World Academy of Science, Engineering and Technology
International Journal of Aerospace and Mechanical Engineering
Vol:11, No:1, 2017

Systems Engineering Management Using Transdisciplinary Quality System Development Lifecycle Model

Mohamed Asaad Abdelrazek, Amir Taher El-Sheikh, M. Zayan, A.M. Elhady

***Abstract*—**The successful realization of complex systems is dependent not only on the technology issues and the process for implementing them, but on the management issues as well. Managing the systems development lifecycle requires technical management. Systems engineering management is the technical management. Systems engineering management is accomplished by incorporating many activities. The three major activities are development phasing, systems engineering process and lifecycle integration. Systems engineering management activities are performed across the system development lifecycle. Due to the ever-increasing complexity of systems as well the difficulty of managing and tracking the development activities, new ways to achieve systems engineering management activities are required. This paper presents a systematic approach used as a design management tool applied across systems engineering management roles. In this approach, Transdisciplinary System Development Lifecycle (TSDL) Model has been modified and integrated with Quality Function Deployment. Hereinafter, the name of the systematic approach is the Transdisciplinary Quality System Development Lifecycle (TQSDL) Model. The QFD translates the voice of customers (VOC) into measurable technical characteristics. The modified TSDL model is based on Axiomatic Design developed by Suh which is applicable to all designs: products, processes, systems and organizations. The TQSDL model aims to provide a robust structure and systematic thinking to support the implementation of systems engineering management roles. This approach ensures that the customer requirements are fulfilled as well as satisfies all the systems engineering manager roles and activities.

***Keywords*—**Axiomatic design, quality function deployment, systems engineering management, system development lifecycle.

I. Introduction

TO stay competitive, the manufacturer has to deliver high quality systems (products) in a short time and at the lowest cost. Systems engineering management is the application of scientific, engineering, and managerial efforts to direct the design, development, synthesis and creation of systems.

Systems engineering management is very necessary to resolve complex problems, or to manage the development of large systems which consist of humans, hardware and software. There are many studies that indicate the difficulties and failures associated with the development of large systems, for example [1]:

1) Difficulty in identifying customer requirements.
2) Increased cost of large systems.
3) The final large system did not achieve the customer requirements.
4) The final system is not delivered in a timely manner.
5) Difficulty in developing the large system documentation.
6) Unexpected risks and hazards often happen.
7) Poor communication between management, designers and customers.
8) Difficulty to perform traceability.

These studies also represent that for solving these problems often needs greater effort in the management of developing the systems than the technological concerns. Direct attention to the systems and its subsystems without suitable attention to the process of development leads to low-quality and expensive system. Therefore, a systems engineering manager must be able to deal with new systematic approaches and management tools. These new systematic approaches will be used to develop a complex system.

The goal of this paper is to integrate the TSDL model after modification with the QFD tool in one model to develop a systematic approach that will be used as a design management tool. This approach will be used to solve the difficulties associated with the development of large systems. Furthermore, it fulfills all systems engineering manager roles which are performed during the system development lifecycle.

This paper is organized as follows. Section II presents the systems engineering manager roles. Section III provides a brief overview of quality function deployment. Section IV provides a brief overview of axiomatic design and TSDL model. Section V describes the TQSDL Model and discusses how the TQSDL model fulfills the systems engineering manager roles. Section VI summarizes the conclusion.

II. Systems Engineering Manager Roles

A system engineering manager has to perform a set of different roles during the process of developing complex systems. These roles can be summarized to [1]-[3]:

1) Customer needs identification and linkage to system requirements.
2) Requirements management.
3) Change management.
4) Architecture and system design.
5) Integration.

Mohamed Asaad Abdelrazek is with Egyptian Armed Forces, Cairo, Egypt (e-mail: mohamed35.asaad@gmail.com).
Amir Taher EL-Sheikh is with Administrative Control Authority, Cairo, Egypt (e-mail amir.arafa@gmail.com).
M. Zayan is with Nilesat, Cairo, Egypt (e-mail m.zayan@nilesat.com).
A. M. Elhady is with NARSS Cairo, Egypt (e-mail bakr20081@gmail.com).

6) Process management
7) Analysis and testing.
8) Technical and risk management.
9) Leading, coordinating and managing.
10) Information management.

Therefore, managing the total process of a system's development, and dealing with the customer is performed by the systems engineering manager. The degree to which each of these roles is performed during the system development depends on the type of system [4].

III. Quality Function Deployment Overview

Quality function deployment (QFD) was developed in Japan in the late of 1960 by Professor Yoji Akao. Akao defines QFD as "QFD provides specific methods for ensuring quality throughout each stage of the product development" and the American Supplier Institute considers QFD as "a system for translating consumer or user requirements into appropriate company requirements at every stage from research, through product design and development, to manufacture, distribution, installation and marketing, sales and service" [5].

The main reasons for developing the QFD method are:
1) To develop products that can achieve customer needs.
2) To obtain a quality control charts before starting the actual production.
3) The main advantages and benefits of the QFD are [6], [7]:
4) Increased customer satisfaction.
5) Reduction in implementation time.
6) Improve interaction and communications between teamwork.
7) Reduction in startup and engineering costs.
8) Provides a full documentation for the product.

The benefits when QFD is correctly used are: 50% reduction in product development time, 20%-60% reduction in startup cost, 30%-50% reduction in engineering changes and 20%-50% fewer warranty claims [7], [8]. The QFD process involves four phases:
1) Product planning (house of quality).
2) Product design.
3) Process planning.
4) Process control (quality control chart).

QFD contains seven sections as shown in Fig. 1 [9], [10].

Section 1 is called "voice of the customer" or "customer requirements (the whats)". This section expresses the needs and expectation of customers to the final product in the customer's own language using a questionnaire form or a face-to-face interview with all stakeholders.

Section 2 represents the importance degree for each customer requirement on a scale of 1 to 5. On this scale 5 denotes very high and 1 denotes relatively very low [9].

Section 3 includes a customer competitive assessment. This is to let the customer rate how well our company performs on each requirement in relation to our competitors, usually expressed by a 5-point scale. On this scale 5 denotes excellent and 1 denotes relatively very poor.

Section 4 is the engineering characteristics matrix (voice of the engineer (the hows)). The objective of this section is to determine a set of technical characteristics that can be used to satisfy customer requirements.

Section 5 is correlation matrix. This section represents the correlation between engineering characteristics. By acting to improve one requirement may help another related requirement in the positive direction and meet the target value. On the other hand, by acting to improve one requirement it may have a negative effect on the other related requirement and will be hard to achieve the target value.

Section 6 is relationship matrix. This matrix identifies the level of relationship between every customer requirement and every engineering characteristic. Usually this relationship is measured by strong relationships, medium relationship or weak relationship.

Section 7 is the technical evaluation matrix. It includes the target values which reflect what is needed to assure customer satisfaction and technical competitive advantage which evaluate the performance of the company's product and its competitors on each of the engineering characteristics.

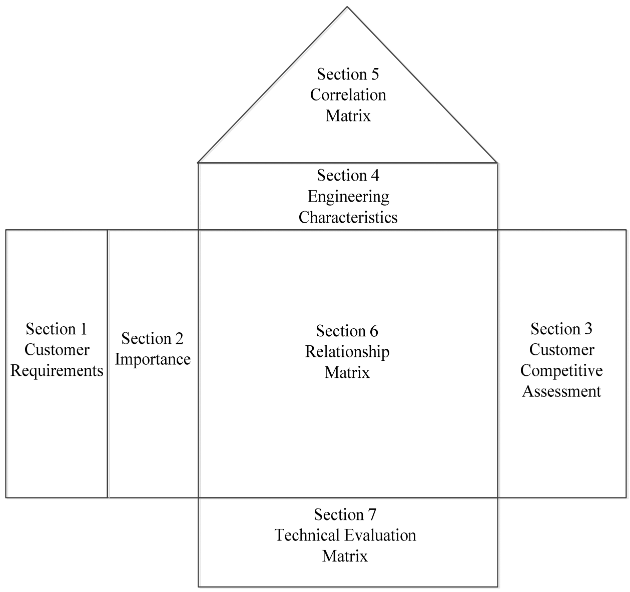

Fig. 1 QFD

QFD proved that it is an important management tool used to translate customer requirements into new products which fulfilled customer requirements. On the other hand, there are studies asked to enhance the features of QFD to increase customer satisfaction and to overcome the drawbacks of the QFD [11]. An increase in customer satisfaction by 1% was associated with a 2.37% increase in the return over investment; furthermore, a decrease of customer satisfaction by 1% was associated with a decrease of 5.08% in the return over investment [12]. Integrating the Kano model with the QFD method, one of the advanced QFD methods used to solve the problems associated with traditional QFD, for example ambiguity in the VOC. This method depends on classifying the customer requirements into three categories: One-dimensional requirements, must-be requirements and attractive requirements using Kano questionnaire, as shown in Fig. 2. Finally, the Kano model is used to classify customer requirements to increase customer satisfaction and deliver a product that meets the basic requirements "Must Be", maximizes the "One-Dimensional" and includes as many "Attractive" features as possible at a reasonable cost. For more information on the integrating of the Kano model and QFD review, see [13]-[16].

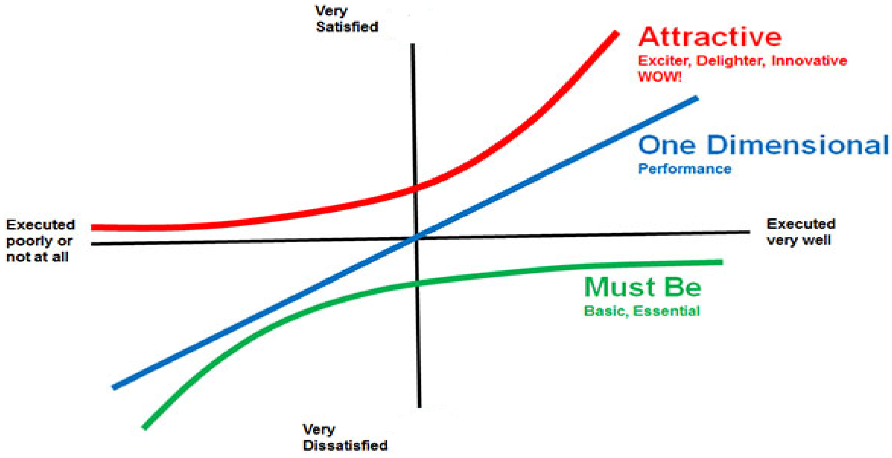

Fig. 2 Kano Model

IV. TSDL Model Overview

The TSDL model is a system development lifecycle model proposed by Bulent Gumus based on axiomatic design (AD) [17]. The TSDL model provides a systematic approach to designers and development team members for performing the system development and management activities.

A. Axiomatic Design

Axiomatic design is developed by Nam P. Suh at MIT in the engineering field (1990-2001). The motivation and the ultimate goal for developing axiomatic design, is to provide a systematic and scientific basis for making design decisions. Furthermore, it can be applied to many fields like product design, systems design, organization and software [18]. Axiomatic design consists of four concepts:

1) Domain.
2) Zigzagging.
3) Hierarchy.
4) Axioms.

Design is interplay between "what we want to achieve" and "how we choose to satisfy the need". To systematize this interplay process AD creates four domains:

1) Customer domain.
2) Functional domain.
3) Physical domain.
4) Process domain.

Customer domain is characterized by the requirements (CNs) that the customers wants to be in the product. The customer requirements are specified into functional requirements (FRs) and constraints in the function domain. In the physical domain, we conceive design parameters (DPs) to satisfy FRs. Finally, to get the desired product which is requested by the DPs, we set a process that is characterized by process variables (PVs). Fig. 3 represents the TSDL domains structure.

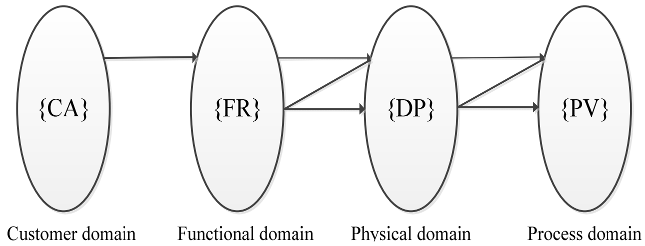

Fig. 3 Axiomatic design domains

For each pair of adjacent domains, the left domain represents the "what we want to achieve", whereas the right domain represents the "how we choose to satisfy the need". Decisions in the "what" domain is constantly transformed into decisions in the "how" domain via a horizontal mapping operation. Through the mapping between the two adjacent domains, the decomposition process must be performed layer by layer and hierarchies of FRs, DPs and PVs will be established which are representative of design architecture. The mapping between two domains is accompanied with top-down zigzagging as shown in Fig. 4.

The basic postulate of axiomatic design is that there are two axioms that govern the design process:

1) Axiom 1: The independence axiom. It states that "Maintain the independence of the functional requirements (FRs)". It means that when there are more than one FRs, each one of the FRs can be satisfied without affecting the other FRs.
2) Axiom 2: The information axiom "Minimize the information content of the design". This axiom provides a quantitative measure of the merits of a given design, so that it is used to select the best among those designs.

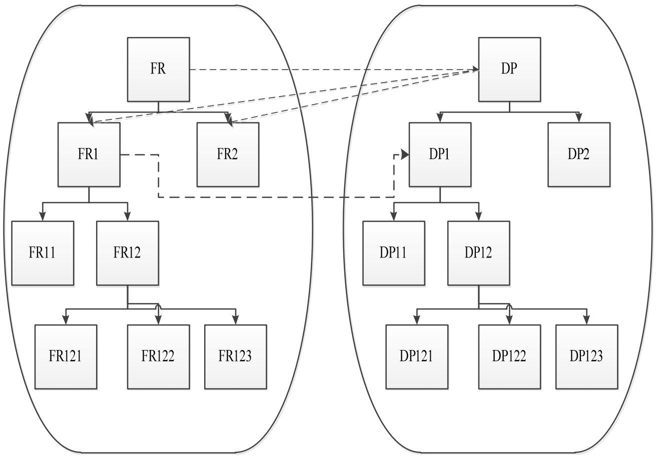

Fig. 4 Hierarchy of FRs and DPs, zigzagging from functional domain to physical domain

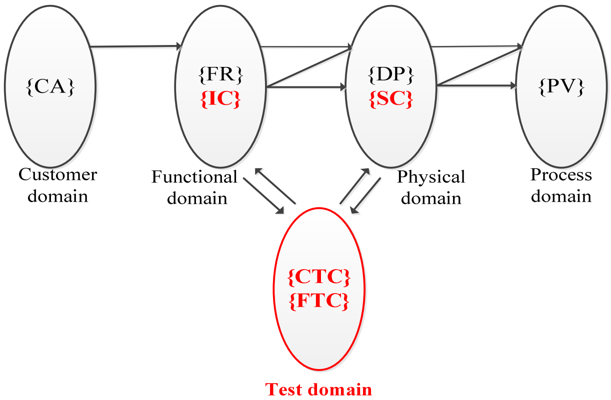

Fig. 5 TSDL domains

$$\{FR\} = [A]\{DP\} \quad (1)$$

$$\{DP\} = [B]\{PV\} \quad (2)$$

where: {FR}: Functional requirement vector, {DP}: Design parameter vector, {PV}: Process variable vector, [A]: Design matrix, [B]: Process matrix

To satisfy the independence axiom the design matrix must be either diagonal (uncoupled design) or triangular (decoupled design). In case of several designs satisfy the independence axiom the information axiom can be used to select the best design. The design with the highest probability of success is the best design. In general case of an nFR for an uncoupled design information content is:

$$I = \sum_{i=1}^{n} -\log(p_i) \quad (3)$$

where *I:* Information content; p_i: Probability of DPi satisfies FRi

Axiomatic design helps to avoid the traditional design-build-test-redesign cycle of design solutions and determines the best solution among the whole proposed designs.

B. TSDL

The axiomatic design method does not support the whole system (product) development lifecycle. TSDL model is extended to support the test domain of the system development lifecycle [17]. Fig. 5 represents the TSDL model domains structure.

In TSDL model, one new domain (test domain) and four new characteristics vectors (input constraints (IC), system component (SCs), component test case (CTCs) and functional test case (FTCs)) are added. The new relationship between the characteristics vectors can be written as:

$$\{CN\} = [R]\{FR_i\} \quad (4)$$

$$\{CN\} = [C]\{IC\} \quad (5)$$

$$\{FR\} = [D]\{DP\} \quad (6)$$

$$\{IC\} = [CA]\{DP\} \quad (7)$$

$$\{DP\} = [SS]\{SC\} \quad (8)$$

$$\{SC\} = [P]\{PV\} \quad (9)$$

$$\{FR\} = [FT]\{FTC\} \quad (10)$$

$$\{SC\} = [CT]\{CTC\} \quad (11)$$

where: {IC}: Input constraint vector, {SC}: System component vector, {FTC}: Functional test case vector, {CTC}: Component test case vector, {CN}: Customer need vector, [R]: Requirement matrix, [C]: Constraint matrix, [D]: Design Matrix, [CA]: Constraint allocation matrix, [SS]: System Structure Matrix, [P]: Process matrix, [FT]: Functional test matrix, [CT]: Component test matrix

The input constraint vector is added to the functional domain along with functional requirements vector. Input constraints which are imposed by the stakeholders are collected in the constraint vector. The SCs vector consists of the physical entities that provide the design solution stated in DPs. The test domain is added to the axiomatic design domains to cover the whole system development lifecycle. The test domain is characterized by two vectors, FTCs and CTCs. CTCs are used to verify that the selected components represented by the SCs vector, satisfies the allocated FRs and ICs. The FTCs vector is used to prove that the customer requirements are achieved by the developed system. The TSDL model process is represented in V-shaped, the detailed design is developed by the left side (top-down), while the right side (bottom-up) is used to produce and test the system, as shown in Fig. 6.

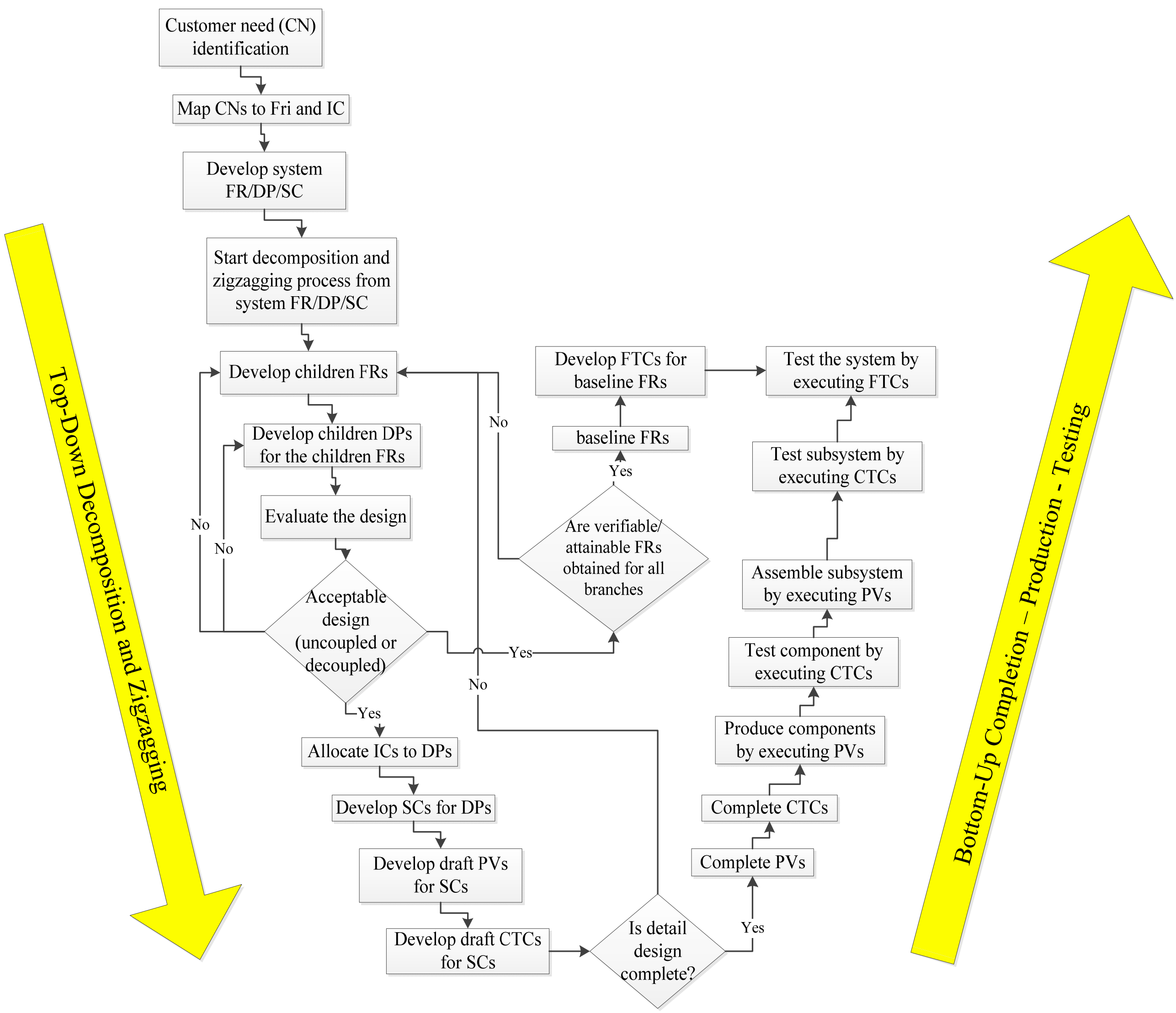

Fig. 6 TSDL process

V. TQSDL

A. TQSDL Model Domains and Process

The TQSDL model is a design management tool, which provides systematic thinking to support the design and management activities across the systems development lifecycle. With increasing competition for new markets, customer satisfaction is a growing concern and the ultimate objective of every business. The increasing of customer satisfaction will lead to increasing customer loyalty. An increase in customer loyalty by 5% can increase the profit of a business by 100% [12]. In order to obtain a high level of customer loyalty, we must understand the customer requirements very well. Furthermore, we must obtain a full picture of who our customer actually is. The customer domain in the TSDL model is characterized by the needs that the customer is looking for in a system [18]. Stakeholders' identities are not included in the customer domain. Moreover, stakeholders' identification is the first and the important step in the system development process. This step helps to ensure that no important needs are neglected. For these reasons, the stakeholder domain will be added to the TSDL model domains, as shown in Fig. 7. Stakeholders are defined as "the people, groups, or organizations that could impact or be impacted by the project" [19]. The stakeholder domain is characterized by the stakeholders identification vector {SI}. Stakeholders' identification is performed by stakeholders' identification and analysis techniques. Fifteen techniques are presented by John Bryson for stakeholder identification [20]. The mapping process between the stakeholders' domain and customer domain can be mathematically expressed as:

$$\{SI\} = [SA]\{CN_i\} \tag{12}$$

where: {SI} Stakeholders identification vector, [SA] Stakeholders allocation matrix.

The first axiom (independence axiom) is not applicable for this equation because it is possible that several stakeholders identify the same requirement as well as multiple requirements are identified by one stakeholder. This equation represents the relationship between each of the stakeholders (Who) and each of the customer needs (What). A new theorem was created to supplement the TSDL model theorems. This theorem is used to control the process of mapping and zigzagging between the stakeholder domain and customer needs domain.

1. New Theorem (Allocate Stakeholders {SI} to Customer Needs {CNs})

The stakeholders that are identified {SI} from the stakeholders identification and analysis techniques are allocated to {CNs} without restricting to independence axiom. Several stakeholders allocate to one need or multiple needs mapping to one stakeholder.

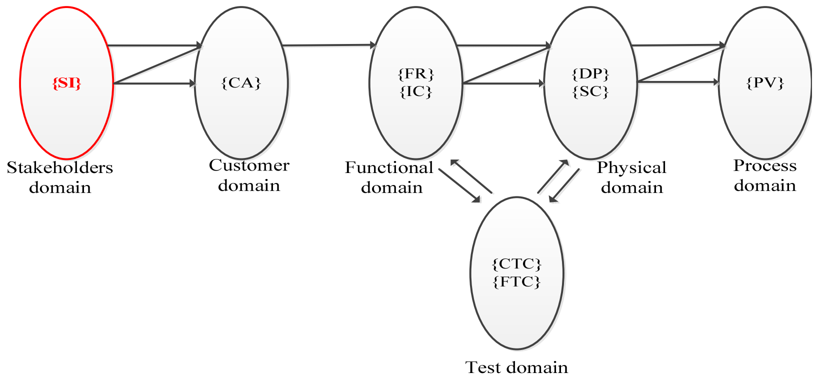

Fig. 7 TQSDL model domains (presented method)

A road map of the TQSDL model process is presented in a V-shaped process, as in the TSDL model, with some modifications in the top-down side (left side), as shown in Fig. 8. These modifications could lead to enhancement in the system development process. The process starts with stakeholders identification and the output will be recorded in the stakeholders register which contains at least, name, organization, location, role in the project and contact method [19]. Errors in gathering or predicting the customer needs can lead to incorrect system or to complete project failure. Therefore, the mapping between stakeholders and customer needs are performed by QFD to provide a visual relationship between each stakeholder and each customer needs, and to ensure that all stakeholders' needs are gathered.

From analyzing the QFD, it ensures that each stakeholder (each row in QFD chart) has at least one need. If this does not occur, check the relationship matrix again or run a new session with the stakeholder to get the missing needs. On the other hand, in the case of existing customer needs (each column in QFD chart) without a relationship with any stakeholder, it means that this customer need is not requested. The achievement of this extra need will lead to an increase in the total cost of the system. This extra need will be removed, or review the relationship matrix again to get the missing relation. The weight of each stakeholder in the project will be determined by using the degree of importance. The importance will help to determine the effect on customer satisfaction in case of failure to implement one of the customer needs. The importance of rating the customer needs will be used to determine which CNs have priority and should receive the most attention to achieve customer satisfaction. Usually, customers use vague expressions in defining their needs. Therefore, the mapping of customer needs to functional requirements will be divided into two stages. First, translating the customer needs into critical to quality (CTQ) characteristics, then translating the CTQs to FRs and ICs. These two stages will be performed by QFD.

CTQs are the translation of customer requirements into quantitative terms. The main benefit of translating CNs to CTQs is to break down the CNs into identifiable and measurable terms. Moreover, these terms can be used later as input to the final acceptance test to determine the customer satisfaction degree. The importance rating of CTQs will be used to determine which CTQs have priority and should receive the most resources allocation. In the second stage, each CTQs will be defined in terms of functionality in order to determine a set of FRs which can help to fulfill CTQs. After the completion of mapping CNs to FRs and ICs, the top level of DP and SC should be proposed. Once FR/DP/SC top level is developed the design decomposition and zigzagging process will be started to get system architectures. In the case that there are several DPs that could satisfy the FR and several SCs could be used to apply DP, a second axiom can be used as a quantitative measure of a given design, and thus, it is useful in selecting the best design from different designs alternatives that may be accepted with regard to the independence axiom [18]. The remaining process of the TQSDL model will be similar to the TSDL model process [17]. Moreover, during the execution of the final acceptance test to verify that the system satisfies the top-level FRs, CTQs will be used to measure the degree of customer satisfaction and ensure that the final system achieves the customer needs.

B. How to Use the TQSDL Model to Fulfill Systems Engineering Manager Roles

1. Need Identification and Customer Linkage

This role is used to identify customer needs and to create the link between customer requirements and the system design.

The understanding of customer needs is very important in the system design. Therefore, the systems engineering manager needs a step-by-step tool to fulfill this role. Since, the modification of the TSDL model has performed by adding the stakeholder's domain to give a complete vision of who our customer is, and to guarantee that all their needs are gathered. QFD tool will be used to fulfill this role to ensure a better understanding of the vague customer needs.

2. Requirements Management and Change Management

Requirements management is the process to capture, analyze, and track system requirements [21]. The main activities of requirements management are [22]:

1) Managing requirement development.
2) Requirement traceability.
3) Managing requirement changes.

To achieve the first activity, the TQSDL model provides an effective structure method for gathering the requirements by using the QFD tool to translate vague customer needs into functional requirements.

Requirements traceability is the critical activity in requirements management [21] and it is defined as the ability to trace the requirements in both directions (bidirectional) back to the stakeholders and forward to the final system. Mapping matrices between TQSDL model domains can provide an easy way to follow the requirement. The requirements can be traced back to the stakeholders using [SA] and [R] matrices and can be followed forward using [D], [CA], [SS], [P], and [FT] and [CT] matrices. Furthermore, any changes in customer needs, functional requirements and design can be followed in both direction. Systems architectures which are developed by the TQSDL model can be used to assess the impact of the changes on the final system.

3. Architecture and System Design

This role is used to develop the system architecture and to create the link between the system's requirements and the system's configuration. System architecture is defined as: "The arrangement of elements and subsystems and the allocation of functions to them to meet system requirements" [23]. The decomposition and zigzagging process in TQSDL model is performed layer by layer between FRs/DP/SCs to create the system architecture. The decomposition outputs are:

1) Functional requirements (FRs) hierarchy (functional requirements architecture).
2) DPs hierarchy (design solution architecture).
3) SCs hierarchy (system physical architecture).
4) PVs hierarchy. (Resources Architecture)

These architectures are very useful in simplifying design problems for complex system, and also represent the interrelationship between system requirements and SCs through the zigzagging process. Moreover, they facilitate the communication between engineers, managers and stakeholders. The SCs hierarchy will be used to calculate the primary cost for the physical entities, and to assess the effect of design changes on the cost budget.

Axiomatic design has three equivalent ways to represent the system architecture, but each one highlights different features of the system [18]:

1) Hierarchical diagram represent the entire decomposition steps of FR/DP/SC/PV and the corresponding matrices.
2) Module-junction diagram, this architecture depends on modules which are defined as "the row of the design matrix that yields FR when it is provided with (or multiplied by) the input of its corresponding DP". It is used to show the type of each design matrix and develop the system structure.
3) Flow diagram represents the interaction between modules and the sequence of design the modules.

All of these types of system architecture can be developed automatically by using an axiomatic design software package.

4. Integration

In this role, the systems engineering manager is responsible to integrate all the system disciplines to produce the system as a whole and also manage interfaces between disciplines to get the optimal system.

PVs hierarchy collects all the processes and disciplines that are used to produce, manufacture, integrate, and implement etc., the SCs [17], [18]. All of these processes represent how to realize the SCs which are the physical entities for the design solution defined in DPs which are chosen to satisfy a certain FRs. During the TQSDL model process, the PVs should be identified for each SC according to the level of SCs. For example, at the system level, PVs are used to identify the assembly and integration process of subsystems to form the system, but at the component level the PVs is the process used to produce the components or purchase request of the commercially available components. These PVs are identified after the selection of the optimal SCs using the second axiom as described in the TQSDL model process. After the achievement of all PVs the system will be ready for executing CTCs for subsystem, then FTCs for the system as a whole to ensure that the final system to achieve customer satisfaction.

5. Process Management

In this role, the system engineering manager directs and follows the systems engineering process.

The V-model approach is one of the systems engineering methodology used to ensure that the system achieves the customer needs [21]. In the same way, the TQSDL model process is presented in a V-shape. The top-down approach on the left side is used to develop, decomposition and zigzagging. The bottom-up approach on the right side is used in production, integration and testing. The most important feature in the TQSDL model is the ability to trace the customer requirements to the final system or vice versa by using mapping matrices. This feature helps to confirm that all CNs have been achieved in the final system. Therefore, The TQSDL process fulfills the systems engineering process and achieves the objective of the V-model approach, as shown in Fig. 8.

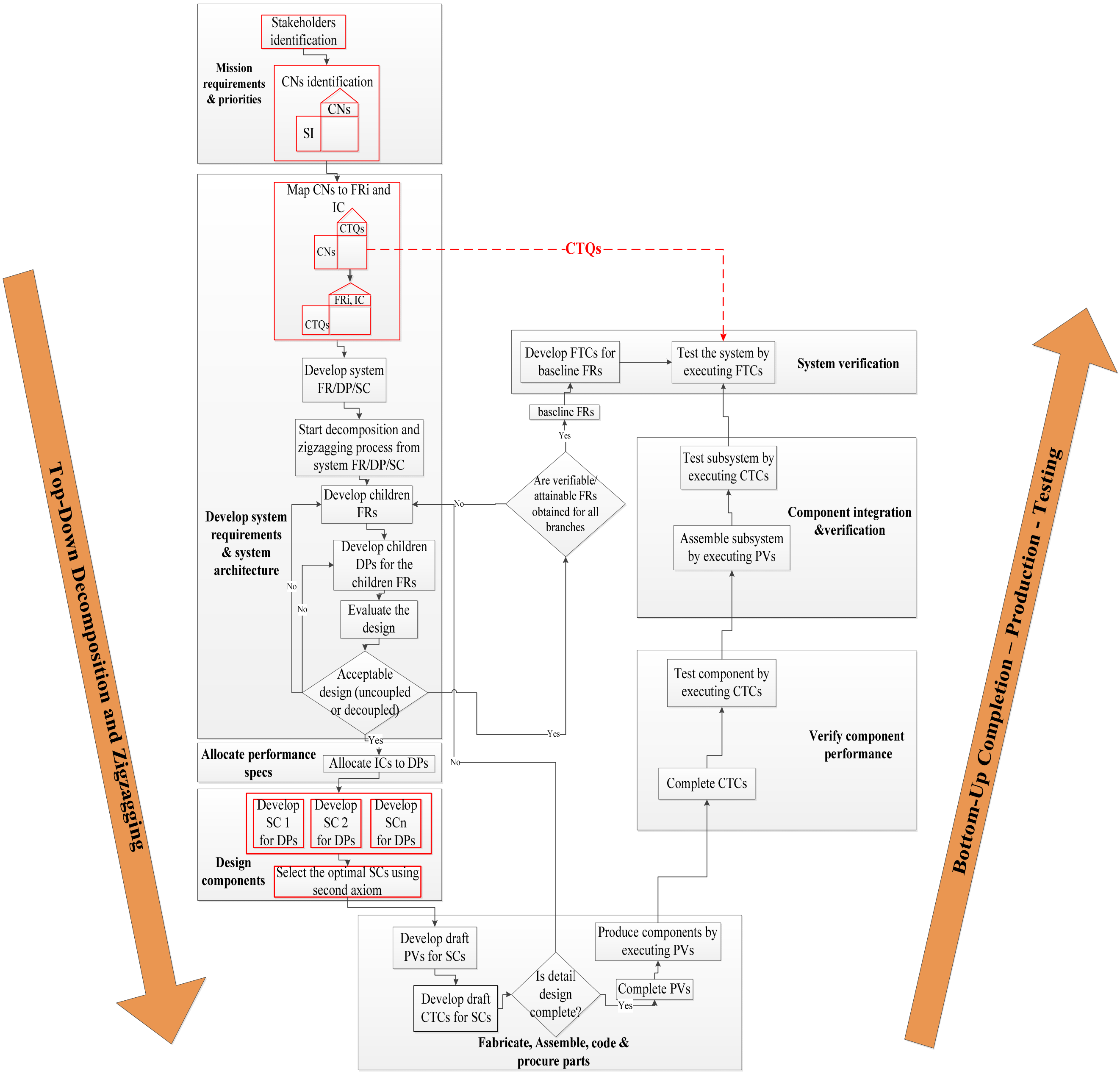

Fig. 8 TQSDL process (presented model)

6. Analysis and Testing

This role is used to confirm that the system is designed according to its requirements and achieve customer satisfaction.

Test domain in the TQSDL model has two vectors FTCs vector and CTCs vector. The purpose of FTCs is to ensure that the designed system satisfies the top level of functional requirements and comply with CTQs. CTCs are used to ensure the corresponding component achieves the allocated FRs and ICs.

7. Technical and Risk Management

This role addresses the trade-off analysis and represents the conflicts at different interface points during the design process. Furthermore, it involves the risk assessment of various system elements.

The goals of trade-off management are [21]:

1) Develop a balanced requirements baseline.
2) Select the best functional requirements architecture.
3) Select the best solution from proposed designs.

One of the goals of using the QFD during the mapping between CNs and FRs is to perform trade-off analysis. QFD is the most common method used to perform trade-off analysis [21].

The relationships between CTQs are represented by the correlation matrix in QFD as shown in Fig. 1.There are three types of relationship can be presented in this matrix [9]:

1) No relationship.

2) Positive relationship.
3) Negative relationship.

Positive relationship means that improvement in one CTQs may help another CTQs in a positive direction to achieve target value. Negative relationship means that improvement one CTQs has a negative effect on the other CTQs. This negative relationship shows where a trade-off situation exists which must be resolved by generating new alternatives [24], [25].

Failure modes and effects analyses (FMEAs) is one of the risk assessment techniques. It is used to identify potential failures, causes, effects and mitigation strategy that can be executed to control or minimize the effects of failures [22]. In FMEA, the potential failure is identified for each function. Therefore, the functional hierarchy of the TQSDL model will be used as the input to FMEA to identify all possible failures. The triple relationship between FRs/DPs/SCs in a hierarchy can be used to determine the effect of potential failures on the physical architecture and also helps to find the possible root causes. Satisfying the independence axiom by uncoupled design will ensure that the potential failures will not propagate to other subsystems or components [26].

TABLE I
INFORMATION MANAGEMENT PROCESS AND TQSDL PROCESS

Information Management Process	TQSDL Process
System operational needs analysis	• Gathering CNs • Translate CNs to CTQs by using QFD
System requirements and architecture	System architecture (FR/DP/SC/PV) hierarchies
Component design select and plan best solution	• SCs hierarchy for system components • Second axiom to select the best solution
System verification and validation	• Test domain • CTCs and FTCs vectors

8. Leading, Coordinating and Managing I

In this role, the system engineering manager is responsible for managing and leading of people activities.

The success of system development depends on the selected team. At the beginning of any project, special efforts may be needed to create a multifunctional team that cooperates to achieve the required design. The systems engineering manager will be the head of the selected team [2]. Integrated product teams (IPTs) is system engineering management techniques [21] defined as "a process oriented, integrated set of cross-functional teams given the appropriate resources and charged with the responsibility and authority to define, develop, produce, and support a product (and/or service)" [23]. IPTs are composed of members covering all the areas of the system development. The TQSDL model will be used to improve the communication between the IPTs member and to coordinate the processes between different areas during the system development lifecycle, as shown in Fig. 8.

9. Information Management

In this role, the systems engineering manager views the overall information needs for developing the systems as well as managing the information throughout the information lifecycle.

Information management is defined as "a set of activities associated with the collection and management of information from one or more sources, and the distribution of that information to one or more audiences". Fig. 9 represents the role of the systems engineering manager in information management [27].

The TQSDL model fulfills all the processes of the information management lifecycle, as shown in Table I.

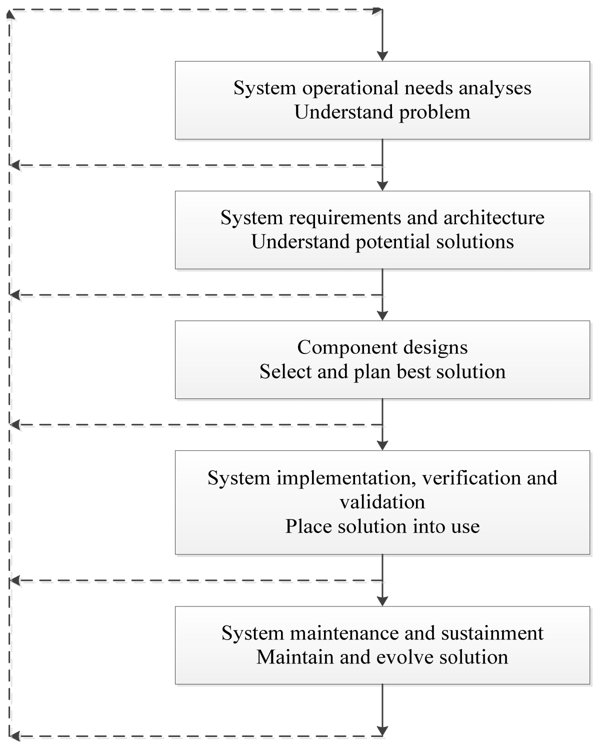

Fig. 9 Information lifecycle process

VI. CONCLUSION

During the system development process, the system engineering manager has to perform many roles to develop the system and to ensure customer satisfaction. In the present work, we introduced a new systematic approach called the TQSDL model used as a design management tool. In order to develop the TQSDL model:

1) TSDL model has modified by adding a new domain. This new domain is the stakeholders' domain with stakeholders' identification vector.
2) A new theorem was created to control the process of mapping and zigzagging between {SI} and {CNs}.
3) Integrate QFD tool into the TQSDL model process (V-shaped).

The TQSDL model inherits all the benefits of the TSDL model and the QFD tool. The TQSDL model can be used in managing, designing and developing complex systems as well as helping systems engineering managers to achieve the intended roles.

The stakeholders' domain ensures that all stakeholders are identified and all needs are gathered. Moreover, the stakeholder allocation matrix is used to trace changes in design toward stakeholders, to assess the effects of these changes on customer satisfaction.

The organization gains a competitive advantage when it achieves its customer needs. By integrating the QFD tool in the TQSDL model process will lead to:

1) Provide a visual relationship between each stakeholder and each customer need.
2) Ensure that all needs are gathered from all stakeholders to maximize customer satisfaction.
3) Translate the vague customer needs into measurable terms which are used to measure customer satisfaction.
4) Improve requirements development process.
5) Support trade-off management process.

The TQSDL model helps to show the flow of work and information during the system development lifecycle. Furthermore, assign the resources (human, financial...) which is needed to develop the system effectively by using PVs hierarchy to ensure no losses in the resources. Finally, successful implementation of the TQSDL model will assist the systems engineering manager for implementing the intended roles in a more effectively manner and develop the complex systems that achieve customer satisfaction. Furthermore, the model solves the difficulties occurred during development of large systems.

Acknowledgment

The authors would like to acknowledge all of the individuals who have contributed to the data collection efforts.

References

[1] A. Sage and W. Rouse, *Handbook of Systems Engineering and Management*, Second Edi. John Wiley & Sons, 2009.
[2] S. a Sheard, "Twelve systems engineering roles," *INCOSE 6th Annu. Symp.*, no. 703, pp. 1–8, 1996.
[3] A. Shenhar, "Systems engineering management: a framework for the development of a multidisciplinary discipline," *Syst. Man Cybern. IEEE*, vol. 24, no. 2, 1994.
[4] B. Sauser, "Toward Mission Assurance : A Framework for Systems Engineering Management," vol. 9, no. 3, pp. 213–227, 2006.
[5] D. Maritan, *Practical Manual of Quality Function Deployment*. 2015.
[6] S. Zaim and M. Şevkli, "The Methodology of Quality Function Deployment with Crisp and Fuzzy Approaches and an Application in the Turkish Shampoo Industry.," *J. Econ. Soc. Res.*, vol. 4, no. 1, pp. 27–53, 2002.
[7] E. S. Jaiswal, "A Case Study on Quality Function Deployment (QFD)," *IOSR J. Mech. Civ. Eng. , ISSN 2278-1684*, vol. 3, no. 6, pp. 27–35, 2012.
[8] V. Bouchereau and H. Rowlands, "Methods and techniques to help quality function deployment (QFD)," *Benchmarking An Int. J.*, vol. 7, no. 1, pp. 8–20, 2000.
[9] L.-K. Chan and M.-L. Wu, "A systematic approach to quality function deployment with a full illustrative example," *Omega*, vol. 33, pp. 119–139, 2005.
[10] F. Pakdil, F. B. Işın, and H. Genç, "A Quality Function Deployment Application using Qualitative and Quantitative Analysis in After Sales Services," *Total Qual. Manag.*, vol. 23, no. 12, pp. 1397–1411, 2012.
[11] K. Sivasamy, C. Arumugam, S. R. Devadasan, R. Murugesh, and V. M. M. Thilak, "Advanced models of quality function deployment: a literature review," *Qual. Quant.*, vol. 50, no. 3, pp. 1399–1414, 2016.
[12] G. Tontini, "Integrating the Kano Model and QFD for Designing New Products," *Total Qual. Manag. Bus. Excell.*, vol. 18, no. 6, pp. 599–612, 2007.
[13] A. Chaudha, R. Jain, A. R. Singh, and P. K. Mishra, "Integration of kano's model into quality function deployment (QFD)," *Int. J. Adv. Manuf. Technol.*, vol. 53, no. 5–8, pp. 689–698, 2011.
[14] K. Matzler and H. H. Hinterhuber, "How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment," *Technovation*, vol. 18, no. 1, pp. 25–38, 1998.
[15] B. Bilgili, A. Erci, and S. Ünal, "Kano model application in new product development and customer satisfaction (adaptation of traditional art of tile making to jewelries)," *Procedia - Soc. Behav. Sci.*, vol. 24, pp. 829–846, 2011.
[16] C. C. Chen and M. C. Chuang, "Integrating the Kano model into a robust design approach to enhance customer satisfaction with product design," *Int. J. Prod. Econ.*, vol. 114, no. 2, pp. 667–681, 2008.
[17] B. Gumus, A. Ertas, D. Tate, and I. Cicek, "The Transdisciplinary Product Development Lifecycle model," *J. Eng. Des.*, vol. 19, no. 3, pp. 185–200, 2008.
[18] N. P. Suh, *Axiomatic Design: Advances and Applications*. 2001.
[19] Project Management Institute, *A guide to the project management body of knowledge (PMBOK ® guide)*. 2013.
[20] J. M. Bryson, "What to do when Stakeholders matter - Stakeholder Identification and Analysis Techniques," *Public Manag. Rev.*, vol. 6, no. 1, pp. 21–53, 2004.
[21] G. Locatelli, M. Mancini, and E. Romano, "Systems Engineering to improve the governance in complex project environments," *Int. J. Proj. Manag.*, vol. 32, no. 8, pp. 1395–1410, 2014.
[22] NASA, *NASA Systems Engineering Handbook*, no. June. 2007.
[23] INCOSE, "Systems Engineering Handbook," no. June, pp. 1–446, 2004.
[24] G. Delano, G. S. Parnell, C. Smith, and M. Vance, "Quality function deployment and decision analysis :A R&D case study," *Int. J. Oper. Prod. Manag.*, vol. 20, no. 5, pp. 591–609, 2000.
[25] A. G. Carlo Cavallini, Paolo Citti, Leonardo Costanzo, "an Axiomatic Approach To Managing the Information Content in Qfd: Applications in Material Selection," *Seventh Int. Conf. Axiomat. Des.*, pp. 32–37, 2013.
[26] H. a Mohsen and E. Cekecek, "Thoughts On The Use of Axiomatic Designs Within The Product Development Process Ethem Cekecek ICAD043," *Int. Conf. Axiomat. Des.*, pp. 188–195, 2000.
[27] BKCASE Editorial Board, "Guide to the Systems Engineering Body of Knowledge," *Guid. to Syst. Eng. Body Knowl.*, p. 1039, 2016.

Mohamed Asaad Abdelrazek received a B.S. & M.Sc. Degree in Electrical Engineering from Military Technical College, Cairo in June 1998 & May 2008, currently studying for fulfillment of Ph.D. in space systems engineering & management from Military Technical College. Worked in the fields Electronic Warfare Engineering, Quality Manager for 18 years and currently working systems engineering.

Dr. Amir Taher El-sheikh has received a B.S. in Electrical Engineering and M.Sc. in artificial intelligent from Military Technical College, Cairo in June 1997 & 2002. His management diplomas in Business administration and crisis management were from Ain Shams University in 2005 & 2007. His Ph.D. in 2011 was from University of Windsor addressing Dynamics of Strategy using System engineering methodologies. He worked in the Military Technical College till 2015 and lately he joined the Administrative Control Authority. His work and experience is focused towards Technology Management and System Dynamics

Dr. Mohamed Zayan has received B.S., M.SC. and Ph.D. Degrees in Electrical Engineering, in June 1991, Feb. 1998, and April 2004 from Faculty of Engineering, Alexandria University, Egypt. He works as Satellites control station manager, NILESAT; Egypt since 1996 till now, and also a visitor lecturer in Aeronautics and Aerospace Branch, Military Technical College; Cairo; Egypt, since 2006 till now. More than 24 years of professional experience in communication engineering and information technology including comprehensive 20 years international experience in aerospace industry design, operation, research and development. His current focus is on the flight dynamics, spacecraft orbit control, and aerospace systems engineering.

A. M. Elhady Adjunct Prof., NExSat-1 Project Manager at NARSS, Lead scientist in Africa City of Technology, Sudan Space Program. He is a satellite designer and certifier. He received his B.Sc. M.SC and Ph. D at Zagazig University. He has trained for five years on satellite design and certification at

Yuzhnoye State Design Office, Ukraine. His research areas are structure dynamics, thermal induced vibration, computational mechanics, satellite mission analysis and mission design, and tethered satellite system dynamics.