} \qquad (h = 1, 2, 3, \ldots, TH) \tag{4.3}$$

Step 8 – determination of questionnaire: to calculate score of each enabler (HOW), different number of questions are prepared and grouped under each enabler (HOW). These questions are prepared in accordance with AS9100D quality management standard requirements and the organization's necessities. Project maturity is also considered during the determination of these questions. In the scope of this, 107 different questions are prepared. All questions are not included in this study because of the security laws applied in the aviation and defense industry. Examples of questions prepared for quality policy and quality objectives enablers can be seen in Table 4.3.

In the following parts of this study, questions are demonstrated as a combination of the capital letters of enabler and letter "Q" and number. For example, "QP-Q1" means the first question of the quality policy enabler and "QO-Q1" means the first question of the quality objective enabler.

Table 4. 3: Questions Prepared For "Quality Policy" and "Quality Objectives" Enablers

Enabler (HOW)	Questions
Quality Policy	Quality Policy includes "Continuous Improvement" of QMS commitment? (QP-Q1)
	Does quality Policy include a commitment to satisfy applicable statutory and regulatory requirements? (QP-Q2)
	Quality Policy is available to all stakeholders and maintained as documented information? (QP-Q3)
	Quality Policy is understood and applied within the organization? (QP-Q4)
	Quality Policy is communicated within the organization? (QP-Q5)
Quality Objectives	Are quality Objectives consistent with Quality Policy? (QO-Q1)
	Quality Objectives are maintained as documented information? (QO-Q2)
	Quality Objectives are monitored and communicated within the organization? (QO-Q3)
	Quality Objectives are measurable and take into consideration applicable requirements? (QO-Q4)
	Quality Objectives are relevant to the conformity of product/services and enhancement of customer satisfaction? (QO-Q5)

Step 9 – determination of weights of questions: the weights of questions are calculated in a way that sum of the weights of all questions grouped in each enabler (HOW) is equal to 1. Therefore, the weights of each question under an enabler (HOW) are accepted as equal to each other. Calculations of weights of questions under each enabler (HOW) are performed in accordance with Equation (4.4)

$$W_h = \frac{1}{TQ_h} \qquad (h = 1, 2, 3, \dots, TH) \tag{4.4}$$

Step 10 – calculation of score of each enabler (HOW) in the current situation: to calculate the score of each enabler (HOW), firstly, experts have stated their opinions as answers to the questions. These opinions are obtained based on 5-scaled linguistic variables which are increasingly sequenced as "very poor (VP)", "below average (BA)", "average (A)", "above average (AA)", and "excellent (E)". Then, max aggregation and centroid defuzzification are applied to inputs to obtain crisp values as outputs. These outputs demonstrate the judgment values of experts regarding questions. Eventually, the score of each enabler (HOW) is calculated in accordance with Equation (4.5).

$$CS_h = \sum_{h=1}^{TH} W_h * SJV_h \tag{4.5}$$

In this equation, the CS_h value represents the current score of the h^{th} enabler (HOW) and the SJV_h represents the sum of the judgment values of answers in response to questions under h^{th} enabler (HOW).

Step 11 – calculation of maturity score of each target (WHAT) in the current situation: After the judgment values for each question are obtained from experts for the current situation and the CS_h of enablers (HOWs) are calculated, the maturity score for each target (WHAT) is calculated in accordance with Equation (4.6).

$$CMS_w = \sum_{h=1}^{TH} CS_h * R_{wh} \qquad w = 1, 2, 3, \dots, TW \tag{4.6}$$

In this equation, the CMS_w value represents the current maturity score of the w^{th} target (WHAT).

Step 12 – calculation of total quality maturity score in the current situation: after the calculation of the CMS_w for each target (WHAT), the current total quality maturity score is calculated in accordance with Equation (4.7).

$$CTQMS = \sum_{w=1}^{TW} CMS_w \tag{4.7}$$

The *CTQMS* in this equation means the current total quality maturity score.

Step 13 – calculation of score of each enabler (HOW) in the maximum possible situation: to calculate the maturity score of each target (WHAT) for the maximum possible situation, all experts' opinions in response to questions are accepted as "excellent (E)" linguistic variable. After applying max aggregation and centroid defuzzification, all judgment values of experts regarding questions are calculated as 1. Then, the maximum possible maturity scores of each enabler (HOW) are calculated in accordance with Equation (4.5) by using related judgment values for enablers (HOWs) in this equation. As a results, the MS_h values that represent the maximum possible score of the h^{th} enabler (HOW) are obtained.

Step 14 – calculation of maturity score of each target (WHAT) in the maximum possible situation: after the MS_h of enablers (HOWs) are calculated, the maximum possible maturity score for each target (WHAT) is calculated in accordance with Equation (4.6) by using the related maximum possible scores of enablers (HOWs) in this equation. As a results, The MMS_w values that represent the maximum possible maturity score of the w^{th} target (WHAT) is obtained.

Step 15 – calculation of the total quality maturity score for the maximum possible situation: After the calculation of the MMS_w for each target (WHAT), the maximum possible total quality maturity score is calculated in accordance with Equation (4.7) by using the related maximum possible maturity scores of targets (WHATs) in this equation. As a results, The *MTQMS* values that represent the maximum possible total quality maturity score is obtained.

Step 16 – calculation of the quality management maturity index: Finally, as a result of the maturity measurement, the *QMMI* is calculated as the ratio of the *CTQMS* to the *MTQMS* in accordance with Equation (4.8).

$$QMMI = CTQMS/MTQMS \tag{4.8}$$

The *QMMI* value in this equation represents the quality management maturity index. After this index is calculated, the maturity level is determined according to Table 4.4.

Table 4. 4:The QMMI Intervals for Maturity Levels

Maturity Level	QMMI Intervals
Understanding	0 – 20%
Incomplete Deployment	21% - 40%
Complete Deployment	41% - 60%
Performing	61% - 80%
Benchmarking	81%-100%

5. NUMERICAL EXAMPLE

The QMMM study explained in this study is conducted in a design and development project of an aviation organization. This aviation organizanization is subject to the AS9100D certification process. Thereby, this aviation organization has an established QMS in accordance with requirements stated in the AS9100D quality management standard. The development of a systematic and comprehensive methodology QMMM is requested by the top-level management of the design and development project of this aviation organization. The frequency of the QMMM study is stated as quarterly and the purpose of this measurement is stated as to determine opportunities in planning and prioritizing the improvement and/or innovation activities needed to move to a higher level of maturity. In line with this stated purpose, deficiencies and improvement necessities will be defined according to the results of the QMMM quarterly and actions will be taken until the next maturity measurement period.

In this section, the application of each step of the proposed MMM described in Section 4.4 will be explained in detail. In addition to that, the results of the applications will be demonstrated as well.

Step 1 – the application of the proposed MMM starts with the determination of the targets. These targets are necessary dimensions for establishing and operating a QMS. During the determination process of targets, the group brainstorming technique with the participation of seven different experts who have 5-15 years of experience in QMSs is conducted. The determined targets that will be used in this study can be seen in Table 4.1.

Step 2 – after targets (WHATs) are determined, enablers (HOWs) that are required for accomplishing these targets are determined. It can be said that these enablers (HOWs) are the significant means for sustainability of the targets (WHATs) and eventually of the QMS. The group brainstorming technique with the participation of the same experts is conducted. The determined enablers (HOWs) that will be used in this study can be seen in Table 4.2.

Step 3 – in order to calculate the importance weights of the targets (WHATs), firstly, experts have stated their opinions based on 5-scaled linguistic variables which are increasingly sequenced as "not important (NI)", "slightly important (SI)", "moderately important (MI)", "important (I)", "very important (VI)". Experts' opinions can be seen in Table 5.1.

Table 5. 1: Experts' Importance Opinions For WHATs

Targets (WHATs)	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
T1	I	SI	I	MI	I	MI	SI
T2	VI	MI	MI	MI	I	I	I
T3	MI	I	SI	SI	MI	I	I
T4	I	I	MI	I	MI	I	MI
T5	SI	MI	I	MI	SI	SI	MI
T6	SI	SI	SI	MI	SI	MI	MI
T7	I	MI	VI	I	I	VI	SI

Triangular fuzzy numbers in response to these linguistic variables can be seen in Table 5.2.

Table 5. 2: Triangular Fuzzy Numbers in Response to Step-3 Linguistic Variables

Linguistic Variable	Triangular Fuzzy Numbers
Not Important (NI)	(0 / 0 / 0)
Slightly Important (SI)	(0 / 0.25 / 0.50)
Moderately Important (MI)	(0.25 / 0.50 / 0.75)
Important (I)	(0.50 / 0.75 / 1)
Very Important (VI)	(1 / 1 / 1)

Then, max aggregation and centroid defuzzification are applied to inputs to obtain crisp values as outputs. For max aggregation and centroid defuzzification fuzzy operations MATLAB software is used. After max aggregation and defuzzification are applied in MATLAB, the relative importance weights of targets (WHATs) are obtained. Later, these relative importance weights are normalized and absolute importance weights are obtained in accordance with Equation (4.1). Results can be seen in Table 5.3.

Table 5. 3: Relative and Absolute Weights of Targets (WHATs)

Targets (WHATs)	Relative Weights of "WHATs" (from MATLAB)	Absolute Weights of "WHATs"
T1	0.500	0.137
T2	0.633	0.174
T3	0.500	0.137
T4	0.625	0.172
T5	0.500	0.137
T6	0.375	0.103
T7	0.508	0.139

As an example calculations of the absolute weights of the management system and the resource management targets are as follows:

$AIWW_1$ represent the absolute importance weight of the management system and $AIWW_2$ represent the absolute importance weight of the resource management.

$$AIWW_1 = (0.500) / (0.500+0.633+0.500+0.500+0.625+0.500+0.375+0.508) = 0.137$$

$$AIWW_2 = (0.633) / (0.500+0.633+0.500+0.500+0.625+0.500+0.375+0.508) = 0.174$$

Step 4 – interrelationship power matrices are established between targets (WHATs) and each enabler (HOW) separately in accordance with experts' opinions that is based on 5-scaled linguistic variables. These linguistic variables are in increasing sequence as "very poor (VP)", "poor (P)", "moderate(M)", "strong (S)", "very strong (VS)". As a consequence, there are 24 different 7*7 sized matrices. All expert opinions regarding interrelationship power are not included in this study because of the security laws applied in the aviation and defense industry. In the following parts of this study, experts are demonstrated as a combination of the letters "Ex" and numbers. For example, "Ex1" means Expert 1, "Ex2" means Expert2, "Ex3" means Expert3.

Table 5. 4: Interrelationship Power Opinions For Targets and Quality Policy Enabler

Targets (WHATs)	Quality Policy						
	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7
T1	S	P	M	M	P	M	M
T2	P	P	P	P	P	P	P
T3	P	P	P	P	P	P	P
T4	P	P	P	P	P	P	P
T5	P	P	P	P	P	P	P
T6	S	P	P	S	S	S	S
T7	P	P	P	P	P	P	P

Table 5. 5: Interrelationship Power Opinions For Targets and Quality Objectives Enabler

Targets (WHATs)	Quality Objective						
	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7
T1	M	P	P	M	M	P	M
T2	P	P	P	P	P	P	P
T3	M	P	P	M	M	P	M
T4	P	P	P	P	P	P	P
T5	P	P	P	P	P	P	P
T6	M	M	M	M	M	M	M
T7	P	P	P	P	P	P	M

Triangular fuzzy numbers in response to these linguistic variables can be seen in Table 5.6.

Table 5. 6: Triangular Fuzzy Numbers in Response to Step-4 Linguistic Variables

Linguistic Variable	Triangular Fuzzy Numbers
Very Poor (VP)	(0 / 0 / 0)
Poor (P)	(0 / 0.25 / 0.50)
Moderate (M)	(0.25 / 0.50 / 0.75)
Strong (S)	(0.50 / 0.75 / 1)
Very Strong (VS)	(1 / 1 / 1)

After max aggregation and defuzzification are applied in MATLAB, IP_{wh} values between each target (WHAT) and enabler (HOW) are determined. Results can be seen in Table 5.7.

Table 5. 7: The Interrelationship Matrix Established Between Targets (WHATs) and Enablers (HOWs)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
T1	0.500	0.375	0.625	0.500	0.500	0.375	0.250	0.250	0.250	0.375	0.375	0.375
T2	0.250	0.250	0.500	0.250	0.250	0.750	0.750	0.375	0.250	0.500	0.375	0.250
T3	0.250	0.375	0.625	0.625	0.500	0.500	0.500	0.375	0.250	0.750	0.375	0.750
T4	0.250	0.250	0.500	0.250	0.250	0.375	0.500	0.250	0.250	0.375	0.250	0.250
T5	0.250	0.250	0.500	0.250	0.250	0.250	0.250	0.250	0.375	0.375	0.375	0.375
T6	0.500	0.500	0.625	0.250	0.375	0.500	0.250	0.250	0.625	0.375	0.375	0.250
T7	0.250	0.375	0.625	0.500	0.375	0.375	0.375	0.375	0.375	0.375	0.250	0.500

	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24
T1	0.375	0.250	0.250	0.250	0.375	0.375	0.375	0.375	0.250	0.250	0.375	0.375
T2	0.250	0.250	0.375	0.250	0.250	0.250	0.375	0.375	0.250	0.250	0.375	0.250
T3	0.375	0.375	0.375	0.625	0.250	0.375	0.375	0.375	0.250	0.250	0.375	0.375
T4	0.375	0.625	0.625	0.625	0.625	0.375	0.625	0.500	0.375	0.625	0.375	0.375
T5	0.375	0.250	0.250	0.250	0.375	0.625	0.625	0.625	0.500	0.500	0.250	0.250
T6	0.375	0.625	0.500	0.250	0.500	0.250	0.250	0.375	0.625	0.625	0.500	0.500
T7	0.375	0.250	0.250	0.250	0.250	0.025	0.250	0.025	0.250	0.375	0.625	0.625

Step 5 – a correlation matrix is established between all enablers (HOWs) and the one enabler (HOW) in accordance with experts' opinions each time. Same linguistic variables and triangular fuzzy numbers used in *Step 4* are used for experts'opinion. As a consequence, there are 24 different 24*7 sized matrices. All expert opinions regarding correlation are not included in this study because of the security laws applied in the aviation and defense industry. As an example, the correlation matrix established between all enablers (HOWs) and "quality policy" enabler can be seen Table 5.8. After max aggregation and defuzzification are applied in MATLAB with related data, C_{he} values between each enabler (HOW) are determined. Results can be seen in Table 5.9 and 5.10.

Table 5. 8: Correlation Opinions Between All Enablers and Quality Policy

	E1						
	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7
E1	VS	VS	VS	VS	VS	VS	VS
E2	S	M	M	M	P	P	P
E3	M	M	M	M	M	M	M
E4	VP	VP	VP	VP	VP	P	P
E5	VP	P	P	VP	P	VP	VP
E6	P	P	P	P	P	P	P
E7	P	P	P	P	P	P	P
E8	VP	VP	VP	VP	VP	VP	VP
E9	P	VP	VP	P	VP	VP	VP
E10	M	M	M	P	P	P	P
E11	P	P	P	P	P	P	P
E12	VP	VP	VP	VP	VP	VP	VP
E13	VP	VP	VP	VP	VP	VP	VP
E14	VP	VP	VP	VP	VP	VP	VP
E15	VP	VP	VP	VP	VP	VP	VP
E16	VP	VP	VP	VP	VP	VP	VP
E17	P	M	P	VP	P	VP	P
E18	VP	VP	VP	VP	VP	VP	VP
E19	VP	VP	VP	VP	VP	VP	VP
E20	VP	VP	VP	VP	VP	VP	VP
E21	M	M	M	P	M	P	M
E22	VP	VP	VP	VP	VP	VP	VP
E23	VP	VP	VP	VP	VP	VP	VP
E24	VP	VP	VP	VP	VP	VP	VP

Table 5. 9: The Correlation Matrix Established Between All Enablers and First 12 Enablers

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1.000	0.500	0.500	0.240	0.240	0.250	0.250	0.000	0.240	0.375	0.250	0.000
E2	0.500	1.000	0.500	0.240	0.000	0.375	0.000	0.000	0.375	0.375	0.240	0.367
E3	0.500	0.500	1.000	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
E4	0.240	0.240	0.500	1.000	0.375	0.000	0.375	0.000	0.000	0.375	0.375	0.375
E5	0.240	0.000	0.500	0.375	1.000	0.000	0.000	0.000	0.240	0.375	0.000	0.375
E6	0.250	0.375	0.500	0.000	0.000	1.000	0.375	0.000	0.375	0.250	0.250	0.250
E7	0.250	0.000	0.500	0.375	0.000	0.375	1.000	0.000	0.375	0.000	0.250	0.000
E8	0.000	0.000	0.500	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
E9	0.240	0.375	0.500	0.000	0.240	0.375	0.375	0.000	1.000	0.000	0.000	0.000
E10	0.375	0.375	0.500	0.375	0.375	0.250	0.000	0.000	0.000	1.000	0.250	0.500
E11	0.250	0.240	0.500	0.375	0.000	0.250	0.250	0.000	0.000	0.250	1.000	0.000
E12	0.000	0.367	0.500	0.375	0.375	0.250	0.000	0.000	0.000	0.500	0.000	1.000
E13	0.000	0.000	0.500	0.000	0.000	0.000	0.375	0.000	0.000	0.375	0.250	0.240
E14	0.000	0.000	0.500	0.000	0.000	0.000	0.240	0.000	0.000	0.240	0.000	0.375
E15	0.000	0.000	0.500	0.375	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000
E16	0.000	0.000	0.500	0.000	0.000	0.240	0.000	0.000	0.000	0.367	0.000	0.000
E17	0.367	0.000	0.500	0.000	0.000	0.375	0.000	0.000	0.000	0.000	0.000	0.000
E18	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.240
E19	0.000	0.000	0.500	0.000	0.000	0.240	0.250	0.000	0.000	0.250	0.375	0.375
E20	0.000	0.000	0.500	0.000	0.000	0.000	0.240	0.000	0.000	0.000	0.375	0.240
E21	0.375	0.240	0.500	0.240	0.000	0.367	0.000	0.000	0.375	0.000	0.375	0.375
E22	0.000	0.000	0.500	0.000	0.000	0.250	0.367	0.000	0.250	0.240	0.240	0.000
E23	0.000	0.000	0.500	0.000	0.000	0.250	0.000	0.000	0.000	0.367	0.240	0.500
E24	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.000

Table 5. 10: The Correlation Matrix Established Between All Enablers and Second 12 Enablers

	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24
E1	0.000	0.000	0.000	0.000	0.367	0.000	0.000	0.000	0.375	0.000	0.000	0.000
E2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.000	0.000
E3	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
E4	0.000	0.000	0.375	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.000	0.000
E5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
E6	0.000	0.000	0.500	0.240	0.375	0.000	0.240	0.000	0.367	0.250	0.250	0.000
E7	0.375	0.240	0.000	0.000	0.000	0.000	0.250	0.240	0.000	0.367	0.000	0.000
E8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
E9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.250	0.000	0.000
E10	0.375	0.240	0.000	0.367	0.000	0.250	0.250	0.000	0.000	0.240	0.367	0.240
E11	0.250	0.000	0.000	0.000	0.000	0.000	0.375	0.375	0.375	0.240	0.240	0.000
E12	0.240	0.375	0.000	0.000	0.000	0.240	0.375	0.240	0.375	0.000	0.500	0.000
E13	1.000	0.000	0.000	0.000	0.000	0.000	0.500	0.375	0.375	0.250	0.240	0.375
E14	0.000	1.000	0.375	0.250	0.375	0.000	0.375	0.000	0.000	0.250	0.000	0.000
E15	0.000	0.375	1.000	0.375	0.375	0.000	0.250	0.000	0.000	0.000	0.000	0.000
E16	0.000	0.250	0.375	1.000	0.240	0.000	0.250	0.000	0.000	0.000	0.000	0.000
E17	0.000	0.375	0.375	0.240	1.000	0.250	0.500	0.240	0.375	0.375	0.250	0.000
E18	0.000	0.000	0.000	0.000	0.250	1.000	0.625	0.375	0.375	0.250	0.250	0.000
E19	0.500	0.375	0.250	0.250	0.500	0.625	1.000	0.625	0.500	0.375	0.240	0.240
E20	0.375	0.000	0.000	0.000	0.240	0.375	0.625	1.000	0.375	0.240	0.240	0.000
E21	0.375	0.000	0.000	0.000	0.375	0.375	0.500	0.375	1.000	0.625	0.375	0.240
E22	0.250	0.250	0.000	0.000	0.375	0.250	0.375	0.240	0.625	1.000	0.367	0.240
E23	0.240	0.000	0.000	0.000	0.250	0.250	0.240	0.240	0.375	0.367	1.000	0.625
E24	0.375	0.000	0.000	0.000	0.000	0.000	0.240	0.000	0.240	0.240	0.625	1.000

Step 6 – relationship matrix values are calculated between each target (WHAT) and each enabler (HOW) by multiplication of the interrelationship power matrix ([IP]) and the correlation matrix ([C]) according to Equation (4.2). As a result of this, R_{wh} values between each target (WHAT) and enabler (HOW) are calculated. Results can be seen in Table 5.10. An example is demonstrated below to describe how the relationship matrix value between the "management system" target and "quality policy" enabler and the relationship matrix value between the "resource management" target and "quality objective" enabler are calculated. In this example calculation, R_{11} represents the relationship matrix value between the management system target and quality policy enabler, and R_{22} represents the relationship matrix value between the resource management target and quality objective enabler.

$$R_{11} = (0.500*1)+(0.375*0.5)+(0.625*0.5)+(0.5*0.24)+(0.5*0.24)+(0.375*0.25)$$

$$+(0.25*0.25)+(0.25*0)+(0.25*0.24)+(0.375*0.375)+(0.375*0.25)+(0.375*0)$$

$$+(0.375*0)+(0.25*0)+(0.25*0)+(0.25*0)+(0.375*0.367)+(0.375*0)+(0.375*0)$$

$$+(0.375*0)+(0.25*0.375)+(0.25*0)+(0.375*0)+(0.375*0) = 1.922$$

$$R_{22} = (0.25*0.5)+(0.25*1)+(0.5*0.5)+(0.25*0.24)+(0.25*0)+(0.75*0.375)+(0.75*0)$$

$$+(0.375*0)+(0.25*0.375)+(0.5*0.375)+(0.375*0.24)+(0.25*0.367)+(0.25*0)$$

$$+(0.25*0)+(0.375*0)+(0.25*0)+(0.25*0)+(0.25*0)+(0.375*0)+(0.375*0)$$

$$+(0.25*0.24)+(0.25*0)+(0.375)+(0.25*0) = 1.490$$

Table 5. 11: The Relationship Matrix Established Between Targets (WHATs) and Enablers (HOWs)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
T1	1.922	1.720	4.625	1.880	1.462	2.086	1.679	0.563	1.334	2.533	1.959	2.267
T2	1.647	1.490	4.375	1.618	0.995	2.492	2.054	0.625	1.433	2.191	1.929	1.943
T3	1.891	1.950	5.438	2.367	1.730	2.535	1.991	0.688	1.415	3.248	2.131	2.955
T4	1.597	1.302	5.188	1.554	0.948	2.516	2.000	0.500	1.339	2.429	1.926	2.158
T5	1.520	1.408	4.563	1.444	1.025	2.019	1.675	0.500	1.339	2.221	1.990	2.185
T6	2.203	2.017	5.438	1.750	1.286	2.771	1.970	0.563	2.007	2.602	2.141	2.346
T7	1.627	1.658	4.463	1.820	1.353	2.134	1.688	0.688	1.447	2.487	1.715	2.255

	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24
T1	1.821	1.353	1.359	1.130	1.912	1.590	2.677	1.828	2.610	1.996	2.074	1.363
T2	1.791	1.394	1.469	1.221	1.789	1.373	2.612	1.732	2.283	2.101	1.918	1.159
T3	2.145	1.863	1.734	1.721	1.926	1.743	3.113	1.948	2.686	2.193	2.399	1.453
T4	2.103	2.195	2.016	1.800	2.721	1.904	3.567	2.227	2.895	2.760	2.256	1.481
T5	2.057	1.447	1.203	1.100	2.115	2.153	3.305	2.389	3.006	2.480	2.145	1.278
T6	2.040	1.869	1.734	1.347	2.537	1.654	3.111	1.964	3.343	2.869	2.494	1.716
T7	1.858	1.368	1.281	1.069	1.570	1.123	2.250	1.342	2.423	2.054	2.326	1.769

Step 7 – to calculate the importance weights of the enablers (HOWs), the absolute weights of the targets (WHATs) in Table 5.3 and relationship matrix values in Table 5.11 are used according to Equation (4.3). These calculated weights are the relative values. Later, these relative importance weights are normalized and absolute importance weights are obtained in accordance with Equation (4.1) by using related importance weights for enablers (HOWs) in this equation. Results can be seen in Table 5.12.

Table 5. 12: Relative and Absolute Importance Weights of Enablers (HOWs)

Enabler (HOW)	Relative Weights	Absolute Weights
E1	1.75	0.04
E2	1.62	0.03
E3	4.84	0.10
E4	1.76	0.04
E5	1.24	0.03
E6	2.36	0.05
E7	1.87	0.04
E8	0.59	0.01
E9	1.45	0.03
E10	2.51	0.05
E11	1.96	0.04
E12	2.28	0.05
E13	1.97	0.04
E14	1.64	0.03
E15	1.55	0.03
E16	1.35	0.03
E17	2.08	0.04
E18	1.65	0.03
E19	2.95	0.06
E20	1.92	0.04
E21	2.72	0.06
E22	2.34	0.05
E23	2.21	0.05
E24	1.44	0.03

As an example calculations of the relative weights of the quality policy and the quality objective enablers are as follows: In this example, $RIWH_1$ represents the relative importance weight of the quality policy enabler. $RIWH_2$ represents the relative importance weight of the quality objectives enabler.

$$RIWH_1 = (0.137*1.922)+(0.174*1.647)+(0.137*1.891)*(0.172*1.597)+(0.137*1.52)$$

$$+(0.103*2.203)+(0.139*1.627) = 1.75$$

$$RIWH_2 = (0.137*1.72)+(0.174*1.49)+(0.137*1.95)+(0.172*1.302)+(0.137*1.408)$$

$$+(0.103*2.017)+(0.139*1.658) = 1.62$$

Step 8 – in this step of the MMM, different number of questions are prepared and grouped under each enabler (HOW). These questions are prepared in accordance with AS9100D quality management standard requirements and the organization’s necessities. Project maturity is also considered during the determination of these questions. In the scope of this, 107 different questions are prepared. All questions are not included in this study because of the security laws applied in the aviation and defense industry. Examples of questions prepared for “Document Management” can be seen in Table 5.13.

Table 5. 13: Questions Prepared for “Document Management Enabler

Enabler (HOW)	Questions
Document Management	Document Management rules are created and retained as documented information? (DM-Q1)
	Document Management process (creation, classification, approval, route, revision, cancellation,) created and retained as documented information? (DM-Q2)

Step 9 – to calculate the weights of questions, firstly, the total number of questions under each enabler (HOW) is determined. Then, the weights of questions are calculated in a way that the sum of the weights of all questions grouped in an enabler (HOW) is equal to 1. Results can be seen in Table 5.14.

Table 5. 14: The Weights of Questions Under Each Enabler (HOW) Group

Enabler (HOW)	Nu. of Questions	Weight of Questions
E1	5	0.200
E2	5	0.200
E3	4	0.250
E4	4	0.250
E5	3	0.333
E6	9	0.111
E7	6	0.167
E8	3	0.333
E9	3	0.333
E10	3	0.333
E11	3	0.333
E12	3	0.333
E13	3	0.333
E14	3	0.333
E15	3	0.333
E16	3	0.333
E17	3	0.333
E18	3	0.333
E19	7	0.143
E20	5	0.200
E21	8	0.125
E22	9	0.111
E23	4	0.250
E24	5	0.200

As an example calculations of the weights of the questions under the quality policy and the general (continuous improvement) enablers are as follows.

In this example, W_1 represents the weight of the questions under quality policy enabler and W_{21} represents the weight of the questions under general (improvement) enabler.

W_1 : (1/5) = 0.200 W_{21} : (1/8) = 0.125

Step 10 – in order to calculate the score of each enabler (HOW) for the current situation, firstly, experts have stated their opinions as answers to the questions that are under these enablers (HOWs). These opinions are obtained based on 5-scaled linguistic variables which are increasingly sequenced as "very poor (VP)", "below average (BA)", "average (A)", "above average (AA)", and "excellent (E)". All opinions are not included in this study because of the security laws applied in the aviation and defense industry. An example of how these opinions for the current situation are obtained for some of the questions under the quality policy enabler is demonstrated in Table 5.15.

Table 5. 15: Experts' Opinions in Response to The Questions Under Quality Policy Enabler

Enabler	Question	Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7
Quality Policy	QP-Q1	AA	AA	A	A	AA	A	AA
	QP-Q2	E	AA	AA	AA	AA	E	AA
	QP-Q3	AA	A	A	A	A	AA	AA
	QP-Q4	AA	A	A	AA	A	A	A
	QP-Q5	E	E	AA	AA	E	E	AA

Triangular fuzzy numbers in response to linguistic variables used in Step 10 can be seen in Table 5.16.

Table 5. 16: Triangular Fuzzy Numbers in Response to Step-10 Linguistic Variables

Linguistic Variable	Triangular Fuzzy Numbers
Very Poor (VP)	(0 / 0 / 0)
Below Average (BA)	(0 / 0.25 / 0.50)
Average (A)	(0.25 / 0.50 / 0.75)
Above Average (AA)	(0.50 / 0.75 / 1)
Excellent (E)	(1 / 1 / 1)

After max aggregation and defuzzification are applied in MATLAB, outputs as the "judgment values" of experts regarding questions are obtained. Eventually, the score of each enabler (HOW) is calculated in accordance with Equation (4.5). The judgment values (for the current situation) regarding the questions under quality policy enabler and the score of this enabler can be seen in Table 5.17. All enabler scores can be seen in Table 5.18.

Table 5. 17: Judgment Values of The Questions Under Quality Policy and Score of the Quality Policy (for current situation)

Enabler	Question	Judgment Value	Weights of the Questions	The Score of the Enabler
Quality Policy	QP-Q1	0.625	0.20	0.679
	QP-Q2	0.760	0.20	
	QP-Q3	0.625	0.20	
	QP-Q4	0.625	0.20	
	QP-Q5	0.760	0.20	

An example calculation of the current score of the quality policy is demonstrated below. In this example, CS_1 represents the current score of the quality policy enabler.

$$CS_1 \quad = 0.20*(0.625+0.760+0.625+0.625+0.760)= 0.679$$

Table 5. 18: Scores of All Enablers (HOWs)

Name of the Enabler (HOW)	Scores	Name of the Enabler (HOW)	Scores
E1	0.679	E13	0.371
E2	0.627	E14	0.701
E3	0.594	E15	0.495
E4	0.498	E16	0.495
E5	0.663	E17	0.749
E6	0.468	E18	0.619
E7	0.355	E19	0.501
E8	0.495	E20	0.400
E9	0.578	E21	0.406
E10	0.371	E22	0.541
E11	0.413	E23	0.469
E12	0.454	E24	0.400

Step 11 – in order to calculate the current maturity score of each target (WHAT), the current scores of enablers (HOWs) in Table 5.18 and the relationship matrix values in Table 5.11 are used according to Equation (4.6). As a consequence, *CMSw* values are obtained and these values can be seen in Table 5.19.

Table 5. 19: The Current Maturity Scores of Targets (WHATs)

Targets (WHATs)	The Current Maturity Score
T1	23.434
T2	22.226
T3	27.190
T4	26.385
T5	23.742
T6	27.682
T7	22.263

An example calculation of how the current maturity score of the management system target is demonstrated below. In this example, CMS_1 represents the current maturity score of the management system enabler.

$$CMS_1 = (0.679*1.922)+(0.627*1.72)+(0.594*4.625)+(0.498*1.88)+(0.663*1.462)$$

$$+(0.468*2.086)+(0.355*1.679)+(0.495*0.563)+(0.578*1.334)+(0.371*2.533)$$

$$+(0.413*1.959)+(0.454*2.267)+(0.371*1.821)+(0.701*1.353)+(0.495*1.359)$$

$$+(0.495*1.130)+(0.749*1.912)+(0.619*1.59)+(0.501*2.677)+(0.4*1.828)$$

$$+(0.406*2.610)+(0.541*1.996)+(0.469*2.074)+(0.40*1.363) = 23.434$$

Step 12 – after the calculation of the current maturity score for each target (WHAT), the *CTQMS* is calculated in accordance with Equation (4.7).

$$CTQMS = 23.434+22.226+27.190+26.385+23.742+27.682+22.263 = 172.921$$

Step 13 – in order to calculate the maturity score of each target (WHAT) for the maximum possible situation, all experts' opinions (for the maximum possible situation) in response to questions are accepted as "excellent (E)" linguistic variable. After applying max aggregation and centroid defuzzification, all judgment values of experts regarding questions are calculated as 1. Then, the maximum possible maturity scores of each enabler (HOW) are calculated in accordance with Equation (4.5) by using related judgment values for enablers (HOWs) in this equation. The judgment values (for the maximum possible situation) regarding the questions under quality policy enabler and the score of this enabler can be seen in Table 5.20. Similar to quality policy enabler, the score of other enablers are equal to 1 in the maximum possible situation.

Table 5. 20: Judgment Values of The Questions Under Quality Policy and Score of the Quality Policy (for the maximum possible situation)

Enabler	Question	Judgment Value	Weights of the Questions	The score of the Enabler
Quality Policy	QP-Q1	1	0,20	1
	QP-Q2	1	0,20	
	QP-Q3	1	0,20	
	QP-Q4	1	0,20	
	QP-Q5	1	0,20	

An example calculation of the maximum possible score of the quality policy enabler is demonstrated below. In this example, MS_1 represents the maximum possible score of the quality policy enabler.

$$MS_1 \quad = 0,20*(1+1+1+1+1)= 1$$

Step 14 – after the maximum possible scores of enablers (HOWs) are calculated, the maximum possible maturity score for each target (WHAT) is calculated in accordance with Equation (4.6) by using the related maximum possible scores of enablers (HOWs) in this equation. As a consequence, MMS_w values are obtained and these values can be seen in Table 5.21.

Table 5. 21: The Maximum Possible Maturity Scores of Targets (WHATs)

Targets (WHATs)	The Maximum Possible Maturity Score
T1	45.744
T2	43.632
T3	53.262
T4	51.380
T5	46.566
T6	53.769
T7	43.768

An example calculation of the maximum possible maturity score of the management system target is described below. In this example, MMS_1 represents the current maturity score of the management system enabler.

$$MMS_1 = (1*1.922)+(1*1.72)+(1*4.625)+(1*1.88)+(1*1.462)+(1*2.086)+(1*1.679)$$
$$+(1*0.563)+(1*1.334)+(1*2.533)+(1*1.959)+(1*2.267)+(1*1.821)+(1*1.353)$$
$$+(1*1.359)+(1*1.130)+(1*1.912)+(1*1.59)+(1*2.677)+(1*1.828)+(1*2.610)$$
$$+(1*1.996)+(1*2.074)+(1*1.363) = 45.744$$

Step 15 – after the calculation of the maximum possible maturity score for each target (WHAT), the *MTQMS* is calculated in accordance with Equation (4.7) by using the related maximum possible maturity scores of targets (WHATs) in this equation.

$$MTQMS = 45.744+43.632+53.262+51.380+46.566+53.769+43.768 = 338.120$$

Step 16 – the *QMMI* is calculated as the ratio of the *CTQMS* to the *MTQMS* in accordance with Equation (4.8).

$$QMMI = (172.921) / (338.120) = 51\%$$

As a result, the maturity of the QMS in this aviation organization is determined as “complete deployment”.

6. DISCUSSIONS

The MMM proposed in this study is applied in an aviation organization's design and development project. However, because of the security laws applied in the aviation and defense industry, some of the answers and therefore the scores of enablers (HOWs) are calculated based on artificial data. Additionally, all questions are not included in this study because of the security laws applied in the aviation and defense industry again.

The framework of the proposed MMM takes the maturity of this project (phase of the project) into consideration and experts are stated their opinions in accordance with the maturity of this design and development project.

As a result of the application, it is observed that resource management and audit management targets (WHATs) have the highest importance weights for the QMS at this phase of the project. Secondly, process management and planning management targets have approximately the same importance weight. Considering the maturity of the project, resource management requires attention to establish appropriate processes and audit management should be given attention as well to monitor and control these processes. Furthermore, it is observed that continuous improvement has the lowest importance level among the targets (WHATs). According to experts' feedback, the concept of continuous improvement is mostly associated with manufacturing activities in the organization. Considering this feedback and the maturity of the project, it can be stated that calculated maturity levels of the targets (WHATs) are accepted as reasonable.

Due to the fact that documented information is one of the most essential principles of the quality management standard, document management has a powerful interrelationship with all targets (WHATs). As it can be concluded from the results, the management system has a more powerful interrelationship with quality policy, authorization management, and change management enablers than other enablers, because these enablers determine the top-level rules that can be associated with all processes in the organization.

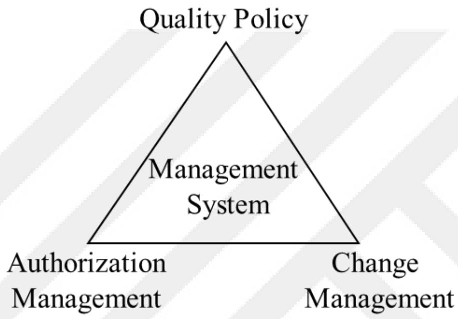

Figure 6. 1: Management System Target Interrelationship Power Evaluation

Considering the maturity of the project, the resource management target has a more powerful interrelationship with human resource, external provider, and general planning enablers. Since general planning activities are associated with human resource enabler, it has an effect on resource management target.

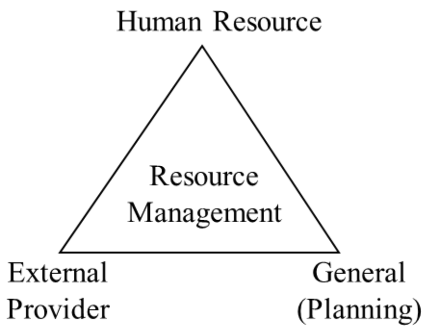

Figure 6. 2: Resource Management Target Interrelationship Power Evaluation

Planning management has a powerful interrelationship with general planning enabler because this enabler is related to the project planning activities. Additionally, the planning management target has a powerful interrelationship with authorization management because, proper planning of processes requires the usage of appropriate resources and authorization of the related people, and giving them responsibility directly increase the effectiveness of planning management. Since, change management, human resource, and external providers have an effect on project planning, these enablers have a powerful interrelationship with the planning management target at this phase of the project.

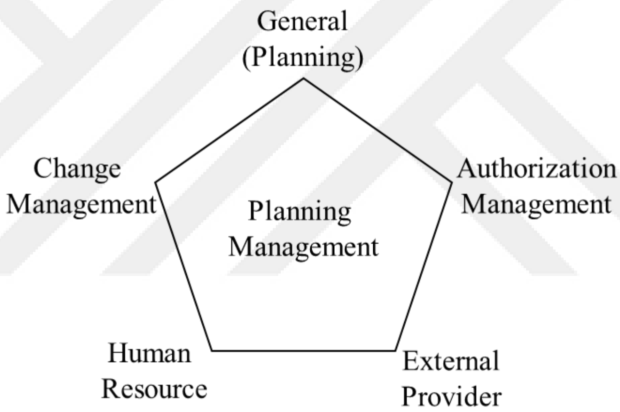

Figure 6. 3: Planning Management Target Interrelationship Power Evaluation

The scope that determines the boundaries of audit, the team who is responsible for performing audits, the schedule that is needed to be complied and the results of an audit that should be taken into consideration have a powerful interrelationship with audit management. Since these audit activities are performed both internally and externally, external provider enabler has a powerful interrelationship with audit management as well. The results of audits can be used as inputs in QMR and can cause the initiation of nonconformity and corrective action process. Therefore, inputs (QMR) and nonconformity/corrective action enablers have a powerful interrelationship with audit management target.

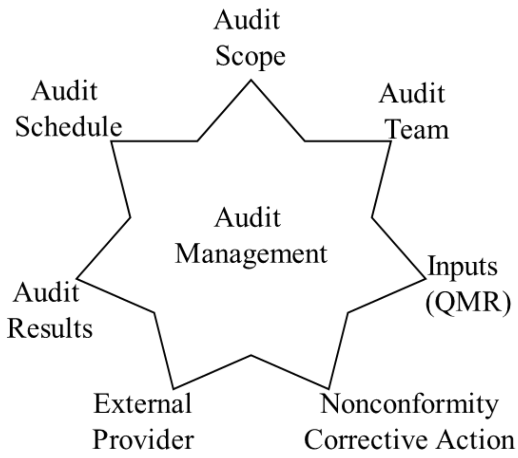

Figure 6. 4: Audit Management Target Interrelationship Power Evaluation

According to the results, the QMR target has a powerful interrelationship with general (QMR), inputs (QMR), outputs (QMR), and then nonconformity/corrective action and general (improvement) enablers. The general (QMR) is related to the planning of the QMR and its attributes. Since inputs (QMR) and nonconformity/corrective action enablers affect the efficiency of the QMR, they have a powerful interrelationship with the QMR target. The outputs (QMR) demonstrate the effectiveness of the QMR, so it has a powerful interrelationship. Due to the fact that results of the QMS reviews may be the key drivers for continuous improvement activities, there is a powerful interrelationship among them.

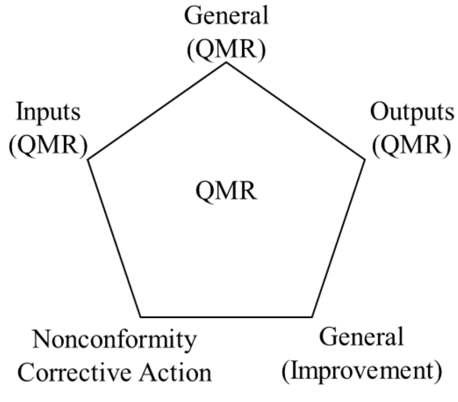

Figure 6. 5: QMR Target Interrelationship Power Evaluation

The continuous improvement target has a more powerful interrelationship with organizational knowledge, general (improvement), audit scope, the audit team, and nonconformity/corrective action enablers. The organizational knowledge enabler includes types of best practices and know-how history, audit scope enabler determines the content of the audit that can affect the improvement initiations, competency of the audit team member may affect the determination of improvement necessities, the nonconformity/correct action enabler may be useful to establish organizational knowledge and know-how history. Other than that, quality policy, quality objectives, and human resources enablers have a powerful interrelationship with the continuous improvement target.

Figure 6. 6: Continuous Improvement Target Interrelationship Power Evaluation

According to the results, the general (process) enabler that describes process management rules and the process measurement enabler that determines what to be measured, who will measure it, when will be measured, and how will be measured have a powerful interrelationship with the process management target. Additionally, the authorization management target that is essential for the establishment and successful operation of the processes has a powerful relationship with the process management target.

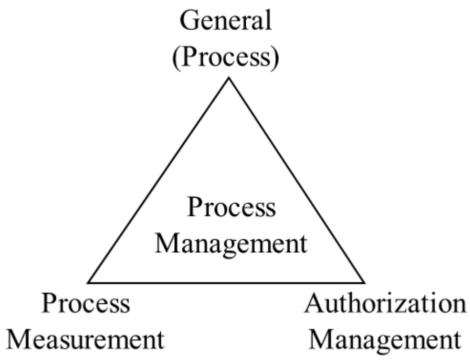

Figure 6. 7: Process Management Target Interrelationship Power Evaluation

The correlation term describes the degree to which two variables move in coordination with one another. The correlation matrix established between enablers (HOWs) is prepared in accordance with the idea of the effectiveness of the application of the enabler. Therefore, the higher effectiveness of the application of an enabler has a positive effect on other enablers or has no effect on them. So, that means the negative correlation is not considered. In addition to that, this correlation matrix is established as per the maturity of the project. Eventually, this correlation matrix is established symmetrically.

Since documented information is one of the most essential principle of the QMS standard, document management has a moderate correlation with all other enablers (HOWs).

The quality policy has a more powerful correlation with quality objectives than other enablers. Also, it is observed that there is a positive correlation between the quality policy enabler and general (planning), audit results, general (improvement), authorization management, change management, human resource, external provider, organizational knowledge, and risk and opportunity planning enablers. The quality objective enabler has a more powerful correlation with the quality policy enabler. Besides, it is observed that the quality objective enabler has a positive correlation with organizational knowledge, human resource, general (planning), contractual data documentation planning, authorization management, risk and opportunity planning, and general (improvement) enablers.

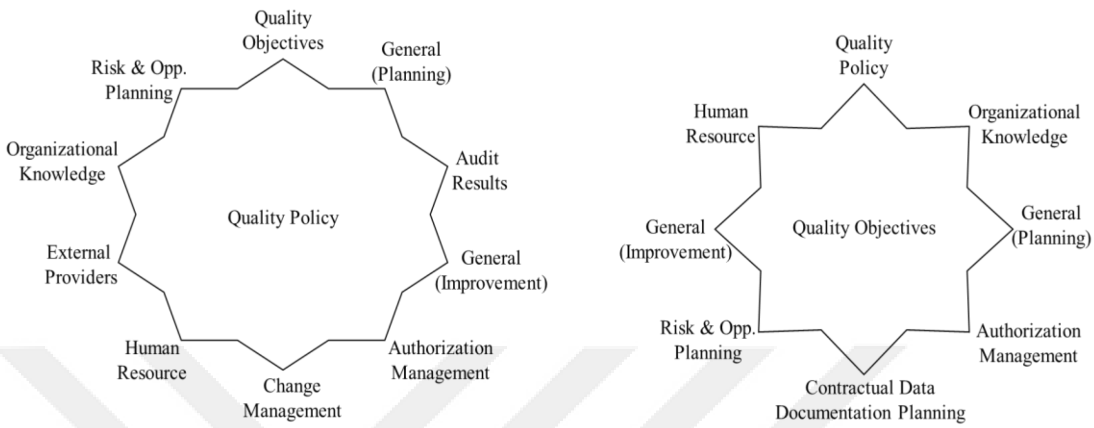

Figure 6. 8: Quality Policy and Quality Objective Enablers Correlation Evaluation

In addition to the its previous correlations, the authorization management enabler has a positive correlation with change management, external provider, general (planning), risk and opportunity planning, contractual data documentation planning, audit team, and general (improvement) enablers as well. The change management enabler has a positive correlation with contractual data documentation planning, general (planning), and organizational knowledge enablers in addition to its previous correlations.

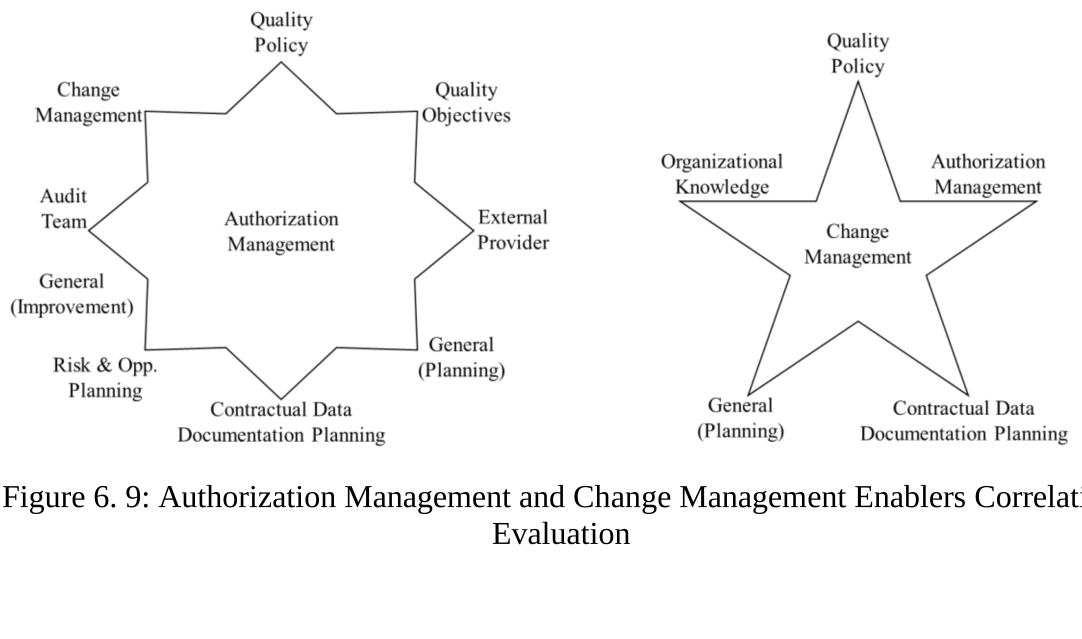

Figure 6. 9: Authorization Management and Change Management Enablers Correlation Evaluation

Apart from the correlations with its previous enablers, the human resource enabler has a more positive correlation with the audit team enabler than others. Besides, it is concluded from the results that, there is a positive correlation between human resource enabler and external provider, organizational knowledge, audit results, general (improvement), general (planning), risk and opportunity planning, contractual data documentation planning, audit schedule, nonconformity/corrective action, general (process) and inputs (QMR) enablers. The external provider enabler has a positive correlation with the organizational knowledge, project review and monitoring, nonconformity/corrective action, risk and opportunity planning, inputs (QMR), and outputs (QMR) enablers as well.

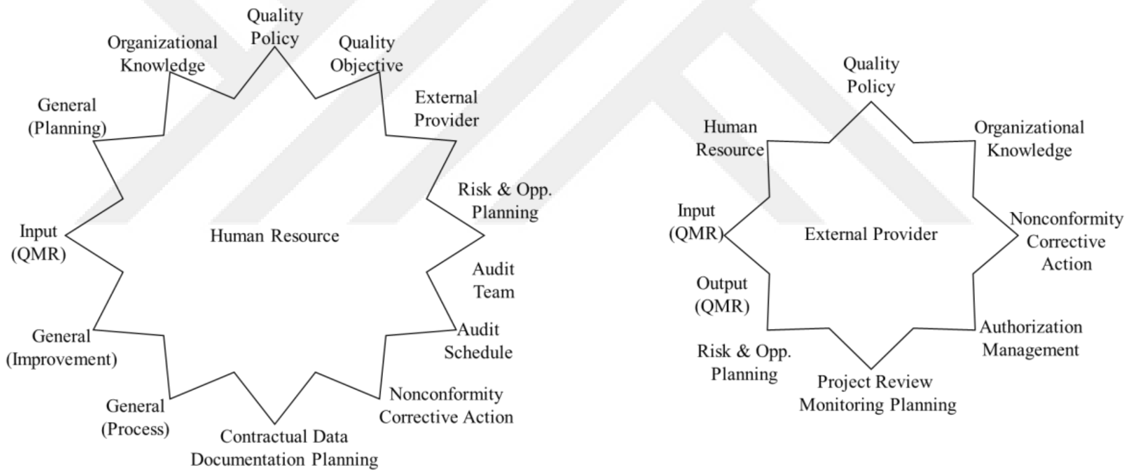

Figure 6. 10: Human Resource and External Provider Enablers Correlation Evaluation

According to the results, it is seen that the infrastructure enabler has no correlation with other enablers.

It is observed that there is a positive correlation between the organizational knowledge enabler and, general (improvement) and nonconformity/corrective action enablers in addition to its previous correlations.

As it can be concluded from the results, general (planning) has a positive correlation with risk and opportunity planning, contractual data documentation planning, project review and monitoring, audit schedule, inputs (QMR), outputs (QMR), nonconformity/corrective action, general (process) and process measurement enablers apart from its previous correlations.

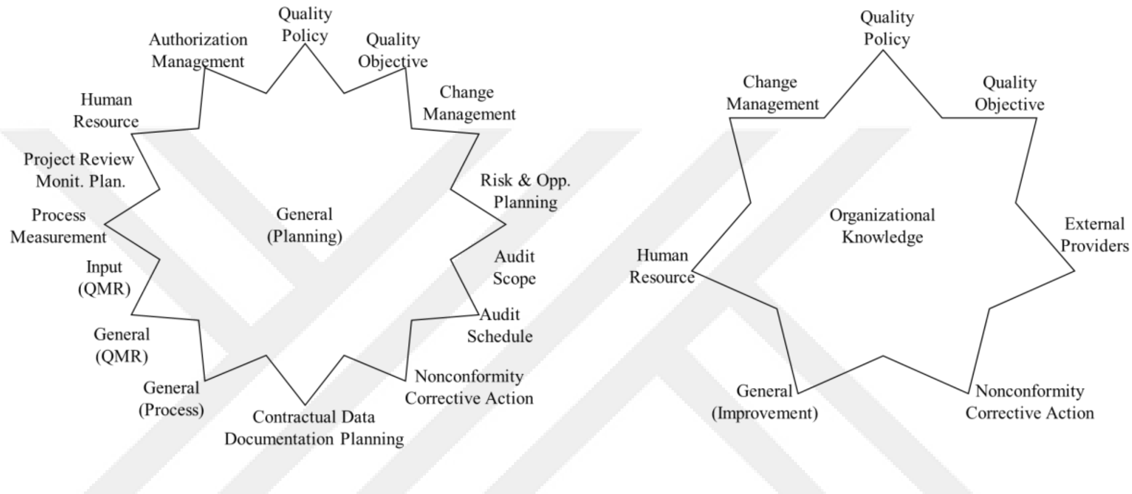

Figure 6. 11: General (Planning) and Organizational Knowledge Enablers Correlation Evaluation

The risk and opportunity planning enabler has a positive correlation with, inputs (QMR), outputs (QMR), general (improvement), nonconformity/corrective action, project review and monitoring, and general (process) enablers. The contractual data documentation planning enabler has a positive correlation with, project review and monitoring, audit scope, general (QMR), inputs (QMR), outputs (QMR), general (improvement) and general (process) enablers in addition to its previous correlations. It is observed that there is a positive correlation between project review and monitoring and inputs (QMR), outputs (QMR), general (improvement), nonconformity/corrective action, general (process) and process measurement enablers in addition to its previous correlations.

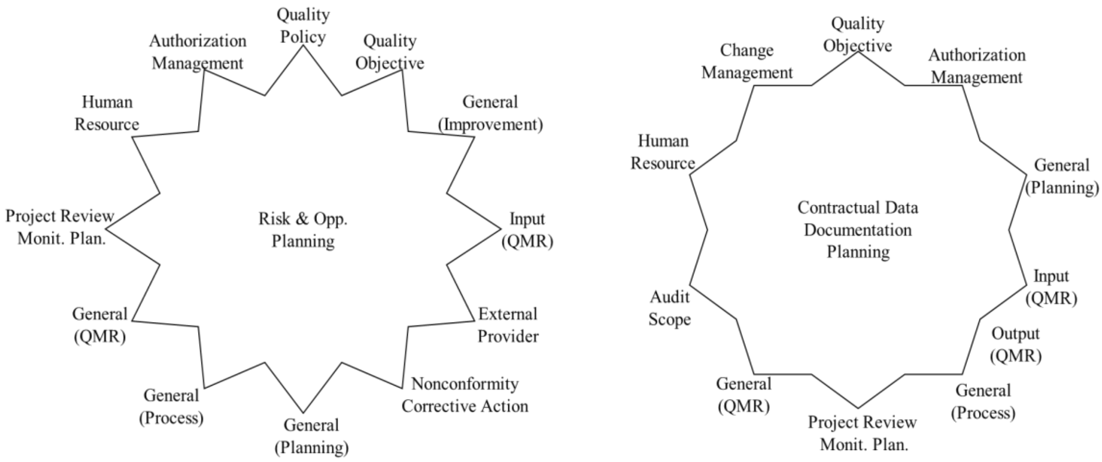

Figure 6. 12: Risk & Opportunity Planning and Contractual Data Documentation Planning Enablers Correlation Evaluation

As a result, it can be seen that a positive correlation is established between the audit scope and audit team, audit schedule, audit results, inputs (QMR), and nonconformity/corrective action enablers as well. The audit team enabler has a positive correlation with audit schedule, audit results, inputs (QMR) enablers in addition to its previous correlations.

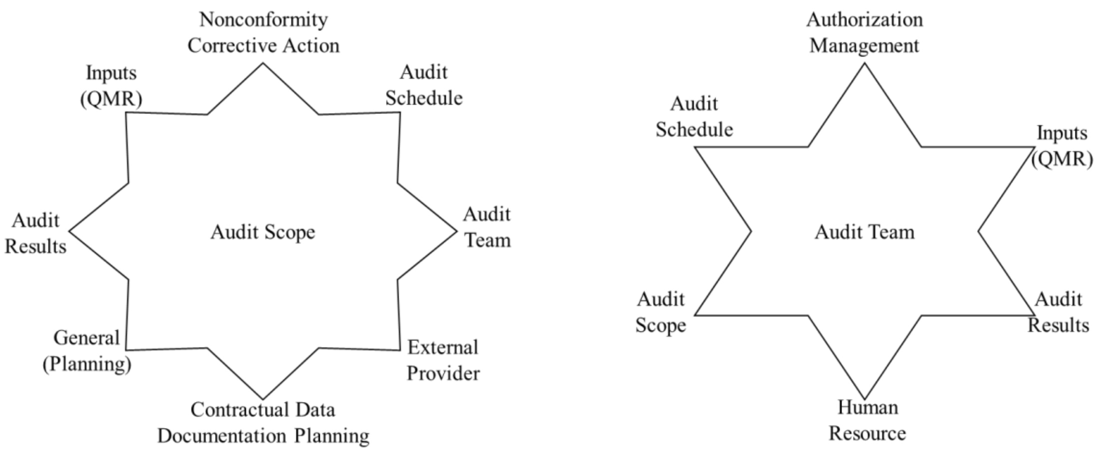

Figure 6. 13: Audit Scope and Audit Team Enablers Correlation Evaluation

It is indicated by the results that the audit schedule enabler has a positive correlation with audit results and inputs (QMR) enablers as well. As it can be concluded from the results, the audit results enabler has a positive correlation with general (QMR), inputs (QMR), outputs (QMR), general (improvement), nonconformity/corrective action and general (process) enablers in addition to its previous correlations.

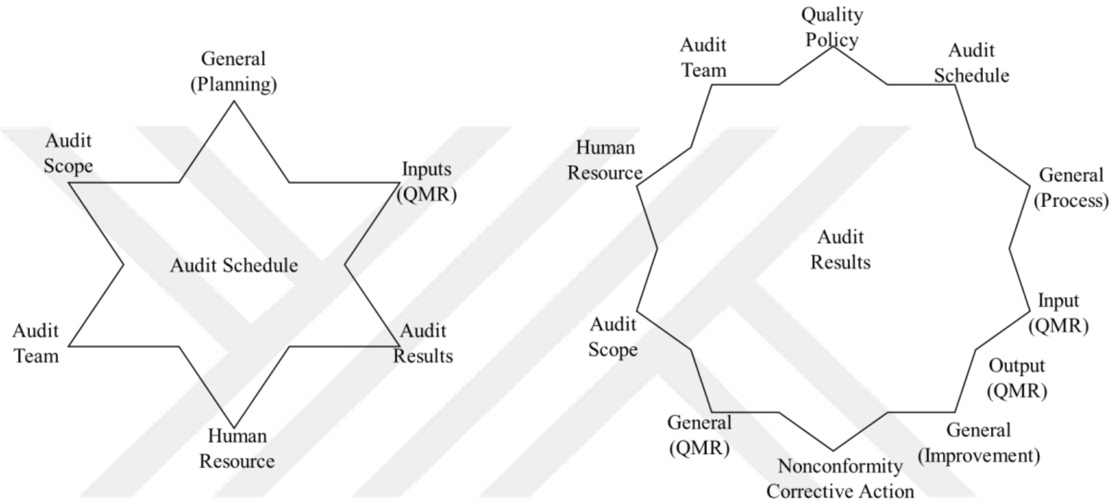

Figure 6. 14: Audit Schedule and Audit Results Enablers Correlation Evaluation

It is observed that the general (QMR) enabler has a positive relationship with inputs (QMR), outputs (QMR), general (improvement), nonconformity/corrective action and general (process) enablers as well. As a result, it can be understood that a positive correlation is established between the inputs (QMR) and outputs (QMR), general (improvement), nonconformity/corrective action, general (process) and process measurements enablers.

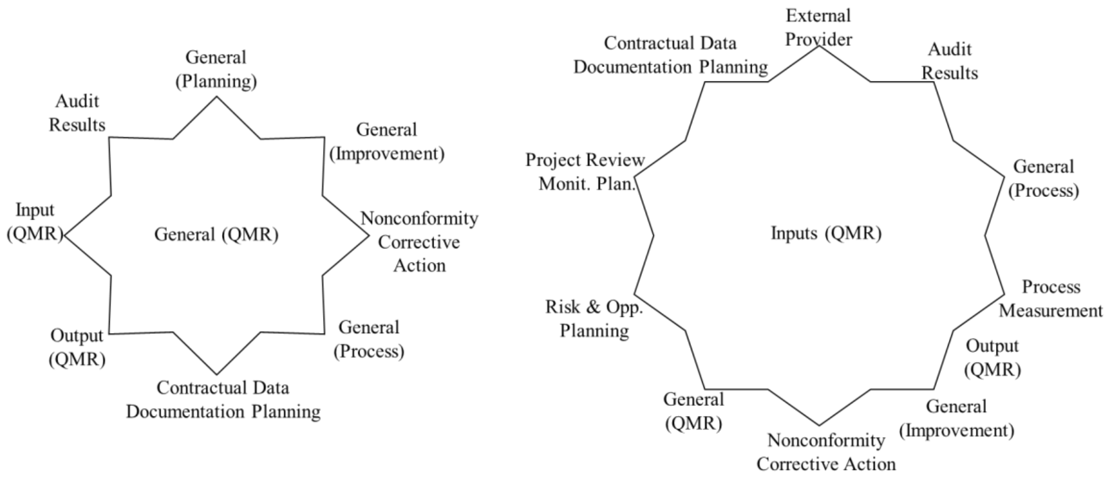

Figure 6. 15: General (QMR) and Inputs (QMR) Enablers Correlation Evaluation

In addition to its previous correlations, outputs (QMR) has a positive correlation with general (improvement), nonconformity/corrective action and general (process) enablers as well. The results demonstrate that general (improvement) has a positive correlation with nonconformity/corrective action, general process and process measurement enablers.

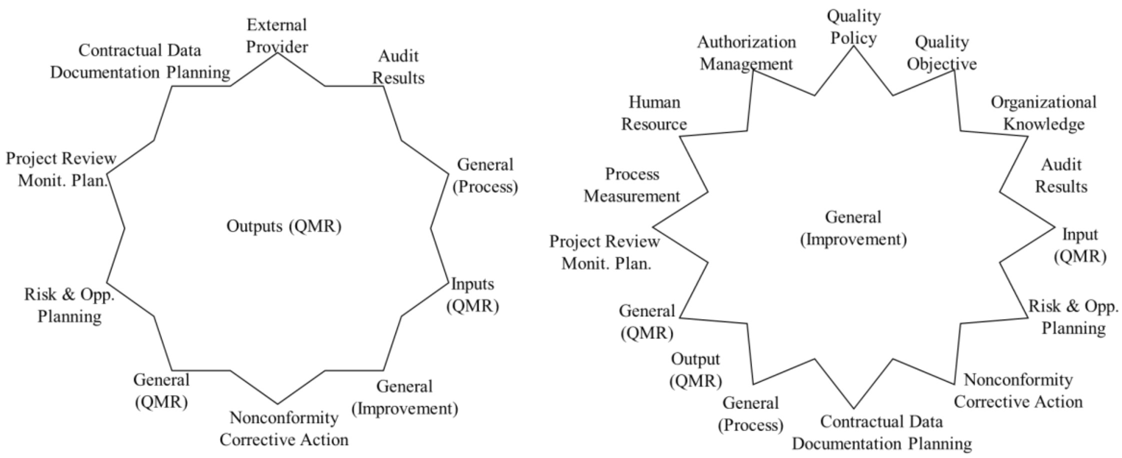

Figure 6. 16: Output (QMR) and General (Improvement) Enablers Correlation Evaluation

The nonconformity/corrective action enabler has a positive correlation with general (process) and process measurement enablers and eventually general (process) enabler has a positive correlation with process measurement enabler. According to the results, the quality maturity index is calculated as %51 and it corresponds to the "complete deployment" maturity level. Considering the maturity of the project, the importance level of targets (WHATs), and the score of each target; it is observed that resource management, process management and management system enablers should be improved to increase the level of maturity of the quality management system.

According to results of the scoring of enablers (HOWs) in the current situation, the highest scores are observed in the audit results, audit scope, quality policy, change management, quality objectives, general (QMR) and document management enablers and the lowest scores are observed in the external provider, project review and monitoring planning, general (planning), process measurement, outputs (QMR), general (improvement) and risk/opportunity planning enablers.

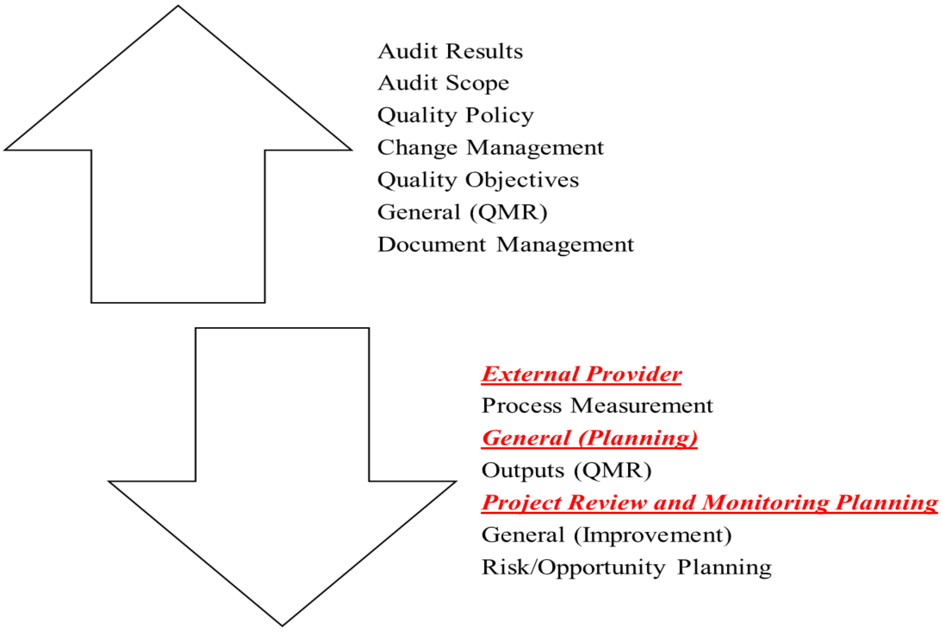

Figure 6. 17: Scoring Results of Enablers

Thanks to, audit results are managed as documented information and the management of nonconformities and corrective actions created by audit results performed effectively, the score of the audit results enabler is the highest one. Proper determination of the scope of audit in accordance with applicable statutory or regulatory requirements and the organization's own requirements increases the score of audit scope enabler. The quality policy and quality objective enablers are required for the establishment of a quality management system. Therefore, the scores of these enablers one of the highest. The determination and management of rules and processes regarding change management and document management activities increase the score of these enablers Eventually, planning of the QMRs and performing of these reviews in accordance with the planned schedule increase the score of the general (QMR) enabler.

In order to increase the effectiveness of external provider enabler, actions regarding document management on the subcontractor level should be planned. For project review and monitoring planning enabler, actions such as planning and execution of related processes and tools are needed to be planned for increasing the score of this enabler in the next cycle of maturity measurement. Actions that are related to project organization structure planning and work breakdown structure planning will be performed in a timely manner to increase the effectiveness of general (planning) enabler. For process measurement enabler, actions regarding the determination of concepts of what to be measured, who will measure it, when will be measured, and how will be measured should be planned. In order to increase the effectiveness of outputs (QMR) enabler, actions determined in this management review should be closed in the agreed timescale. This will improve the score of the outputs (QMR) enabler. Awareness of employees about continuous improvement and contribution of them to improvement activities should be increased to obtain higher scores for general (improvement) enabler. In order to increase the effectiveness of risk/opportunity planning enabler, rules that are needed for the management of the risk/opportunity process should be determined and the status of risk/opportunities should be reviewed periodically.

7. CONCLUSIONS

The quality management maturity model framework demonstrated with a numerical example is developed upon request of top-level management in an aviation organization. This maturity model is prepared in accordance with the requirements of the AS9100D quality management standard, and the necessities of the organization. Besides, the maturity of the project is also considered.

This project is in the design and development phase currently. In the next phases, the initiation of manufacturing activities is considered. Correspondingly, it is recommended to evolve the structure of the proposed model in such a way as to include the requirements of manufacturing activities in the next phases of the project.

Some of the steps in the proposed maturity model are performed with the participation of experts who have sufficient experience in the aviation industry. However, these experts have different years of experience in the aviation industry and in the scope of the study, this difference is not considered. As a future study, it is proposed to include the years of experience as weights of experts' opinions in the maturity model.

In the organization, this study is accepted as the initial version of the quality management maturity measurement activities and the experts involved in this study are aviation industry experienced. In order to establish a initial maturity model and to perform the first cycle of the maturity measurement, it is assumed that all data obtained from experts as linguistic variables comply with the triangular fuzzy membership function. In the next phases of the project, when this maturity model is evolved, different types of fuzzy membership functions (trapezoid, gaussian, z-shaped, sigmoid e.g.) should be taken into consideration.

As it stated in the previous paragraph, this study is accepted as the initial version of the quality management maturity measurement activities. Since this study is accepted as an initial and 5-scaled linguistic variables are considered easily understandable, in this study, this scale is used. As a future study, different scaled linguistic variables may be used.

In this study, prioritization of importance of targets (WHATs) and enablers (HOWs) are conducted in accordance with experts' opinions. However, how the targets (WHATs) can be prioritized among themselves and how the enablers (HOWs) can be prioritized among themselves are not taken into consideration. Therefore, as part of the future study, it is recommended to apply pairwise comparison during prioritization of importance of targets (WHATs) and enablers (HOWs).

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BIOGRAPHICAL SKETCH

After he had graduated from Bursa Boy's High School in 2007, his university education had started in Industrial Engineering Department at Eskişehir Osmangazi University. In scope of the bachelor of science program, he mostly studied on operational research, production planning, statistics, quality management and control areas. His bachelor of science program thesis was related to scheduling problem of plastic injection machines and this thesis was published in "Journal of Industrial Engineering" issued by Chamber of Mechanical Engineers.

After he had graduated from university in 2013, he had started his compulsory military service in Industrial Engineering Department at the Turkish Military Academy as a third lieutenant, instructor. In his professional career, he had worked in areas such as production quality, quality management system, and continuous improvement in the ceramic sanitaryware industry between 2014 and 2020 years.

Since, September 2019, he has been a master of science program student in Industrial Engineering at the Graduate School of Science and Engineering of Galatasaray Unıversity. He has been working as a design quality engineer in a design and development project of an aviation industry organization since 2020.