SOFT SYSTEMS METHODOLOGY FOR DESIGN PROCESS IMPROVEMENT

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ABSTRACT

SOFT SYSTEMS METHODOLOGY FOR DESIGN PROCESS IMPROVEMENT

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Organizations from different business sectors, which are certified by some standardization organizations, are increasingly prioritizing the process improvement to raise their product's quality. The process improvement in these organizations has focused principally on the refinement of existing processes to improve what is currently done through the application of previously developed tools and techniques. This thesis study describes the application of Soft Systems Methodology (SSM) for engineering design process improvement in an organization whose process approach have some similarities with existing standards and guidelines. The SSM uses systems thinking in a cycle of action research and learning to help understand the various perceptions that exist in the minds of different people involved in the problematic situations. In the concept of thesis study, it will lead to identify problematic situations about design process and its sub-processes by involving the human, social and cultural factors besides the technical factors.

This thesis study includes four case studies of SSM's use to analyze the sub-processes of design process named as Requirements Management, Technical Solution, Integration, Verification and Validation sub-processes. There are seven stages of SSM and they are applied to design process and its sub-processes except the stage seven, implementation stage. The rich pictures of sub-processes are drawn based on gathered data from semi-structured interviews and then the root definitions are defined by using Customer-Actor-Transformation-Worldview-Owner-Environment (CATWOE) rule. The conceptual models are built for sub-processes and they are compared with real world activities to address the proposed changes.

The outcomes of the study will show how the rich pictures, root definitions and conceptual models approaches of SSM can help to identify the problematic situations and address the proposed changes. It also enables to realize the required activities needed to perform the improvement in design process and its sub-processes for the employees, process owners and managers in the organization.

Keywords: Soft Systems Methodology, Systems Thinking, Engineering Design Processes, Process Improvement.

ÖZ

TASARIM SÜREÇ GÜNCELLEMESİ İÇİN SOFT SYSTEMS METHODLOGY

Bayraktaroğlu, Bengül
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Bazı standart organizasyonları tarafından sertifikalandırılan, farklı sektörlerde yer alan organizasyonlar, ürünlerinin kalitesini artırmak için süreç güncelleme çalışmalarına artan ölçekte öncelik vermektedirler. Bu organizasyonlardaki süreç güncelleme çalışmaları temel olarak daha önceden geliştirilmiş olan araç ve tekniklerin geliştirilerek mevcutta bulunan süreçlerin iyileştirilmesidir. Bu tez çalışması, mevcut kullanılan standart ve kılavuzlarda tanımlanan süreç yapısıyla bazı benzerlikleri olan bir kuruluşun mühendislik tasarım süreçlerinin geliştirilmesi kapsamında Soft Systems Methodology (SSM)'nin uygulanmasını konu almaktadır. Bu metot aktif araştırma ve öğrenme döngüsü kapsamında problemli durumlara dâhil olan farklı insanların zihinlerinde yer alan çeşitli algılamalar için sistemsel düşünmeyi kullanır. Bu metot tez çalışması kapsamında teknik faktörlerin yanı sıra insan, sosyal ve kültürel faktörleri dâhil ederek tasarım ve geliştirme süreci ve alt süreçleri hakkında problemli durumların tanımlanmasına öncülük etmektedir.

Tez çalışması, Gereksinimlerin Yönetimi, Teknik Çözüm, Entegrasyon, Doğrulama ve Geçerli Kılma olarak adlandırılan tasarım süreçlerinin alt süreçlerini analiz etmek için SSM'nin uygulandığı 4 vaka analizini içermektedir. SSM'nin yedi evresi vardır ve yedinci evre, uygulama evresi dışında tüm evreler tasarım süreci ve alt süreçlerine uygulanmıştır. Yarı yapılandırılmış röportajlardan toplanan bilgiler doğrultusunda alt süreçlerin zengin resimleri çizilmiş ve sonrasında Müşteri-Aktör-Dönüşüm-Dünya Görüşü-Sahip-Çevre (CATWOE) kuralı kullanılarak kök tanımı yapılmıştır. Tasarım alt süreçleri için kavramsal modeller oluşturulmuş ve önerilecek değişiklikleri adreslemek için gerçek dünyada uygulanmakta olan faaliyetler ile karşılaştırılmıştır.

Çalışmanın çıktıları, tasarım süreçleri ve alt süreçleri için gerçekleştirilecek iyileştirmeler kapsamında gerekli duyulan faaliyetleri gerçekleştirmek için SSM kapsamında oluşturulan zengin resimlerin, kök tanımının ve kavramsal modellerinin küçük ve orta ölçekli kuruluş çalışanlarına, süreç sahiplerine ve yöneticilerine nasıl yardım edeceğini gösterecektir.

Anahtar Sözcükler: Soft Systems Methodology, Sistemsel Düşünme, Mühendislik Tasarım Süreçleri, Süreç İyileştirme

To My Family

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I would also like to thank all of participants, employees, process owners and managers from the small and medium-sized enterprise who willingly participated and helped in the process of data gathering for the research study.

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LIST OF ABBREVIATIONS

ADM	Balloon Analog Risk Task
CI	Continuous Improvement
CMMI	Capability Maturity Model Integration
CPI	Continuous Process Improvement
HAS	Human Activity Systems
ISO	International Organization for Standardization
PDS	Product Design Specification
PI	Process Improvement
PDCA	Plan-Do-Check-Act
SSM	Soft Systems Methodology
TQM	Total Quality Management

CHAPTER 1

INTRODUCTION

1.1 Introduction

Most organizations uses process approach, that are usually adapted from some standards and/or guidelines, and improving them is important for the product's quality of organizations. Process Improvement (PI) is generally thought as an important approach for increasing organizational performance by improving the effectiveness and efficiency of business processes. PI activities that are related to organizational level changes are directly interested in the role of humans. The parameters to sustain the process improvement, named as Continuous Improvement (CI), are based on involvement of management, improvement of the goals, performance criteria of processes, measures and being provided with sufficient resources.

Design processes are main part of the products that are designed and developed because of including design activities and aiding the improvement of the product. There are many different definitions for design phases in the literature and so the definition of design process can be changeable from organization to organization in accordance to their product's spectrums. Mainly, the core phases of design process can be defined as 'planning and task clarification', 'conceptual design'; 'embodiment design' and 'detailed design' after comparing existing definitions of the design process in the literature (refer 2.1.1). Some guidelines like Capability Maturity Model Integration (CMMI); International Organization for Standardization (ISO) can be preferred by organizations to build their process definitions and activities for their business. These guidelines generally address the development activities to whole lifecycle of the products or services. All of them can be applicable or not for the organizations in accordance to their design process definition. On the other hand, there are some additional processes, categorized as 'support processes', to raise the designed products' quality.

Although there are many process improvement methodologies in the literature that can be applicable to design process in an organization, choosing the most suitable methodology has the most important manner for the organizations. At this point, there can be a need about merging or modifying the existing improvement methodologies to provide the desired outputs or outcomes for process improvement. In standards or guidelines, process improvement is mainly focused on people, process/methods and tools/equipment. The selection of improvements is based on mainly understanding the aimed benefits and predicted costs of deploying related improvements to the existing processes.

Design process and its sub-processes can be assumed as a system because of the system definition in the literature. It is defined as “a regularly interacting or independent group of items forming a unified whole” in the Merriam-Webster dictionary (Merriam Webster, 2017). On the other hand, systems thinking approach has some similarities with system because of containing three kinds of things labeled as ‘elements’, ‘interconnections’ and ‘a function or purpose’ (Meadows, D. H., 2008). While the one segment of systems thinking, hard systems thinking, is mainly related with well-defined technical problems; the other, soft systems thinking, is concerned with fuzzy ill-defined situations involving human beings and cultural considerations (Checkland P., 2000). Hard systems thinking is not enough to address the real world problems and provide approaches for solving them.

Soft systems thinking is generally preferred to address real world problems and Soft Systems Methodology (SSM) is an action oriented approach that deals with ill structured problems and provides some suggestions to solve them. It can be used for information management and business analysis that can be concluded as process improvement or defining lacks of existing processes because of focusing on human beings involvement, human situations and cultural considerations. It enables the participants to engage in a continuous learning process that enhance the willingness to collaborate in achieving the desired outcomes or outputs. It also helps to identify process areas that need to be improved and also define the weaknesses where hard systems thinking approaches have been unable to do so.

This research aims at extending the application and effectiveness of SSM when applied to the design process of an organization. It will focus on the application of the SSM methodology to four case studies that are the sub-processes of the design process in the organization. The outcomes are evaluated to identify proposed changes about sub-processes of design process. However, implementation is not within the scope of this research study.

1.2 Purpose Statement and Research Questions

The purpose of this study is to identify the proposed changes to improve design process and its sub-processes in an organization. The study determines how are the means of optimizing change in organization’s design process and its sub-processes, using a soft systems approach and how these changes can be defined using Soft Systems

Methodology. Basically, the study aimed to build rich pictures of design sub-process using gathered data with semi-structured interviews, define root statements, build conceptual models and compare the real world activities with conceptual models in pursuant to SSM's seven stages.

This study also aims to establish sustainable communication and interactive evaluation with employees, process owners and managers which would assess the value of any changes and what are their opinions about the methodology, its applicability for other processes in the organization. Semi-structured interviews are performed to collect the data about defining the existing design process and its sub-processes. This analysis provide a deeper understanding of the existing situation about problematic cases and subsequently applying the different stages of SSM enables to generate proposed changes for an improved design process. However, achievement of these changes is outside the scope of this study.

1.3 Significance of the Study

This study is important in two directions. Firstly, design process improvement (PI) will be possible not only guidance of standardization organizations but also some theoretical approaches with low cost. Secondly, SSM will be a preferable and usable methodology for an organization and its use from time to time will enable the continuously improvement (CI) for the existing processes.

Most organizations usually invest in increasing their product's quality for getting a place in business sector and PI is an effective way for it. There are many PI methodologies in the literature (refer 2.1.3). The right selection from existing methodologies depends on various considerations such as technical, organizational, managerial, human factors, cultural factors and so on. It can be assumed that the processes are defined accurately in an organization (refer 2.1.2). But generally, most organizations prefer using the standardization organizations for process improvement. The main reason of this choice can be named as either getting a certification or improving organizations' own processes. But return of investment for PI is still doubtful because the organizations are generally concentrated to obtain a certification. PI has been identified as a primary source of innovation in small or large sized manufacturing firms (Terziovski, M, 2010) and therefore continues to have strong relevance for organizations seeking to develop. Increasing the awareness of PI in the organizations is critical for the products' quality and will help to get competitive advantages and cost savings.

According to SSM, focusing on real problems of the real world by considering human situations, cultural considerations and ill-structured situational problems is possible. This methodology enables breaking the problems into smaller and smaller components and this provides that the problematic cases can be investigated and analyzed individually. But, there are not many studies about improvement of design processes in the literature of SSM applications. Giving attention to the role of process review provides to identify and pursue operational PI and it enables CI in the organization during a long time periods. In this study, design process will be analyzed due to nature of SSM. Moreover, the semi-structured interviews will help to look at problematic situations by considering many parameters directly or indirectly related with the design process.

1.4 Structure of the Thesis

The study is organized in five (5) main chapters. Chapter 1 presents introduction, purpose of the study, significance of the study and structure of the thesis. Chapter 2 reviews literature on process improvements in the organizations, systems thinking, Soft Systems Methodology (SSM) and SSM in design process improvement to present the theoretical underpinnings of the research. Chapter 3 presents the research methodology for investigating the design processes in an organization along research philosophies, the methods for data collection and data analysis, issues inherent in design choices such as trustworthiness and triangulation, and ethical considerations. Chapter 4 provides an explanation of how the SSM is applied in study based on its seven stages. Finally, Chapter 5 presents the discussion of the research findings, contribution to learning, limitations and constraints, practical implications and future research. Figure 1.3.1 offers a visual depiction of the thesis structure.

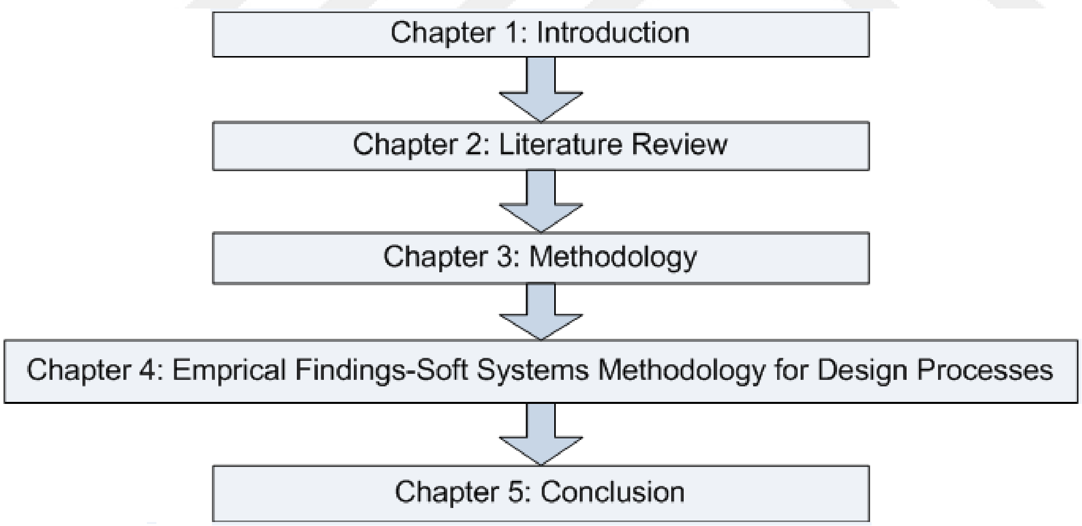

Figure 1.4.1: Structure of the Thesis

CHAPTER 2

LITERATURE REVIEW

2.1 Process Improvement in the Organizations

The majority of development organizations all over the world define their processes and improving their processes and working methods are crucial for their business (Mishra, D. & Mishra, A., 2009). A process can be defined as an environment of capable interrelated resources managing a sequence of activities using appropriate methods and practices to develop a product that conforms to customer's requirements (Zeineddine, R., Mansour, N., 2005). Processes have an important role for organizations to coordinate different teams. Process improvement (PI) is an effective way for such organizations to improve the quality of their products. PI is a long-term approach to improving organizational performance with substantially less risks of destroying value when compared to short-term approaches. The successful implementation of PI models to the organizations can be highly cost because of operating on limited resources and with strict time constraints.

Research on PI in the organizations has focused principally on the refinement of existing processes to improve what is currently done (Wolff, J.A. and Pett, T.L., 2006, Terziovski, M., 2010) though the application of previously developed tools and techniques presenting the benefits firms are able to realize from them (Anthony et al.2005, Lo and Chang 2007). The usage of PI methods to improve process performance is performed using objective process data, but this give limited attention to the sustainability of improvements over time (Matthews, R. L., et al. 2017). The sustainability of PI efforts was taken as a focus of the work by Bateman (2005) who identified key inhibitors and enablers in realizing benefits from PI activities and sustaining improvement activities over time (Bateman, N., 2005).

PI encompass a spectrum of activities, methods and approaches that seek to improve the effectiveness and efficiency of business process over time and ensure the alignment of business processes with the competitive environment (Matthews, R. L., et al. 2017). Research is needed to examine improvement practices in the organizations and how much practices relate to organizational level change (Chaston, I., et al. 2001), in particular to understand how the organizations can learn through PI (Amundson, S. D., 1998). Focusing on Continuous Improvement (CI) and giving attention to the role of process review provide initiating points to identify and pursue operational PI (Jørgensen, F. et al. 2003). To explore how improvement activities can be sustained and become embedded in organizations, Jørgensen et al. (2003) examined the role of human resource practices to promote the engagement of operational staff and achieve CI. They illustrated how human resource infrastructure could formalize improvement practitioner roles, helping to embed improvement behaviors at an organizational level (Matthews et al.2017). Barton and Delbridge (2004) discussed how human resource practices could promote development at an individual level, which could create a competitive advantage. They also highlighted how individuals needed support in order for them to contribute to CI behaviors, due to discretionary effort acting as a potential inhibitor of CI efforts (Matthews et al.2017). The key enablers to sustain PI and achieve CI are the support and involvement of management, improvement goals, measures and being provided with sufficient resources (Lee et al.2000). The personnel dedicated to PI activities promoted the sustainability of PI (Bateman, 2005). Also revising the improvement systems has importance for improving the existing processes to align with the external environment. Zangwill and Kantor (1998) noted how benefits from improvement activities could reduce over time as inefficiencies were removed from processes.

2.1.1 Engineering Design Processes in Literature

In the literature, there have been many defined models for engineering design/development processes representing it for different purposes. These models have been developed to understand, apply, improve and support the design processes. Also, there are some differences between defined models in point of focus and formulation.

In the domain of engineering design, it would appear that leading authors categorize design into similar sections using the terms, the design problem, the design process, the design types (output), the design activity and the design organization/team. Understanding of the design process has an importance for managing the design activity and aiding the improvement of products and the overall efficiency (Howard, T.J., et al. 2008). The improvement of the product and its development process is resulted with quality of the product (Howard, T.J., et al. 2008).

In engineering design, Morris Asimov was the initial author who discussed morphology and developed seven-phase linear chronological structure. The three phases of the developed in seven-phase linear chronological structure are related with design process and they are called as ‘feasibility study’, ‘preliminary design’ and ‘detailed design’. The other four phases of the developed seven-phase linear chronological structure is related with production and consumption cycle phases. The figure of Asimov’s design methodology is given on Figure 2.1.1.1.

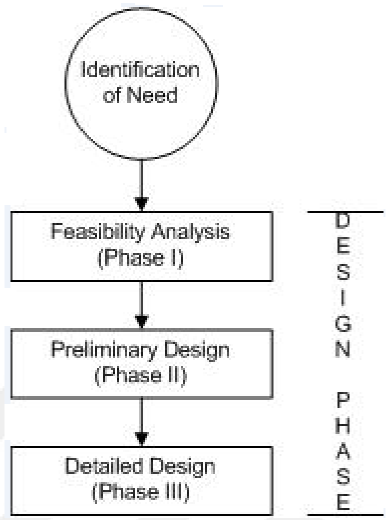

Figure 2.1.1.1: Three phases of Asimov’s model. [Adapted from (Asimov1962, p.12)]

The purposes of the Asimov’s design phases are defined as follow (Adams, K.M., 2015);

- Feasibility study: “to achieve a set of useful solutions to the design problem” (Asimov, M., 1962, p.12).
- Preliminary design: “to establish which of the preferred alternatives the best design concept is” (Asimov, M., 1962, p.13).
- Detailed design: “to furnish the engineering description of a tested and producible design” (Asimov, M., 1962, p.13).

Nigel Cross’ eight stage model is the unique model until 1984 about enabling to broke larger problems into sub- problems and then synthesize the sub-solutions to get total solution (Cross, N., 2008). Mainly, this model based on solving the design problems and uses a feedback mechanism between problem and its solution. The figure of eight stage model is given on Figure 2.1.1.2. The Objectives, Functions, Requirements and Opportunities (left hand side) stages enable to generate, evaluate and provide improvements to alternatives. The Improvement, Evaluation, Alternatives and Characteristics (right hand side) stages provide the feedback to left hand side.

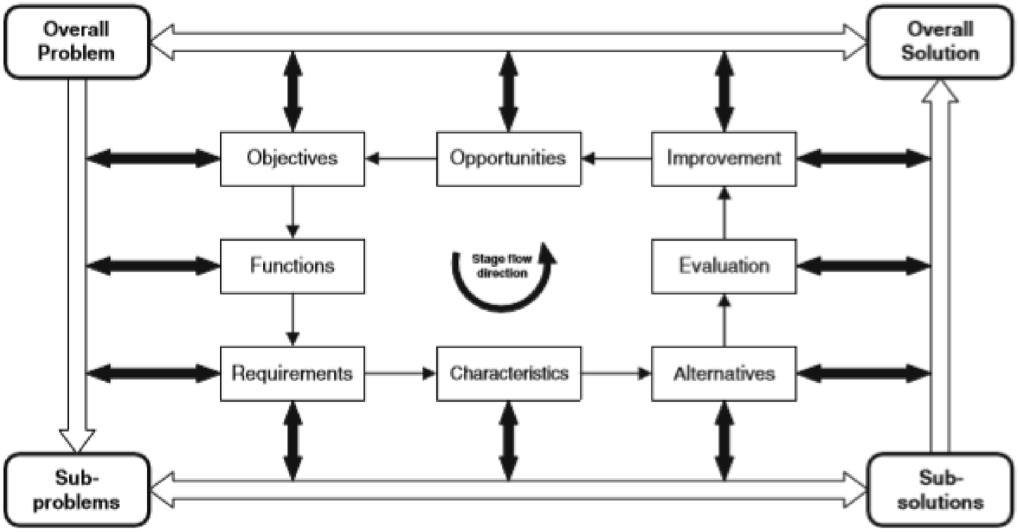

Figure 2.1.1.2: Nigel Cross' eight stages model (Cross, N., 2008, p.57)

Until Pugh's studies about design processes, most engineers focused on technical phases of the design and rarely participated in the development process. Pugh used a transdisciplinary approach for his Total Design method that was derived from consideration of technical and non-technical factors. Total Design Method named as also Total Design Activity Model contains four parts and each part also contains its own phases. The first part defines the main design core that includes six phases. These phases are respectively named as 'user need', 'product specification', 'conceptual design', 'detail design', 'manufacture' and 'sales'. The second part is the Product Design Specification (PDS) and it contains major elements like 'Customer', 'Processes', 'Size', 'Performance', 'Testing', 'Environment', 'Quality' (and list is going on) that are required to design, manufacture and sell of the product. The third part is the inputs of discipline independent methods. The final part contains the inputs from technology and discipline specific sources (Pugh, S., 1991).

In the literature, many different design processes are generated and defined. These processes and their differences/similarities between the phases they include are examined as covering the information produced until 2006 and given on Table 2.1.1.1. The column headings of the table (Table 2.1.1.1) are derived from terminologies that are generally used by design authors. The headings of the column correspond the four major design phases that are called as analysis of task, conceptual design, primary design (embodiment design) and detailed design. The design phase is driven with 'Establishing a Need' (Howard, T.J., et al. 2008) and then the following four major phases are implemented. After completion of the major four design phases, the design process is ended with 'implementation phase' which includes the completion of final engineering drawings and instructions. The design phases that are defined on the literature can be thought that nearly all processes were defined for a market driven process not a technology driven process except from few exceptions (Urban, G.L. and Hauser, J.R., 1993). These four major design phases are called also as linear model in the literature and this model is poor for improving the defined design phases.

Gerhard Pahl, Wolfgang Beitz, Jörg Feldhusen and Karl-Heinrich Grote propose a model that contains four main phases. The phases have been named as respectively planning and task clarification, conceptual design, embodiment design and detailed design (Pahl G. et al.2011). The figure does not warrant a figure but the definition of phases are defined as:

- *Planning and Task Clarification* is defined as "is to collect information about the requirements that have to be fulfilled by the product and also about the existing constraints and their importance" (Pahl G. et al. 2011, p. 131).

- *Conceptual Design* is defined as "This is achieved by abstracting the essential problems, establishing function structures, searching for suitable working principles and then combining those principles into a working structure" (Pahl G. et al. 2011, p. 131). The purpose of this phase is to determine the principle solution.

- *Embodiment Design* is defined as "determine the construction structure (overall layout) of a technical system in line with technical and economic criteria. Embodiment design results in the specification of a layout" (Pahl G. et al. 2011, p. 132).

- *Detailed Design* is defined as "the arrangement, forms, dimensions, and surface properties of all the individual parts are finally laid down, the materials specified, production possibilities assessed, costs estimated, and all the drawings and other production documents produced. The detailed design phase results in the specification of information in the form of production documentation (Pahl G. et al. 2011, p. 132).

Adams and Keating have developed a design methodology named as Axiomatic Design Methodology (ADM) that has ability to not only satisfy technical processes but also invoke some specific axioms of systems theory in order to develop quantitative measures for evaluating systems design (Adams, K. M., 2015). This methodology includes nine critical attributes labeled as transportable, theoretical and philosophical grounding, guide to action, significance, consistency, adaptable, neutrality, multiple utility, rigorous and also four domains named as respectively customer domain, functional domain, physical domain and process domain (Adams K.M. and Keating C.B., 2011). The four domains of the design world according to Adams and Keating are shown on Figure 2.1.1.3.

Table 2.1.1.1: The Comparison of Engineering Design Process Models (Howard T.J. et al., 2008, p.163)

Models	Establishing a need phase	Analysis of task phase	Conceptual design phase	Embodiment design phase	Detailed design phase	Implementation phase
Booz et al. (1967)	X	New product strategy development	Idea generation / Screening & evaluation	Business analysis / Development	Testing	Commercialisation
Archer (1968)	X	Programming / data collection	Analysis / Synthesis	Development	Communication	X
Svensson (1974)	Need	X	Concepts	Verification / Decisions	X	Manufacture
Wilson (1980)	Societal need	Recognize & formalize / FR's & constraints	Ideate and create	Analyze and/or test	Product, prototype, process	X
Urban and Hauser (1980)	Opportunity identification	Design		Testing		Introduction (launch) / Life cycle management
VDI-2222 (1982)	X	Planning	Conceptual design	Embodiment design	Detail design	X
Hubka and Eder (1982)	X	X	Conceptual design	Lay-out design	Detail design	X
Crawford (1984)	X	Strategic planning	Concept generation	Pre-technical evaluation	Technical development	Commercialisation
Pahl and Beitz (1984)	Task	Clarification of task	Conceptual design	Embodiment design	Detailed design	X
French (1985)	Need	Analysis of problem	Conceptual design	Embodiment of schemes	Detailing	X
Ray (1985)	Recognise problem	Exploration of problem / Define problem	Search for alternative proposals	Predict outcome / Test for feasible alternatives	Judge feasible alternatives / Specify solution	Implement
Cooper (1986)	Ideation	Preliminary investigation	Detailed investigation	Development / Testing & Validation	X	Full production & market launch
Andreasen and Hein (1987)	Recognition of need	Investigation of need	Product principle	Product design	Production preparation	Execution
Pugh (1991)	Market	Specification	Concept design		Detail design	Manufacture / Sell
Hales (1993)	Idea, need, proposal, brief	Task clarification	Conceptual design	Embodiment design	Detail design	X
Baxter (1995)	Assess innovation opportunity	Possible products	Possible concepts	Possible embodiments	Possible details	New product
Ulrich and Eppinger (1995)	X	Strategic planning	Concept development	System-level design	Detail design	Testing & refinement / Production ramp-up
Ullman (1997)	Identify needs / Plan for the design process	Develop engineering specifications	Develop concept	Develop product		X
BS7000 (1997)	Concept	Feasibility	Implementation (or realisation)			Termination
Black (1999)	Brief/concept	Review of 'state of the art'	Synthesis / Inspiration	Experimentation / Analysis / reflect	Synthesis / Decisions to constraints	Output / X
Cross (2000)	X	Exploration	Generation	Evaluation	Communication	X
Design Council (2006)	Discover	Define	Develop	Deliver		X
Industrial Innovation Process 2006	Mission statement	Market research	Ideas phase	Concept phase	Feasibility Phase	Pre production

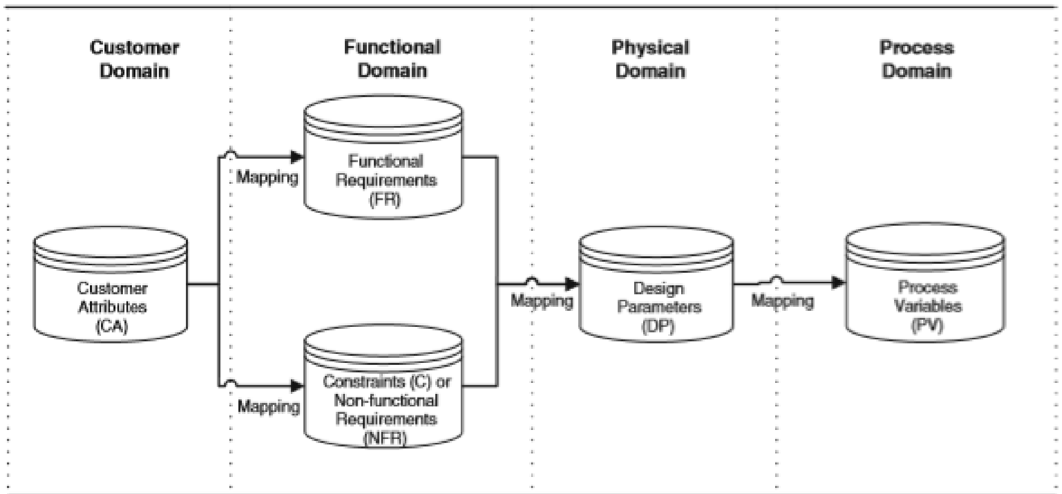

Figure 2.1.1.3: Four domains of design world (Adams, K.M., 2015, p.39)

Process models and modeling approaches have been created to address many different cases in design/development phases of a project. The design processes have been examined and evaluated in point of many different aspects' view. It is seen that each model in the literature emphasizes different elements with offering different terminology.

2.1.2 Process Improvement Methodologies

Improving the quality of process and maintaining acceptable levels of performance quality are critical for the success of any organization. There are many competing methodologies for process improvement that are mainly labeled as Total Quality Management(TQM), Kaizen Methodology, Lean Thinking, Six Sigma Methodology, Plan-Do-Check-Act (PDCA) Methodology, Benchmarking Methodology, Super Methodology and Model-Based Integrated Process Improvement Methodology (MIPI). While evaluating improvement methodologies, implementation needs and limitations of organizations are also taken into account. Therefore, it is important that which type of methodology should be best implemented in which type of organization under what circumstances (Gershon, M., 2010).

TQM methodology has an important place for customer, process and defect reduction (Radnor, Z. J., 2010). It supports improvement ownership, team working and obligation based on the basis of continuous improvement (Rashid O. A. and Ahmad, M. N., 2013). It focuses on four major areas that are based on Deming's 14 points (Neave, H. R., 1987) and these four phases are named as process selection, preparation for improvement, process analysis and redesign and implementation and improvement (Rashid, O. A. and Ahmad, M. N., 2013).

Six Sigma methodology is a newer process improvement methodology than TQM. It is defined as an “application of scientific management methods, but it actually integrates many different creative, technical, and change management methods, tools, and techniques to improve business processes” (Hayler, R. and Nichols, M. D., 2007 p.5) and has been a powerful approach to achieve business process improvements in both manufacturing and more recently service and transactional industries (Hayler, R. and Nichols, M. D., 2007, p. 5). It provides some advantages for aiming the maximization of customer satisfaction, earning customer loyalty, improving profitability, improving employee job satisfaction and market position of the organization (Antony, J.,et al., 2005) On the other hand, it has some disadvantages because of requiring process variation for highest level of quality. This is mentioned as “Six Sigma is, basically, a process quality goal, where sigma is a statistical measure of variability in a process” (Pyzdek, T., 2003, p. 59). Six Sigma methodology has five phases named as following ‘Define’, ‘Measure’, ‘Analyze’, ‘Improve’ and ‘Control’(Rashid O. A. and Ahmad, M. N., 2013). It can be often combined with lean manufacturing to produce a methodology called as Lean Six Sigma. Lean can decrease waste and enhance the efficiency of process because of decreasing variation and improving performance by using Six Sigma.

Lean Thinking has been developed with time after it had originated in Toyota Company. It is used as a substitution to the conventional way of mass production and batching principles for high efficacy, speed, cost and quality (Rashid, O. A. and Ahmad, M. N., 2013). It has five phases labeled as sort, straighten, scrub, systematize and Sustain (Valencia, S., 2006). This methodology is one of the significant improvement methodologies that can be applied for manufacturing and service industries (Buavaraporn, N., 2010).

Plan-Do-Check-Act (PDCA) methodology is used for CI with specifying differences between actual result and a certain target when variance is significant (Sokovic, M., et al., 2010). It consists of four phases called as ‘plan’, ‘do’, ‘check’ and ‘act’. It is generally used for quality policies deployment and development because of combining accurate planning with small potions doing and measuring the most effective method by using feedback (N/D., 1995).

Kaizen methodology is derived by Japanese after Second World War and so it was implemented first by Japanese industries. It based on performing small improvements in large numbers with involvement of all employees on a continuous basis which leads to also improve the relationship between managers and employees (Grecu D., 2010). It uses the same cycle with PCDA and it aims continuous improvement and generation more value and less waste. It is accepted as the best methodology about improving performance within companies due to minimal costs of implementation (Grecu D., et al., 2010).

Benchmarking methodology comprises continuously the organization’s strategy, products, and processes with the successful organizations and then adapts their practices and ideas (Dragolea, L. and Cotirlea, D., 2009). This methodology can be performed within organizations called as internal benchmarking and/or with other organizations called as external benchmarking. Benchmarking methodology includes five phases labeled as following ‘planning’, ‘analysis’, ‘integration’, ‘actions’ and ‘maturity’ (Rashid, O. A. and Ahmad, M. N., 2013). It is usually preferred to gain competitive advantages in marketplace. It has advantages about saving cost in performing operations and supporting the budgeting, strategic planning and capital planning for organizations (Elmuti, D. and Kathawala, Y., 1997).

Super Methodology is a combination of the approaches about continuous process improvement (CPI), business process re-engineering and benchmarking and Lee and Chush stated that this methodology can make significant improvements for organizations (Lee, K. T. and Chuah, K. B., 2000) This methodology contains five phases named as respectively ‘process selection’, ‘process understand’, ‘continue the process of measurement’, ‘process improvement executing’ and ‘improved process reviewing’ (Rashid, O. A. and Ahmad, M. N., 2013).

Model-Based Integrated Process Improvement Methodology (MIPI) can be used for process improvement and re-engineering. MIPI focuses on seven phases labeled as respectively ‘business needs understanding’, ‘process understanding’, ‘process modeling and analyzing’, ‘process redesigning’, ‘new process implementation’, ‘new process and methodology assessment’ and ‘new process reviewing’ (Rashid, O. A. and Ahmad, M. N., 2013). This methodology enables organizations to select the problem that is the main barrier for achieving company vision and mission (Thangthong, E. and Ngaoprasertwong, J., 2013) by including a hierarchical structure comprising like aim, actions, people involved, outcomes, checklists relevant tools and techniques.

Different methodologies are available for process improvement and each of them has also either strengths or weaknesses. Choosing the most appropriate methodology has the most significant matter for the organizations. The right selection from exist methodologies should depend on various considerations such as technical, organizational etc. The selected methodology should not provide the desired outputs/outcomes for organization because there is need for merging or modifying with other methodologies. It can be said that it is possible to develop new methodologies by modifying of any methodology or integrating of several methodologies to ensure the business proves improvement for any organization (Rashid, O. A. and Ahmad, M. N., 2013).

2.2 Systems Thinking

The Systems Thinking term has been defined and redefined in many ways with time since it was defined by Barry Richmond in 1987. A system is defined as a regularly interacting or independent group of items forming a unified whole in the Merriam-Webster dictionary (Merriam Webster, 2017). Basically a system can be defined as collection of its parts. Systems thinking contains three kinds of things labeled as ‘elements’, ‘interconnections’ and ‘a function or purpose’ (Meadows, D. H., 2008). The function or purpose part of the system is the most critical determinant and parameter for system’s behavior.

The definition of the system is adopted with time and also its environment is modified by adding communication and control processes. There are four core processes in systems thinking labeled as communication process, control process, a layered structure and emergent properties (Checkland, P. and Poulter, J., 2006).

There is a requirement for a complete systems thinking definition. This requirement is containing all three kinds of things named as elements, interconnections, and a goal or function.

There are many definitions for systems thinking in the literature. First definition is derived by Barry Richmond as ‘the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure’ (Richmond, B., 1994). This definition is useful but is not enough for explaining the interconnections between the elements of systems thinking.

The other definition is formed by Peter Senge as ‘a discipline for seeing wholes and a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots’ (Senge, P., 1994). This definition describes some critical elements of systems thinking but it does not provide a purpose for system thinking. Also it does not address the interconnections between elements like Barry Richmond’s definition.

Linda Sweeney and John Sterman formed systems thinking definition as the art of systems thinking involves the ability to represent and assess dynamic complexity, both textually and graphically (Sweeney, L. B., & Sterman, J., 2000) and they list systems thinking skills as including the ability to (Arnold, R. D., and Wade, J., 2015);

> *“1. Understand how the behavior of a system arises from the interaction of its agents over time (i.e., dynamic complexity);*
>
> *2. Discover and represent feedback processes (both positive and negative) hypothesized to underlie observed patterns of system behavior;*
>
> *3. Identify stock and flow relationships;*
>
> *4. Recognize delays and understand their impact;*
>
> *5. Identify nonlinearities;*
>
> *6. Recognize and challenge the boundaries of mental (and formal) models.”*

This definition does not address interconnections between elements and is not enough for capturing the overall nature of systems thinking (Arnold, R. D., and Wade, J., 2015).

The other definition for systems thinking was derived by Magean Hopper and Krystyna Stave with incorporating Sweeney and Sterman's work. They performed an extensive review of systems dynamics literature, listed of Systems Thinking Characteristics based on their findings such as recognizing interconnections, identifying feedback, understanding dyamic behavior, differentiating types of flows and variables, using conceptual models, creating simulation models and testing policies (Stave, K. A., and Hopper, M., 2007). Their definition does not contain the interconnections between elements or a statement of purpose for systems thinking.

Squires, Wade, Dominick, and Gelosh's defined the systems thinking as an ability to think the following things (Squires, A., et al., 2011). This definition is useful for systems thinking approach but it does not cover whole interconnections between elements.

Jay Forrester's approach (1994) about systems thinking is as"Systems thinking" has no clear definition or usage. ... Some use systems thinking to mean the same as system dynamics. ... "Systems thinking" is coming to mean little more than thinking about systems, talking about systems, and acknowledging that systems are important. In other words, systems thinking implies a rather general and superficial awareness of systems." (Arnold R. D., and Wade, J., 2015). He is also known as the founder of the system dynamics.

The comparison of Systems Thinking definitions that are derived from the study of Arnold R.D. and Wade J., is summarized on Table 2.2.1 (Arnold R. D., and Wade, J., 2015). When all definitions that are given above are considered, it can be said that common elements tend to include interconnections, the understanding of dynamic behavior, systems structure as a cause of that behavior, and the idea of seeing systems as wholes rather than parts (Arnold R. D., and Wade, J., 2015).

Table 2.2.1: The Comparison of Systems Thinking Definitions (Arnold, R. D. and Wade, J., 2015)

Authors / **Definitions**	**Richmond**	**Senge**	**Rouse**	**Sweeney and Sterman**	**Hooper and Stave**	**Kopainsky, Alessi and Davidson**	**Squires, Wade, Dominick and Gelosh**	**Forrester**
Wholes rather than parts	X	X	X		X			
Dynamic behaviour	X			X	X		X	
Systems as the cause of its behaviour	X			X	X			
Interconnections/Interreleationships		X	X		X		X	
Stock and flow relationship				X	X			
Acknowledging that systems are important								X
Delays				X				
Non-linear relationships				X		X		
Feedback loops	X			X	X	X		
Systems structure generates behaviour	X				X			

2.2.1. Hard and Soft Systems Thinking

Systems thinking is divided into two segments that are labeled as ‘hard systems thinking’ and ‘soft systems thinking’. The hard systems thinking is mainly related with well-defined technical problems while the soft systems thinking is concerned in fuzzy ill-defined situations involving human beings and cultural considerations (Checkland, P., 2000). The differences between hard systems thinking and soft systems thinking are given on Figure 2.2.1.1.

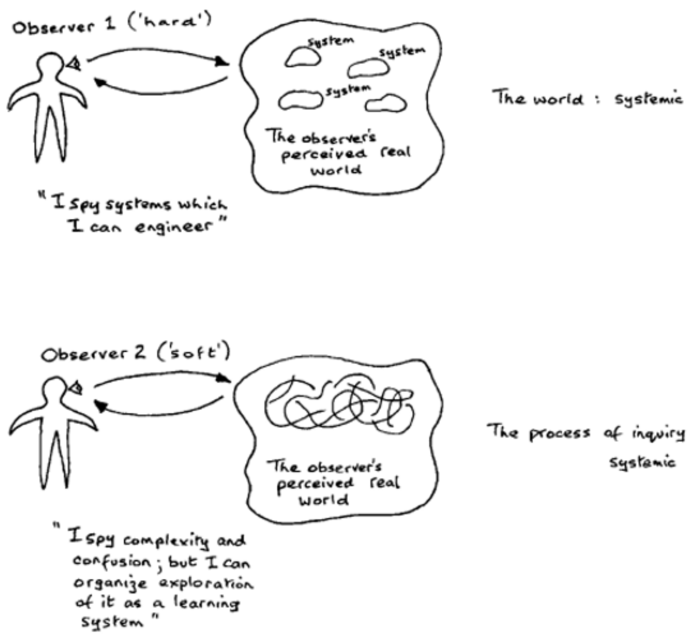

Figure 2.2.1.1: The Hard and Soft Systems Stances (Checkland, P., 2000, p.S18)

Generally, the difference between hard systems thinking and soft systems thinking are described as follows;

“Hard systems thinking assumes that the perceived world contains “holons (Checkland, P., 2000, p. S48)” (as an alternative name to “system” for the concept of whole) and tackles well-defined problems. On the other hand, soft systems thinking takes the stance that the methodology (enquiry process), can itself be created as a holon (Checkland, P., 2000, p. S32). Thus soft systems thinkers adopt soft systems methodologies to address ill-structured, messy, problem situations (Checkland, P., 2000, p. S48, S32).” (Zhang, B. Q., 2011).

2.3. Soft SystemsMethodology (SSM)

There are many different information systems development methodologies but more or less of them are focused on technical approaches that ignore other important social and cultural factors (Memon, S., 2011). Technology-centered methodologies are not enough in real world problem situations especially when the relevant situation is messy and ill structured or when political and cultural factors are prevalent in the organization (Zhou, H., 2011). The reason of the most information systems fail is related with lack of involvement of the social, cultural and political factors and more focusing on the technical side by ignoring real problems of the real world (Memon, S., 2011). There are some considerations about other necessary organizational factors for information system development. In literature, the satisfactoriness of Soft Systems Methodology (SSM) is defined as a reaction to these perceived inadequacies, soft system methodology (SSM) is identified as a valuable candidate for IS analysis methodology (Zhou, H., 2011).

It can be thought that SSM is an action-oriented approach that deals with such phenomena with the intention to improve the situation in 'messy' and 'ill-structured problems' (Memon, S., 2011).). It can be applied in any field with maximum use in the field of information systems (Checkland, P. and Poulter, J., 2006).

Soft Systems Methodology (SSM) was developed by Peter Checkland and his colleagues at 1970s while applying Systems Engineering approaches to solve '-management/business problem (Checkland, P. and Holwell, S., 1998). This problem is defined as failure of hard systems engineering approach in messy management problem situations (Checkland, P., and Scholes, J., 1990) and then it is called as a 'holistic systematic approach'. This methodology focuses on mainly human beings involvement, human situations, cultural considerations and ill-structured situational problems by looking into the system from managerial point of view instead of focusing on technical side (Checkland, P. and Holwell, S., 1998).

SSM is also a problem solving tool except being a methodology. It is used to break a large phenomenon/problem into smaller and smaller components to investigate them individually (Memon, S., 2011). This can be used mainly for information management, information strategy and business analysis that will be concluded as process improvement or defining lacks of existing processes. There are seven stages in the methodology and these activities/stages are categorized according to their labels. Some activities are placed under 'real world' side and the others are in systems thinking side.

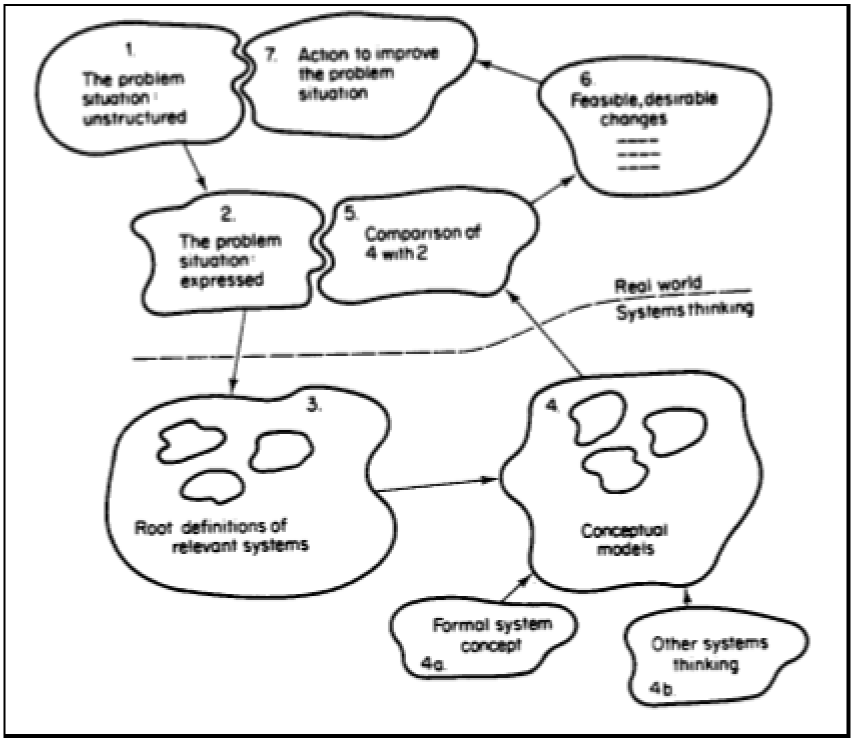

Figure 2.3.1: The Soft Systems Methodology (Checkland, P. and Wiley, J., 1981, p.163)

There are seven stages in SSM (see Figure 2.3.1) but four activities of them define whole picture of SSM. These can be defined as finding out about a problem situation, including culturally/politically, formulating relevant purposeful activity models, debating the situations using models and taking action for problematic situations (Checkland, P., 2000).

This methodology is not just only a process; it also enables developing some tools to help users carry out the SSM steps. These tools are Rich Picture, Root Definition, Conceptual Model, and CATWOE. The details about tools are given at related steps of SSM.

The description of SSM is updated in the book by Checkland and Scholes [1990] as “several hundred applications of the approach by a wide range of people and groups in many different countries" and "SSM is no longer perceived as a seven-stage problem-solving methodology" but "is now seen as one option in a more general approach” (Checkland, P., and Scholes, J., 1990, p.29).

SSM is described with two streams enquiries that are the stream of logic-based enquiry and the stream of cultural enquiry that is given on Figure 2.3.2.

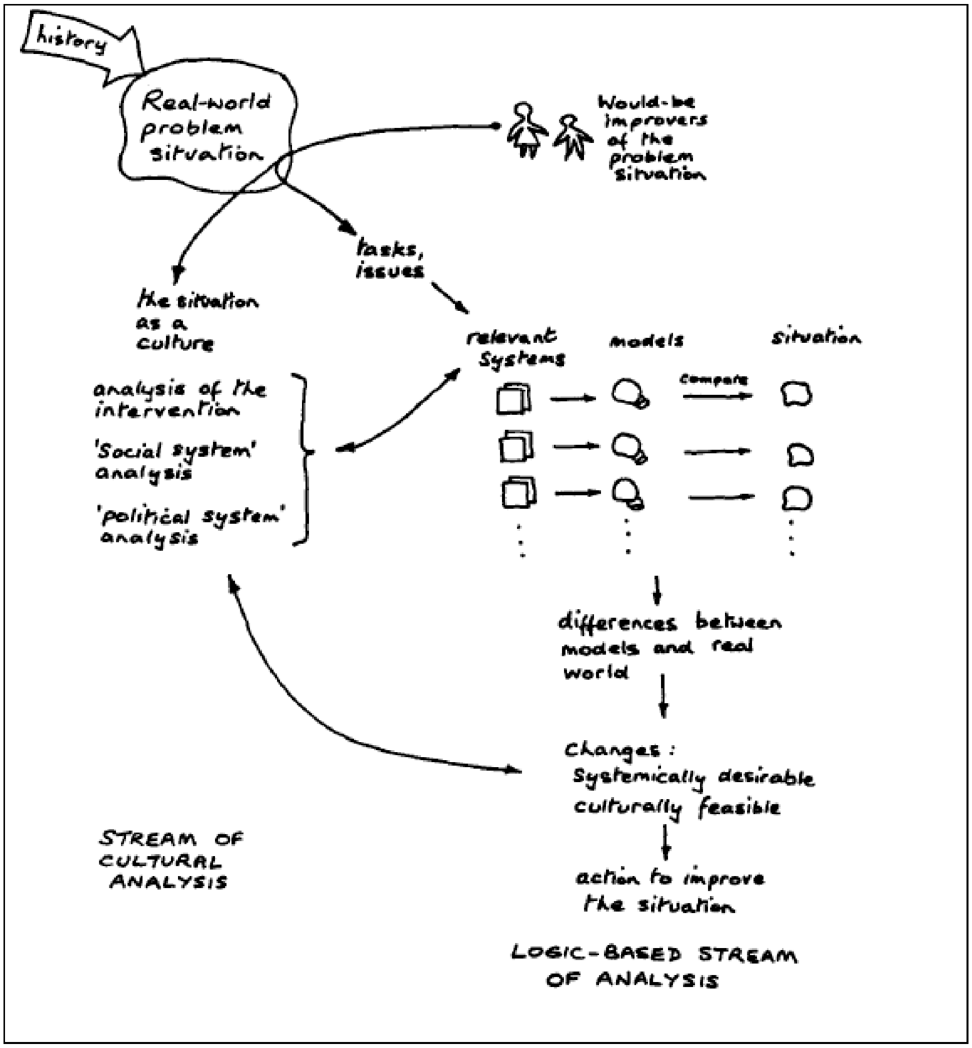

Figure 2.3.2: Stream of Cultural Analysis-Logic Based Atream of Analysis (Checkland, P., and Scholes, J., 1990, p.29)

The stream of logic-based enquiry is formed as adopting 2 levels to core system describing the transformation process additionally standard 7 stages of SSM. A sample conceptual model from Checkland (1990) is given in Figure 2.3.3. The sample was built in accordance to “A householder-owned and manned system to paint a garden fence, by conventional hand painting, in keeping with the overall decoration scheme of the property, in order to enhance the visual appearance of the property” (Checkland, P., and Scholes, J., 1990, p.36)

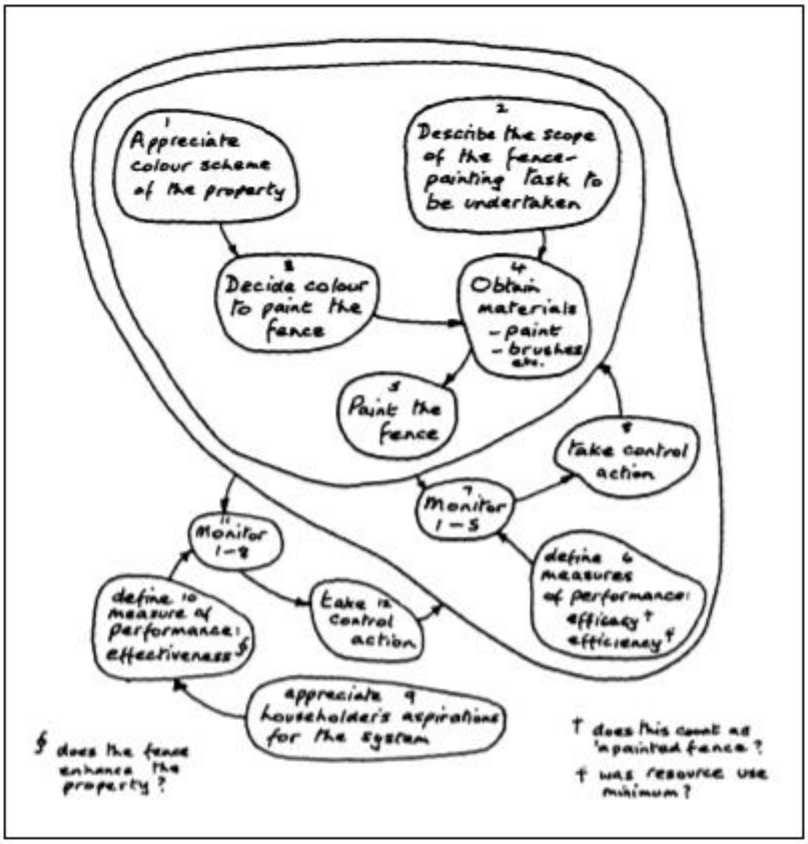

Figure 2.3.3: Sample Conceptual Model (Checkland, P., and Scholes, J., 1990, p.40)

The core system that includes the activities from 1 to 5, describes the transformation process. The first level covers activities seven and eight. The second level enhances the whole transformation process.

The three E's criteria is defined by Checkland (1990) as efficacy (for 'does the means work?'), efficiency (for 'amount of output divided by amount of resources used') and effectiveness (for 'is T [transformation process] meeting the longer term aim?')" (Checkland, P., and Scholes, J., 1990, p.40). For model building, CATWOE and three E's are the basic standard technique used to draw them.

The stream of cultural enquiry is mainly based on three analyses. Analysis one includes three roles labeled as client, would-be problem solver and problem owner. It is mentioned in Checkland (1990) as "This role analysis, now known as 'Analysis One' in SSM, is always relatively easy to do and is very productive, especially through the list of possible problem owners [...] this list [including problem owners and client] is the best source of choices of relevant systems in the logic-driven stream of enquiry" [...] How to use models deriving via relevant systems from these systems from the choices of problem owner would depend upon who was undertaken the study and who caused it to occur: the client" (Checkland, P., and Scholes, J., 1990., p.48; Simonsen, J., 1994).

Analysis two is labeled as Social System Analysis' that supports a simple model of social systems. This social system includes three elements that are named as Roles, Norms and Values. It is mentioned in Checkland (1990) as follows; "By 'role' is meant a social position recognized as significant by people in the problem situation [...] A role is characterized by expected behaviors in it, or norms. Finally, actual performance in a role will be judged according to local standards, or values. These are beliefs about what is humanly 'good' or 'bad' performance by role holders." (Checkland, P., and Scholes, J., 1990 p.49; Simonsen, J., 1994).

Analysis three is labeled as Political System Analysis and It is mentioned in Checkland book (1990) as follows; "[...] politics is taken to be a process by which different interests reach accommodation [...] the accommodations which are generated, modified or dissolved by politics will ultimately rest on dispositions of power. So politics is taken to be power-related activity concerned with managing relations between different interests. In Analysis Three, political analysis is made practical by asking how power is expressed in the situation studied [...] we ask: What are the 'commodities' (meaning the embodiments) through which power is expressed in this situation? How are these commodities obtained, used, protected, preserved, passed on, relinquished? Through which mechanisms? [...] Examples [of commodities] include: formal (role-based) authority, intellectual authority, personal charisma, external reputation, commanding access (or lack of access) to important information, membership or non-membership of various committees or less formal groups, the authority to write the minutes of meetings, etc." (Checkland, P., and Scholes, J., 1990, p.50; Simonsen, J., 1994).

The seven stages of standard SSM are explained in the following parts of the content.

2.3.1. Enter Situation Considered Problematic

This step is about gathering of information and views for problematic situations that are concerned with real world and so the most critical stage where whole methodological approach is based to formulate the desirable solution. This step includes basic research activities to obtain information on current performance, issues and processes.

2.3.2. Express the Problem Situation

Recognizing the real world's problematic situations, the second step is concerned with capturing the multiple views. This is labeled as *'Rich Picture'* was developed to define the problematic situations not only words but also diagrams and pictures. The idea behind Rich Picture is considered as allows; differences of interpretation to be identified, permits agreement to be made on the interpretation to be taken and is a source of inspiration as to what relevant systems could be modeled through the assimilation of relationships, issues etc. (Burge, S., 2015). It helps identify themes to take into the systems world and the main purpose of the rich picture is expressing the problematic situation in well and so there is no rule to draw pictures and sketch the situation (Checkland, P., 2000).

2.3.3. Formulate Root Definition od Relevant Systems

A root definition is a small definition of the main objectives of system which tells clearly about new system's purpose. The purpose are asked with 'what system will do', 'how it is to be done', 'why it is being done' as per formula given below (Checkland, P. and Holwell, S., 1998). It is important because of being used to logically deduce what the company will have to do in order meet the definition.

"A system to do X by mean of Y in order to Z
What system will do (X), how it is to be done (Y), and why it is being done (Z)" (Checkland, P. and Holwell, S., 1998).

A mnemonic CATWOE was developed to help ensure that a draft root definition is acceptable. It is the basis to develop comprehensive root definitions. CATWOE is represented as follows;

Table 2.3.3.1: CATWOE Table (Burge, S., 2015).

C	***The Customer:*** The individual(s) who receive the output from the transformation (in recent times it has been recognised that the out of the transformation may be '"negative" for some customers and "positive" others. This has led to a refinement of CATWOE to BATWOVE where the C is broken into Beneficiaries and Victims!"
A	***The Actors***: Those individuals who would DO the activities of the transformation if the system were made real
T	***The Transformation:*** The purposeful activity expressed as a transformation of input to output
W	***Weltanschauung:*** It's a German word that literally means "world view". It is the belief that makes sense of the root definition
O	***Owner:*** the wider system decision maker who is concerned with the performance of the system
E	***Environmental Constraints:*** the key constrains outside the system boundary that are significant to the system

Transformation is mainly related with system's inputs and outputs. Input can be thought as 'an entity which gets changed into the output' not required resources needed for transformation (Burge, S., 2015). "It may be described in terms of its 'state' by describing the elements which comprise it, their current condition, their relationships with external elements which affect the system, and the condition of these external elements. Alternatively we may provide a systems description by regarding a system as an entity which receives some inputs and produces some outputs; the system itself transforms the inputs into the outputs" (Checkland, P. and Wiley, J., 1981, p.169)

2.3.4. Build Conceptual Models

The 'Human Activity Systems (HAS)' is developed because of reflecting the human beings in a real world to a problematic situation and so this system is based on its own 'weltanschaung' that is known also as 'world-view' (Checkland, P., and Scholes, J., 1990)

The conceptual models are developed for purposeful activity of human situations to show that "what is happening within the system" (Zhou, H., 2011). The conceptual model "is simply the structured set of activities which logic requires in a notional system which is to be that defined in the root definition." (Checkland, P. and Wiley, J., 1981, p.170). Conceptual models are derived for better understanding about problematic situation/phenomena and their interdependencies between processes and business functions (Burge, S., 2015). This helps non-technical and technical people understand the problematic case by comparing the real world and conceptual model. While drawing conceptual model, the analyst makes a conceptual model for each root definition and the activities that are placed on conceptual model should start with an imperative or command verb. This was also stated as "The 'technique' of modelling is to assemble the minimum list of verbs covering the activities which are necessary in a system defined in the root definition" (Checkland, P. and Wiley, J., 1981, p.170).

Checkland defined a rule that was derived from George Miller [1970] study (Miller G. A., 1970). This rule mainly based on defining 7±2 activities in conceptual model. The model includes bubbles with arrows that represent the logical relationships.

Stages 4a (see Figure 2.3.1), checks fundamentally the completeness of the conceptual models. S is a 'formal system' if and only if; "S has an on-going purpose or mission, S has a measure of performance, S contains a decision-taking process, S has sub-systems, S has components which interact and shows connectivity, S exists in wider systems and/or environments, S has a boundary, S has resources, S has some continuity, and will recover stability after some degree of disturbance." (Checkland, P. and Wiley, J., 1981, pp.173ff). Stage 4b that is given on Figure 2.3.1, indicates to use other system concepts as a checklist. This is meant to "make use of whatever systems concepts have by then been developed in order obtain further reassurance that the conceptual models are, if not strictly 'valid', at least defensible" (Checkland, P. and Wiley, J., 1981, pp.176f). "Their purpose is only to generate a high quality discussion with concerned participants in the problem situation." (Checkland, P. and Wiley, J., 1981, p. 236)

2.3.5. Compare Conceptual Models with Real World

At this phase, the analysts compare models that are built in phase 4 and phase 2 to determine the desirable feasible changes. This is mentioned by Checkland as; "[...] parts of the problem situation analyzed in stage 2 are examined alongside the conceptual models: this should be done together with concerned participants in the problem situation with the object of generating a debate about possible changes which might be introduced in order to alleviate the problem condition." (Checkland, P. and Wiley, J., 1981, p. 177).

The comparison between two phases is described as a confrontation of 'what's' with 'how's'. There are four different ways of carrying out the confrontation that are defined by Checkland). These are defined as; "Informal discussion, Formal questioning, Scenario writing based on 'operating' the models ("[...] reconstructing a sequence of events in the past [...] and comparing what had happened in producing it with what would have happened if the relevant conceptual models had actually been implemented") and trying to model the real world in the same structure as the conceptual models (and hence compare)" (Checkland, P. and Wiley, J., 1981, pp. 178f).

2.3.6. Define Proposed Changes

After comparison of the real world and conceptual model, systematically desirable and culturally feasible changes are defined to improve the situation or process or phenomena. This was defined by Checkland as follows;

"[The defined changes] must be arguably systemically desirable as a result of the insight gained from selection of root definitions and conceptual model building, and they must also be culturally feasible given the characteristics of the situation, the people in it, their shared experiences and their prejudices." (Checkland, P. and Wiley, J., 1981, p. 177).

2.3.7. Take Actions to Improve the Problem Situation

This step is about taking action to implement the defined process changes or process improvement.

2.4. SSM in Design Process Improvement

The improvement approaches of engineering design processes are mostly based on creativity in design that also enables the innovation for it. Design is an aggregation of many information exchanges between people within and between organizations (Senesc, R. R. and Haymaker, J. R., 2010). The 'person' and 'environment' are clearly important issues to understand and support process improvement.

There are many process improvement methodologies that can be directly applied to engineering process and the details about these methodologies are given in content (refer 2.1.3). For improving engineering design processes, categorizations of the different design outputs are also useful to analyze and construct the tools, methods and techniques. The most of engineering design researchers have identified different design outputs (Howard T.J. et al. 2008).

Normally, problems or problematic cases can be addressed with methodologies with quantitative approaches. Hard systems methodology can be accepted as a deterministic methodology to address the problems or problematic cases that are real and solvable with quantitative approaches (Ghosh S. et al 2016). On the other hand, problems or problematic cases are neither straightforward nor inseparable from the situations in real world. These complex problems cannot be solved with hard systems methodologies.

The inherent inadequacies of hard systems methodologies towards solving real life ‘messy, unstructured, ill-posed and complex’ problems lead to seek for flexible models that are labeled as ‘soft models’ (Ghosh, S. et al. 2016). The SSM is one of these soft models and it is used to solve and analyze the problems or problematic cases for complex and messy situations.

There are many case studies and researches about application of soft systems methodology. These works are mainly concentrated on a whole system not directly project phases like system engineering, project planning etc. Also it can be said that there are many case studies for different business sectors like knowledge management (Maqsood, T. et al. 2009), information management (Moreau, K. A. and Back, W. E., 2000) etc. but there is no enough information in the literature about the application of SSM for engineering design processes.

CHAPTER 3

METHODOLOGY

3.1 Research Philosophies

Epistemology refers to the assumptions about knowledge and how this knowledge is obtained (Myers, M. D., 1997) that can be thought as the relationship between researcher and the reality. There are three types of epistemologies that are labeled as ‘positivist’, ‘interpretive’ and ‘critical’ (Chua, W. F., 1986). Every research study is based on these philosophies whether it is a qualitative research or quantitative research. The details of the research philosophies are given below.

3.1.1 Positivist Research

Positivist research is described as “inclusion of formal propositions, quantifiable measures of variables, hypotesis testing, and the drawing of interferences about a phenomenon from the sample to a stated population” (Rowlands, B., 2003). Positivist research usually tries to test the theory in order to increase the predictive understanding of phenomena (Myers, M. D., 1997).

3.1.2 Interpretive Research

Interpretive research is defined as “knowledge is gained by social constructions such as language, consciousness and shared meanings” (Rowlands, B., 2003). This research does not concern with dependent or independent variables prior to research. It focuses on “the full complexity of human sense making as the situation arises” (Maxwell, B. and Kaplan, J. A., 1994). Fieldwork is accepted as the fundamental basis of interpretive research because of enabling to access to the people, issues, data and observations and the interviews are the most important part of this research (Walsham, G., 2006).

3.1.3 Critical Research

Critical research deals with the oppositions, conflicts and contradictions in contemporary society and helps to eliminate the causes of alienation and domination (Myers, M. D., 1997). This type of research is meant to pick apart any theories or conclusions made about society and culture. Therefore, the researchers carefully analyze and question claims and findings.

3.2 Research Methods

Research method is defined as "a way to systemize observations, describing ways of collecting evidences and indicating the type of tools and techniques to be used during data collection" (Cavaye, A., 1996). The selection of the most appropriate research method is quite relevant to study's field, topic and nature. Research methods are commonly classified as 'qualitative' and 'quantitative' research.

3.2.1 Qualitative Research

The qualitative research covers textual data, words and pictures rather than numbers. The researcher is interested in "where, when, how and under what circumstances behavior comes into being" (Bogdan, R. C. and Bilken, S. K., 2006). Observing tones, gestures, behavior, body language and response time have an importance place for data analyzes. On the other hand, fieldwork and in-depth interviews are important methods of data collection in qualitative research. Data is gathered by observing natural behavior in fieldwork, while data is collected by open ended questionnaires for interviews. Data analyze technique is defined as "data is analyzed inductively which generate theories from bottom-up rather than top-down where it does not set out to prove or disprove hypotheses" (Bogdan, R. C. and Bilken, S. K., 2006).

3.2.2 Quantitative Research

Quantitative research is concerned with numerical data and its analysis that can be considered as the systematic investigation based on scientific methods emphasizing on quantfiable measures or classification of variables (Kothari, C. et al. 2014). The central of the quantitative research study is mainly based on statistics and measurement for systematic empirical investigation of observable phenomena. Quantitative research is generally preferred in social sciences such as psychology, economics, political science vs. because of relating to empirical methods originating in philosophical positivism and statistics.

3.3 Research Design

This research study is focused on the engineering design process improvement based on qualitative research (refer: 3.2.1) and data analysis which can use appropriate interpretive research (refer: 3.1.2) philosophy. This study uses interpretive philosophy because of gathering empirical data from semi-structured interviews that requires interaction with people to collect real facts, observations and understand the real situation (Walsham G.,

2006) and then this gathered data is used to develop an approach for the improvement of engineering design process.

There are some process improvement methodologies that can be also used for engineering design processes but the most of them are not enough in real world problem situations especially when the relevant situation is messy or ill-structured or when political or cultural factors are prevalent in the organization. Soft Systems Methodology is identified as a valuable candidate for such case analysis as a reaction to these perceived inadequacies (Zhou, H., 2011). The studies generally more focus on technical side which ignores the real problems of the real world based on social, cultural and human factors. Soft Systems Methodology (refer: 2.3) is a methodological approach that enables to deal with such messy or ill-structured problems and this methodology tackles these problematic cases with intention to improve existing processes. This is the reason that SSM is preferred for this research study and it suits best to its nature.

3.4 Data Collection

The required data for study is collected from engineering design organization in an organization by applying to semi-structured interviews. Primarily, a meeting was organized to specify the themes of design process and its sub-processes (see Appendix A). In the following periods, the meetings are individually organized to perform semi-structured interviews for the sub-process labeled as requirements management, technical solution, integration, verification and validation (see Appendix B). Semi-structured interviews include the data gathered from personal interviews, face to face meetings, observations and other traditional methods used to examine the department.

In the organization, the engineering design process is defined as having some sub processes and the owner and the practitioners of these sub processes can be changeable from project to project. All working staff about data collection is relevant to either owners of the process or the practitioners of the process. While gathering data about the engineering design process, the meetings are also performed with managers to collect data about management issues.

The aims of interviews and face to face meetings is getting detailed information and observations about definitions of existing processes, the problems or problematic cases faced while applying them and the outputs of the processes when the processes are applied on a project. During interviews and face to face meetings, generally the following topics are examined such as planning the design activities, improving and managing requirements, improvement of product, verification and validation, decision making and integration. In addition to these topics, quality assurance and configuration management activities that can be classified as support activities are examined. Throughout data collection, observations are also gathered and so the confidentiality is provided for participants and they are encouraged to voice their opinions, express their concerns and explain their understanding to the issues being discussed.

In addition to collected data that are mentioned above, the outputs of the sample projects that contains reports, plans, documents, designed product and the non-conformances related with them are used to define problems or problematic cases for engineering design processes.

3.5 Data Analysis

Data analysis in a qualitative research is implemented with data collection, data interpretation and narrative report writing. After getting reliable information from engineering design processes and its sub-processes, sorting information into categories, formulating the information into a meaningful form or model and defining the problematic cases are performed. When themes are determined (see Appendix A), it is realized that some of them are directly related with the job title or responsibilities of employees. While supporting process activities like ‘Audits’, ‘Quality’, ‘Risk (Identification and Categorization)’ are generally expressed by sub-process owners; ‘Effort and Cost Estimation’ and ‘Planning (Engineering Design Process)’ themes are expressed by design team leaders and managers. This shows that some responsibilities reflect the main concerns of these responsibilities. The importance of themes are also evaluated by taking into account this manner.

The data analysis method for this research follows the process of Soft Systems Methodology, (refer: 2.3) and SSM approach and rich pictures are utilized to identify and extract meaning from the participant’s responses. The data collection and analysis approach is shown on Figure 3.5.1.

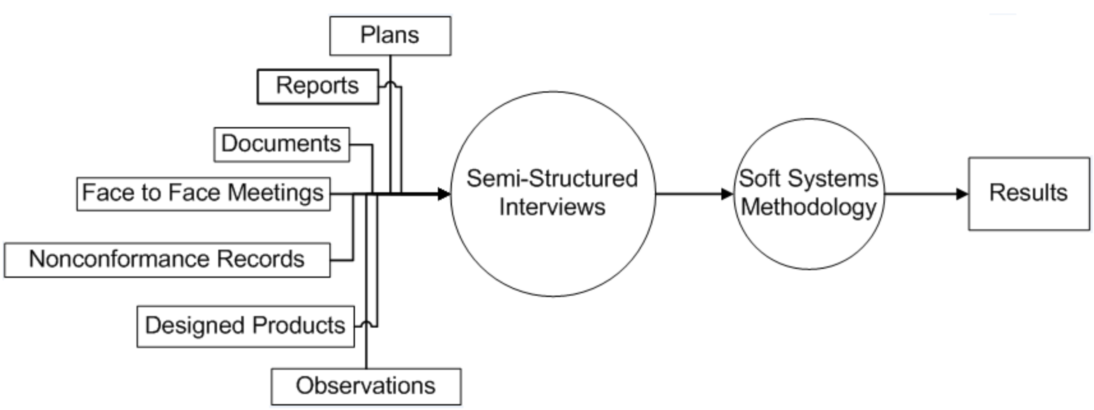

Figure 3.5.1: The Data Collection and Analysis Model

3.6 Trustworthiness and Triangulation

The quality of the qualitative research refers to assuring trustworthiness because of trying to develop a complex picture of the problematic cases for design process. This involves reporting multiple perspectives and identifying the many factors involved in a problematic situation. Creswell enumerates eight procedures (Creswell, J. W., 2007): prolonged engagement and persistent observation in the field; triangulation and multiple sourcing of data; peer review and debriefing for external checks; negative case analysis; clarifying of researcher bias; member checking; thick description; and external audits. Lincoln and Guba (Lincoln, Y. S., & Guba, E. G., 1985) use the terms credibility, transferability, dependability, and confirmability to group various procedures together under larger aims, and establish that trustworthiness of research and its findings are the central issues in positivist ideals of validity and reliability.

Credibility is used to clearly link the study's findings with reality in order to demonstrate the truth of the research study's findings. In this study, triangulation technique is preferred. Triangulation means using multiple data sources in an investigation to produce understanding. It is mentioned by Jokab, A. as "by combining multiple observers, theories, methods, and empirical materials, researchers can hope to overcome the weakness or intrinsic biases and the problems that come from single-method, single-observer, single-theory studies. Often the purpose of triangulation in specific contexts is to obtain confirmation of findings through convergence of different perspectives. The point at which the perspectives converge is seen to represent reality." (Jakob, A., 2001) In this study, methods triangulation is preferred because of being cheched out the consistency of findings generated by different data collection methods like face to face meetings, semi-structured interviews, observations and examination of some reports, plans, documents and nonconformance records. Unfortunately, it is not possible to share the details of the collected data because of some security reasons and limitations for the organization.

Transferability is used to decide that the research's findings could be applicable to other context. When the findings are evaluated (refer 4.7), there are some same findings for four sub processes of the design process like; selection of a tool for bidirectional traceability, definition of a new method for revision of employee's skills, definition of a new policy for risk management activities and implementation of monitoring and controlling activities. On the other hand; in the concept of this study, SSM is applied to only the design process and its sub-processes. In the organization, there are some other processes from design process and this methodology (SSM) can be applicable to other processes with the same approach that was preferred for design process.

Dependability is important about establishing the research study's findings as consistent and repeatable. It is aimed to verify that the findings are consistent with the collected raw data. In the concept of the study, the semi-structured interviews are performed and then the minutes of meetings are prepared for every interview. Then the prepared minutes of meetings are shared with the participants of the semi-structured interviews, their comments are reflected to these records and then the records are finalized. Unfortunately, it is not possible to share the details of the minutes of meetings because of some security reasons and limitations for the organization.

Confirmability is used to reduce the effect of investigator bias and the recognition of shortcomings in study's methods and their potential effects. For this study, the minutes of meetings are evaluated to determine the valuable insights of the design process. The minutes of meetings are analyzed word by word and their densities are associated with their importance for design process and its sub-processes. The details are shared on Appendix A.

On the other hand, qualitative validity means that the researchers check whether the findings of the research study are precise and accurate (Gibbs, G. R., 2007). Validity of a model is commonly related with the degree of representing the reality (Williams, B., 2005). Examining validity of conceptual models generated as a part of SSM is difficult and so it is usually suggested to examine competence of these models. Competence is defined as follows in the literature "… ensuring that the root definitions and conceptual models have been derived systematically from the rich picture and the issues identified within it and also that the conceptual models are built only from the root definition. The relevance of the models is a matter for the participants to determine and is related to the extent to which the models generated improve the understanding of issues and the generation of subsequent actions." (Warwick, J. and South, L., 2008, p.18)

In this research study, it is not feasible to discuss these models with participants because of the organizational limitations. Therefore, the reliability and validity are controlled according to gathered information and observations.

3.7 Ethical Considerations

Ethical issues are defined as "Researchers need to protect their research participants; develop trust with them; promote the integrity of research; guard against misconduct and impropriety that might reflect on their organizations or institutions; and cope with new, challenging problems." (Creswell, J.W., 2013, p. 87)

In this research study, some ethical issues are taken into consideration to protect the rights of participants and organization. The names of participants and organization are not shared in the concept of the study. Therefore, only the gathered data is shared in this study and it is used to analyze engineering design processes and develop improvement approach by using SSM.

CHAPTER 4

EMPRICAL FINDINGS: SOFT SYSTEMS METHODOLOGY (SSM) FOR DESIGN PROCESS

4.1 Engineering Design Process in the Organization

The engineering design process of the organization and its structure is given on Figure 4.1.1. The process named as 'Design Process' contains four sub-processes that are defined as 'Requirement Management', 'Technical Solution', 'Integration' and 'Verification and Validation'. Also there are four support processes in the organization that serve all processes. These support processes can be labeled as 'Configuration Management', 'Measurement and Analysis' and 'Quality Assurance'.

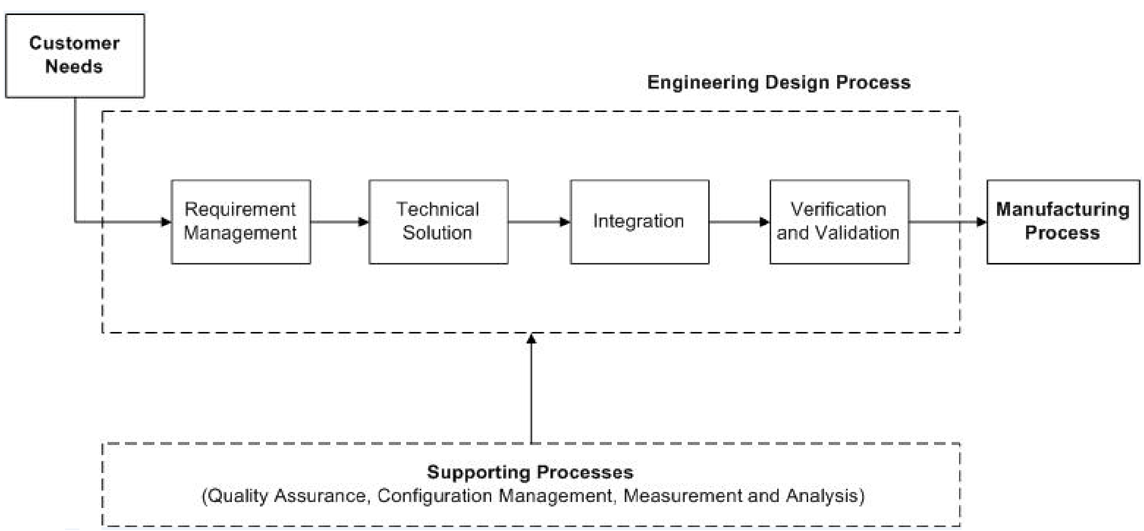

Figure 4.1.1: The Organizational Chart

During data collection, the required data that is used to define problematic cases is obtained from the practitioners of engineering design processes and its sub-processes. While performing group interviews and face to face meetings, some data is also collected about support processes and analyzed their effects on the design process and its sub-processes. Requirement Management sub-process is defined for analyzing and developing the requirements that are defined by customers. At this phase, the feasibility of the given requirements are also analyzed and detailed. Technical Solution sub-process is used for implementing the technical solution of the project that is defined with given requirements by customers. The Integration sub-process serves the definition of integration principles related with prototype and pilot products. Verification and Validation sub-process is used to performing the verification and validation activities for prototype and pilot product. Configuration Management process from support processes is used for traceability of requirements and product trees. The other support process, Quality Assurance mainly concerns with conformity of designed product to defined requirements and uses the produced documents to assure conformity. Measurement, Analysis and Improvement process is used to measure the performance criteria of the engineering design process, analyzing them (if requires) and define improvements in accordance to measurement of them. After completion of engineering design process and its sub-processes, the project activities continue with manufacturing processes.

To give a clear understanding about sub-processes of the design process, the details of each sub-process are defined on the following figures. These sub-processes have generally waterfall approach means that after one of sub-process is completed, the other starts. On the other hand, there are needs to update any of them based on the changes about customers' needs, requirements and so on. The detailed activities for related sub-process are given on following figures.

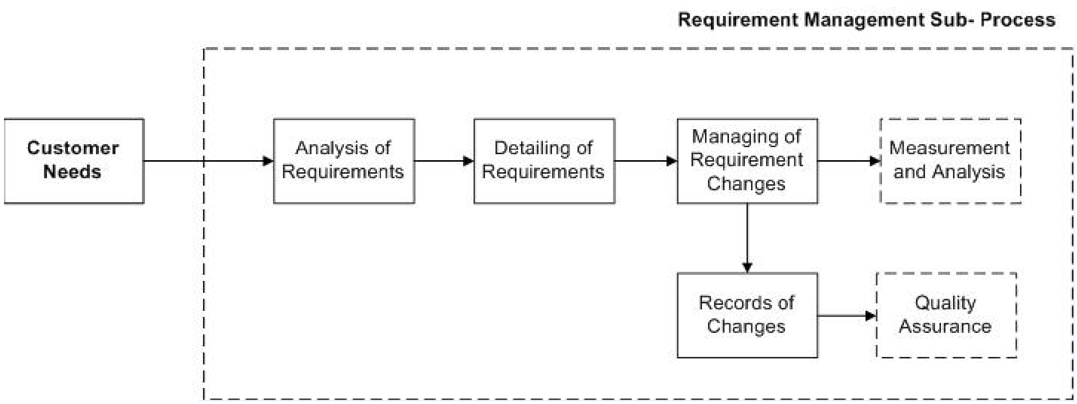

Figure 4.1.2: Requirements Management Sub-Process

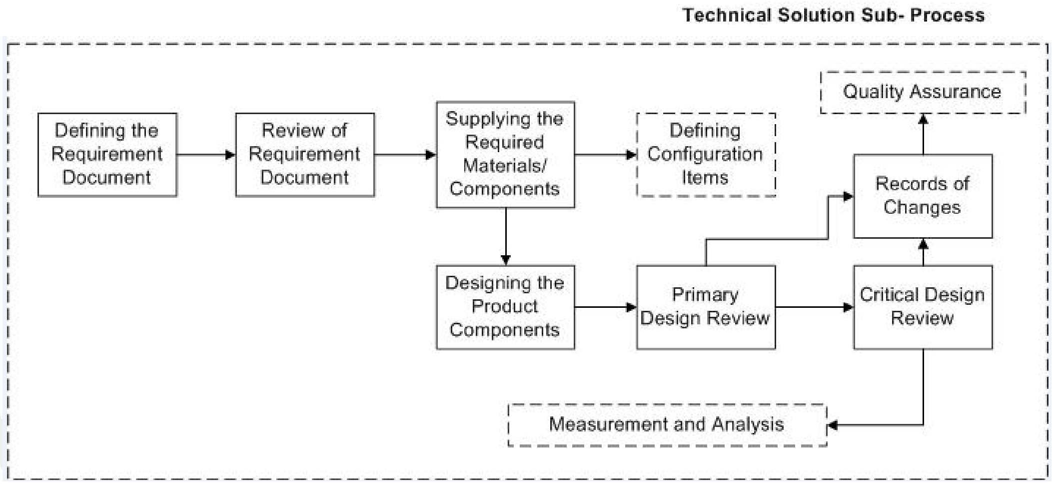

Figure 4.1.3: Technical Solution Sub-Process

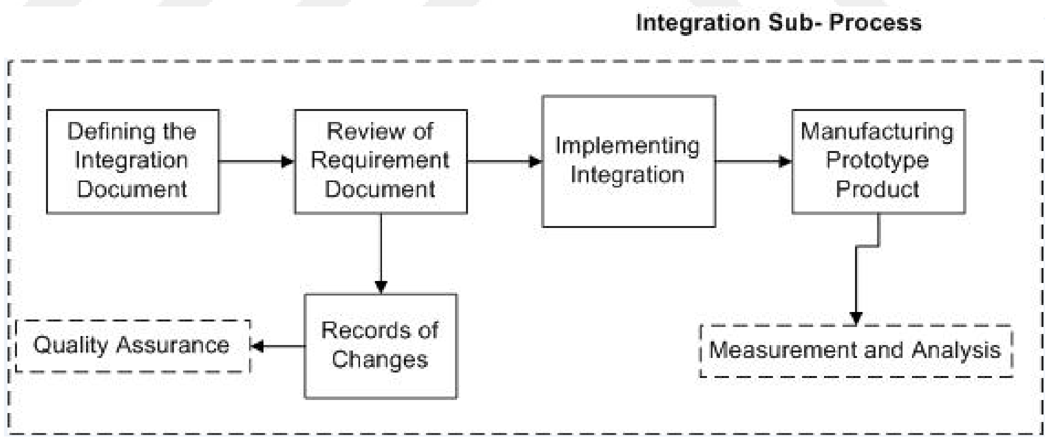

Figure 4.1.4: Integration Sub-Process

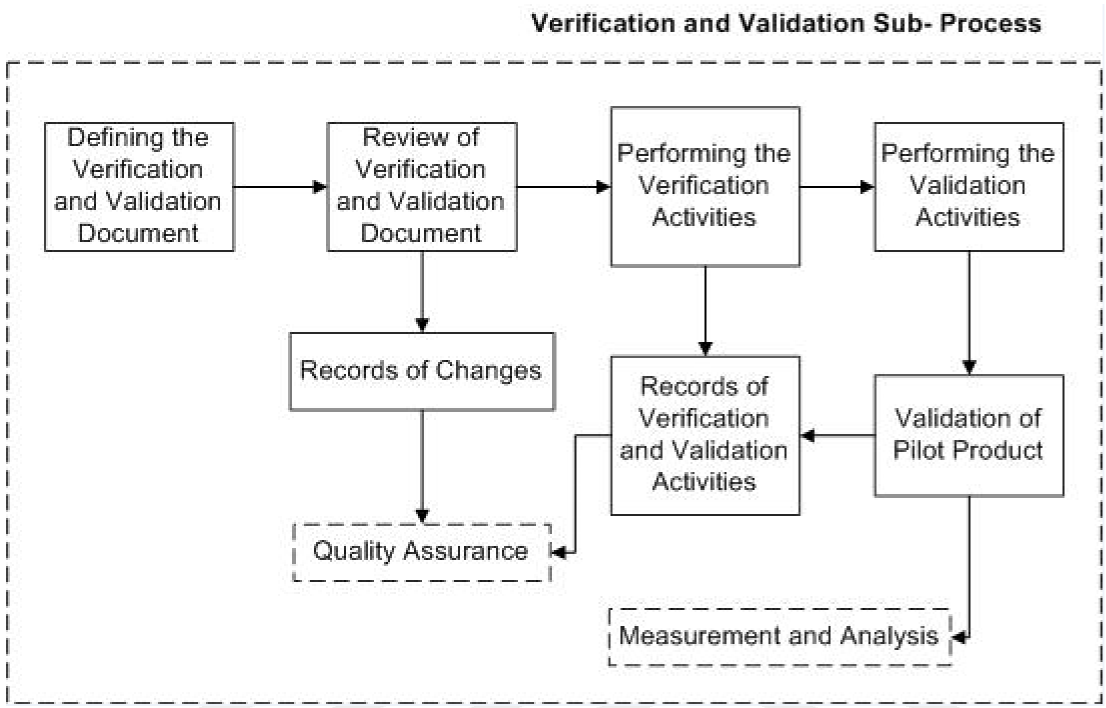

Figure 4.1.5: Verification and Validation Sub-Process

4.2 Stage 1: Enter Situation Considered Problematic

According to Soft Systems Methodology (SSM), everything can produce problematical situations that perceived differently by the various participants because of their worldviews. Therefore, every problematical issue should be defined by using roles and interrelations of involved people in social, cultural and political context.

In this research study, the information is gathered to improve design process and its sub-processes by evaluating the various roles and interrelations between employees, employers, process owners and project team in social and personal context. Employees and process owner activities are expressed with Root Definition that is also used to create Conceptual Models. Conceptual Model enables to question problematical issues in the process and provides knowledge about how to improve it. Addressed changes or improvements about process can be implemented to solve problematical issues but the implementation of defined improvements is outside the scope of this research study.

4.3 Stage 2: Express the Problem Situation

4.3.1 Requirement Elicitation, Analysis, Management and Changes

The group interviews are implemented with design teams that have responsibility on requirements and detailed information is gathered about requirements management sub-process (see Appendix B). The focus groups' rich picture is given on Figure 4.3.1.1. The main activities of this process are requirement elicitation, analysis, management and changes.

The requirements are derived from contract. If there is any misunderstanding about them, meetings are organized with customer and project team is responsible coordinating the meetings. The requirements are defined more clearly and/or detailed after getting customer's opinions. Also the requirements can be detailed with technical researches.

Design teams contain some sub-teams in accordance to their expertise. The project includes generally either software or hardware so the requirements are categorized as 'software requirements' and 'hardware requirements'. The traceability is defined between contract and design documents and also configuration items are addressed. Then related design teams finalize the requirements.

While analyzing requirements, testability is another important manner for designers. Therefore, they define test scenarios that are used to verify related requirements at verification sub-process. During definition of test scenarios, it can be realized that the verification of some requirements is not possible. At this point, designers analyze the case by defining the reasons and project team is informed about it. A meeting is organized to discuss requirement change. The impact analysis of the requirements and reasons are evaluated. If project team decides to change requirement, the customers are informed about this case and a meeting is organized to give detailed information about changes. After agreement about change, the design document is updated. If not, customers are not informed about changes. All of requirement activities that contain elicitation, analysis, management and changes are completed, the design document is freeze and design activities start in accordance to freeze requirements.

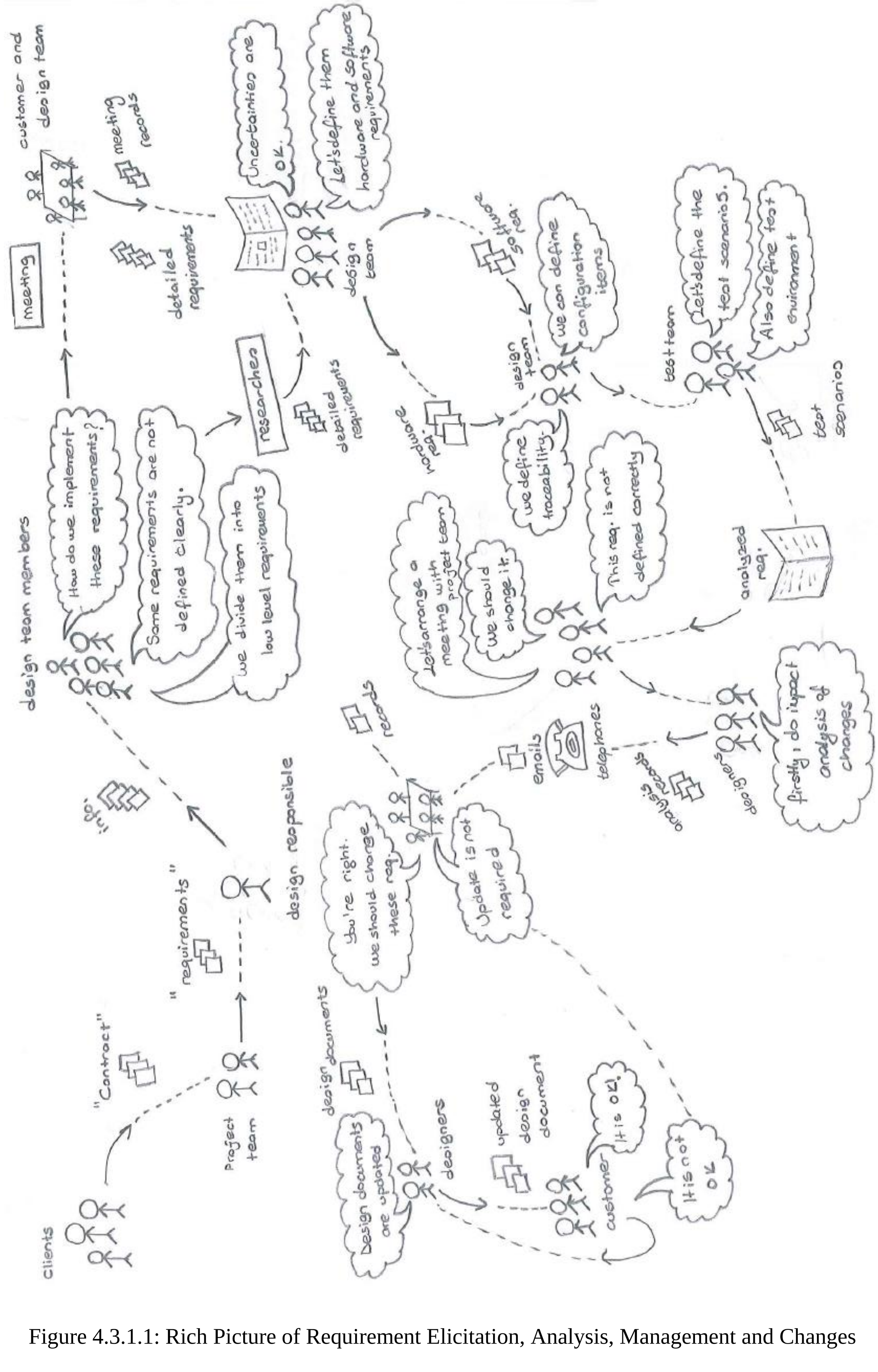

Figure 4.3.1.1: Rich Picture of Requirement Elicitation, Analysis, Management and Changes

4.3.2 Technical Analysis of Design

The group interviews are implemented with design teams that have resposibility on technical analysis of requirements and detailed information is gathered about technical solution sub-process (see Appendix B). The focus groups' rich picture is given on Figure 4.3.2.1. The main activities of this sub process are as follows; deciding to which requirements are critical, product arhitecture definition, configuration items definition, categorization of hardware, software and physical interfaces, purchasing hardware components/materials, development of hardware and software configuration items, definition of the tests for hardware and software configuration items, determination of test environments and reviews.

The requirements and test scenarios are derived from requirement management sub-process. The crititical requirements are specified and the design specifications for them are defined. The schedule, cost, performance are evaluated to implement these activities. The functionality is defined in the concept of derived requirements and its architectural structure is also defined. While this definition, the configuration items are addressed in accordance to two category named as software configuration items and hardware configuration items.

After definition of design configuration items, the interfaces of design are determined as physical and/or hardware/software. If the iterfaces' definitions do not meet all of the defined requirements, requirements changes are realized and also impact analysis is prepared. The related documents are updated to reflect the changes. If the interfaces are enoough for defined requirement, the process continues with development of hardware and software configuration items.

Before starting the development activities of hardware configuration items, purchase activities are completed. During supply process of the required component, hardware designers work on definition of circuit diagrams. Circuits diagrams are drawn on a tool, then they are manufactured. Some verification activities can be implemented on these diagrams but not for all circuit diagrams. After the completion of supply process, the hardware design is implemented and also test environments related with configuration items are defined. On the other hand, the software configuration items are developed and also its test environments are defined. Coding is implemented. Sometimes, special test enviroments can be required by customer and so these request are taken into consideration by design team.

While implemetation of these activities that are mentined above, the all information is recorded on design document. The primary and critical design reviews are implemented for design document, hardware configuration items and software configuration items by designers. After critical design review, technical solution sub process is completed.

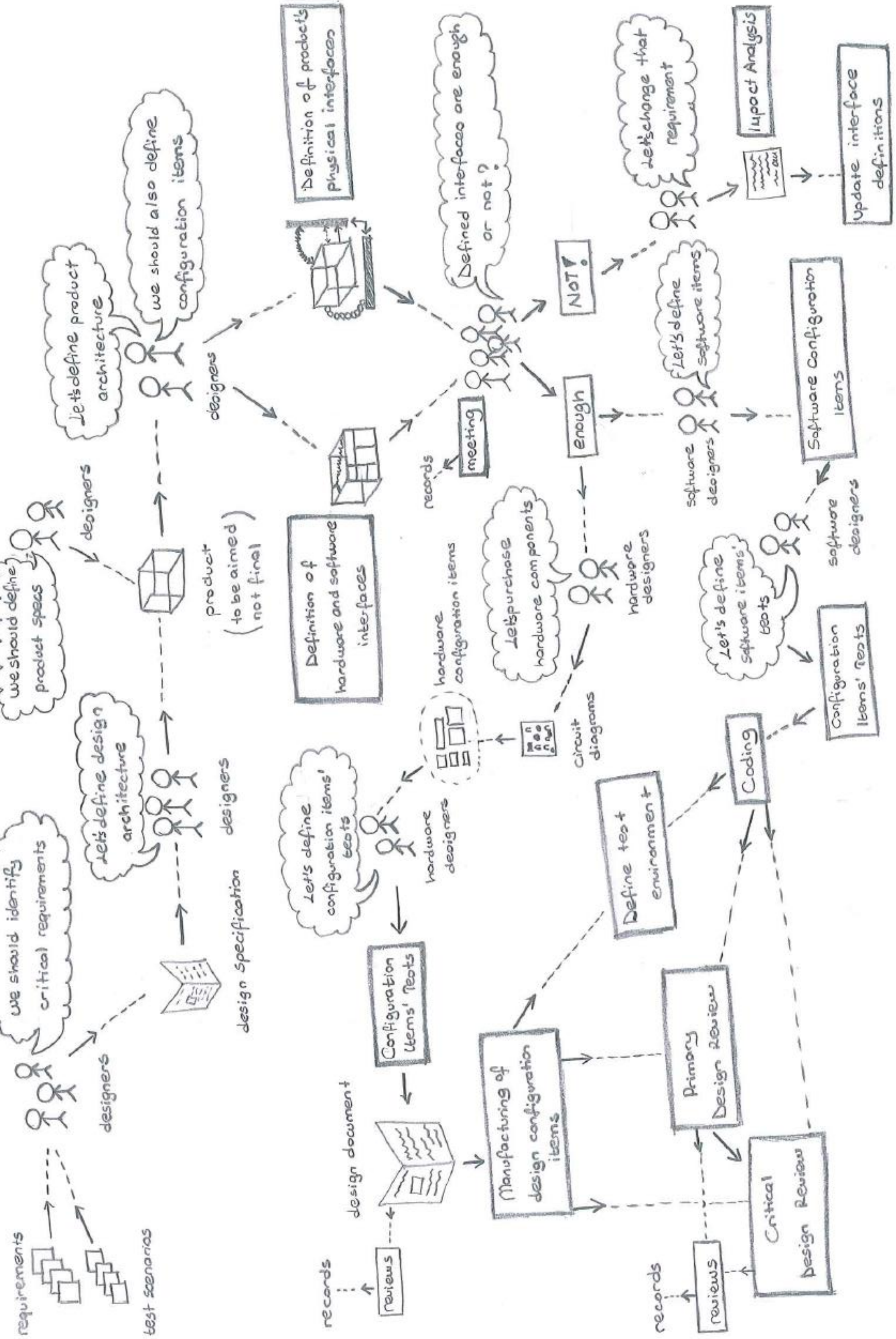

Figure 4.3.2.1: Rich Picture for Technical Analysis of Design

4.3.3 Integration of Designed Configuration Items

The group interviews are implemented with design teams that have resposibility on integration of designed configuration items and detailed information is gathered about integration sub-process (see Appendix B). The focus groups' rich picture is given on Figure 4.3.3.1. The main activities of this sub process are as follows; planning the integration activities based on the documented design document, defining the integration document to cover the test scenarios and the details of design document, integration of configuration items that are defined on technical solution sub porcess, test activities of integrated product.

Before planning the integration activities, the integration concept is defined based on the configuration items and their interfaces. Then the required integration environment is specified in accordance to integration concept. The process of integration and schedule are defined as basically and then the plan is prepared for integration.

The details of integration document and test scenarios are derived from design document. The test methods and integration test scenarios are defined to cover all integration activities for every unit. These units can be thought as hardware/software configuration items and their interfaces. The all information mentioned above are documented on integration document and it is reviewed by integration team.

Integration activities are performed in accordance to integration document and defined schedule. The interfaces between configuration items are checked during integration. The integration of designed configuration items are completed and then defined test scenarios are performed for them. If there are any noncorformances, they are recorded as informally and some corrective activities can be done for noncorformances.

All defined tests in integration document are completed and a report is prepared about performed integration activities. The noncorformances are not reported to project team, only design team has information about them. After preparation of integration report, integration sub process is completed.

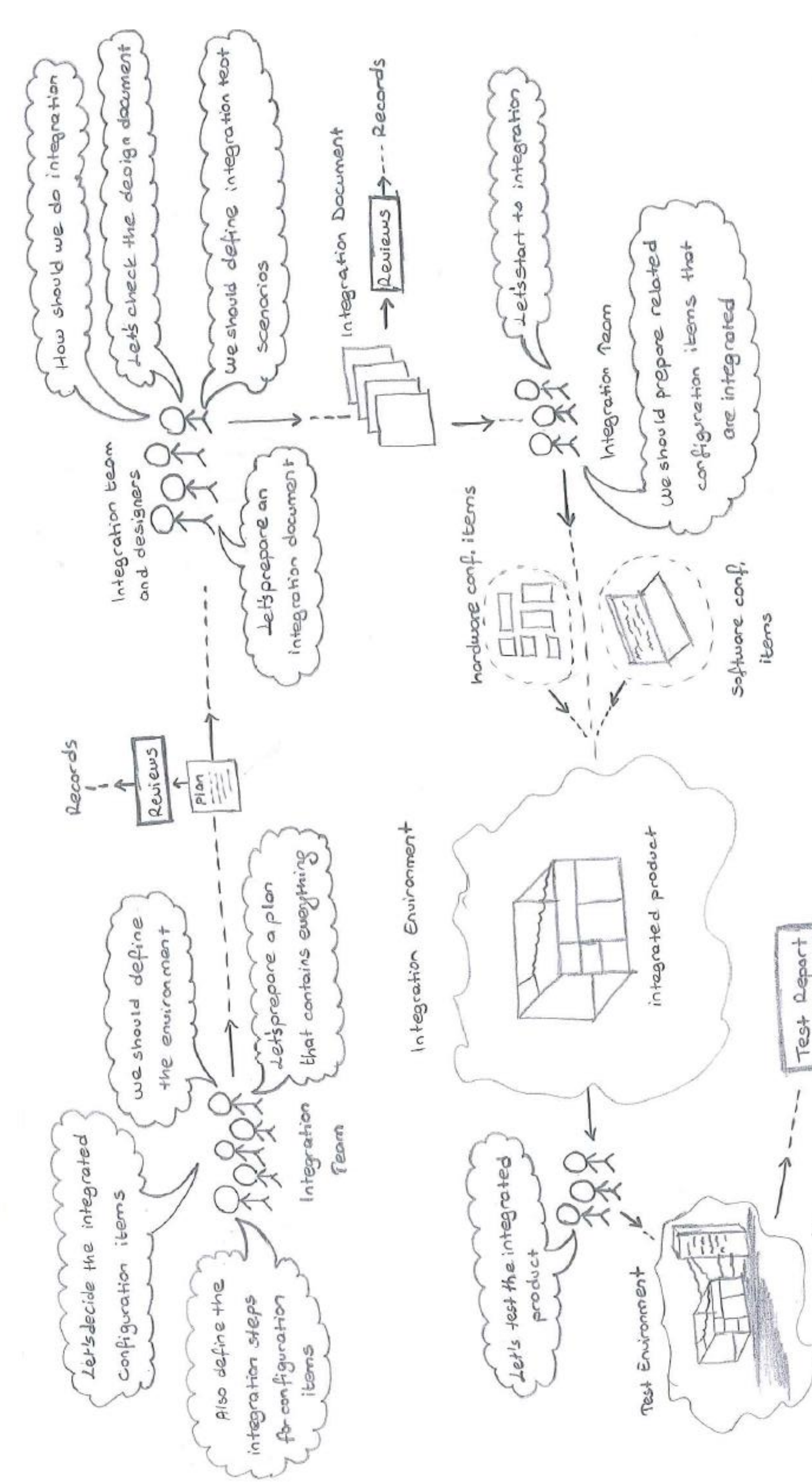

Figure 4.3.3.1: Rich Picture for Integration of Designed Configuration Items

4.3.4 Verification and Validation of Design

The group interviews are implemented with design teams that have resposibility on verification and validation of designed product and detailed information is gathered about verification and validation sub-process (see Appendix B). The focus groups' rich picture is given on Figure 4.3.4.1. The main activities of this sub process are as follows; planning the verification and validation activities based on the prepared design document and integration document, defining the data set that contains requirements, integrated products and their nonconformances/errors, preparing verification and validation document that specializes the test methods and test scenarios, performing test activities based on test scenarios and evaluating the succes of verifcation and validation tests.

Before planning the verification and validation activities, the verification and validation concept is defined based on the integrated products and their test reports. Then the required verification and validation data set is specified in accordance to its concept. The main verification and validation activies, their schedules are defined basically and then the plan is prepared for verification and validation and reviewed by design team.

The details of verification and validation document and test scenarios are derived from design document, integration document and integration test reports. The test methods and verification/validation test scenarios are defined to cover all activities for every integrated products. The all information mentioned above are documented on verification and validation document and it is reviewed by design team.

Verification and validation activities are performed in accordance to prepared verification and validation document and also defined schedule. The all integrated products are tested with their test environments. Test scenarios can be changeable from project to project. If there are any noncorformances, they are recorded as informally and some corrective activities can be done for noncorformances.

All defined tests in verification and validation document are completed and a report is prepared about performed verification/validation activities. The noncorformances are not reported to project team, only design team has information about them. After preparation of verification and validation report, verification and validation sub process is completed and then manufacturing process starts.

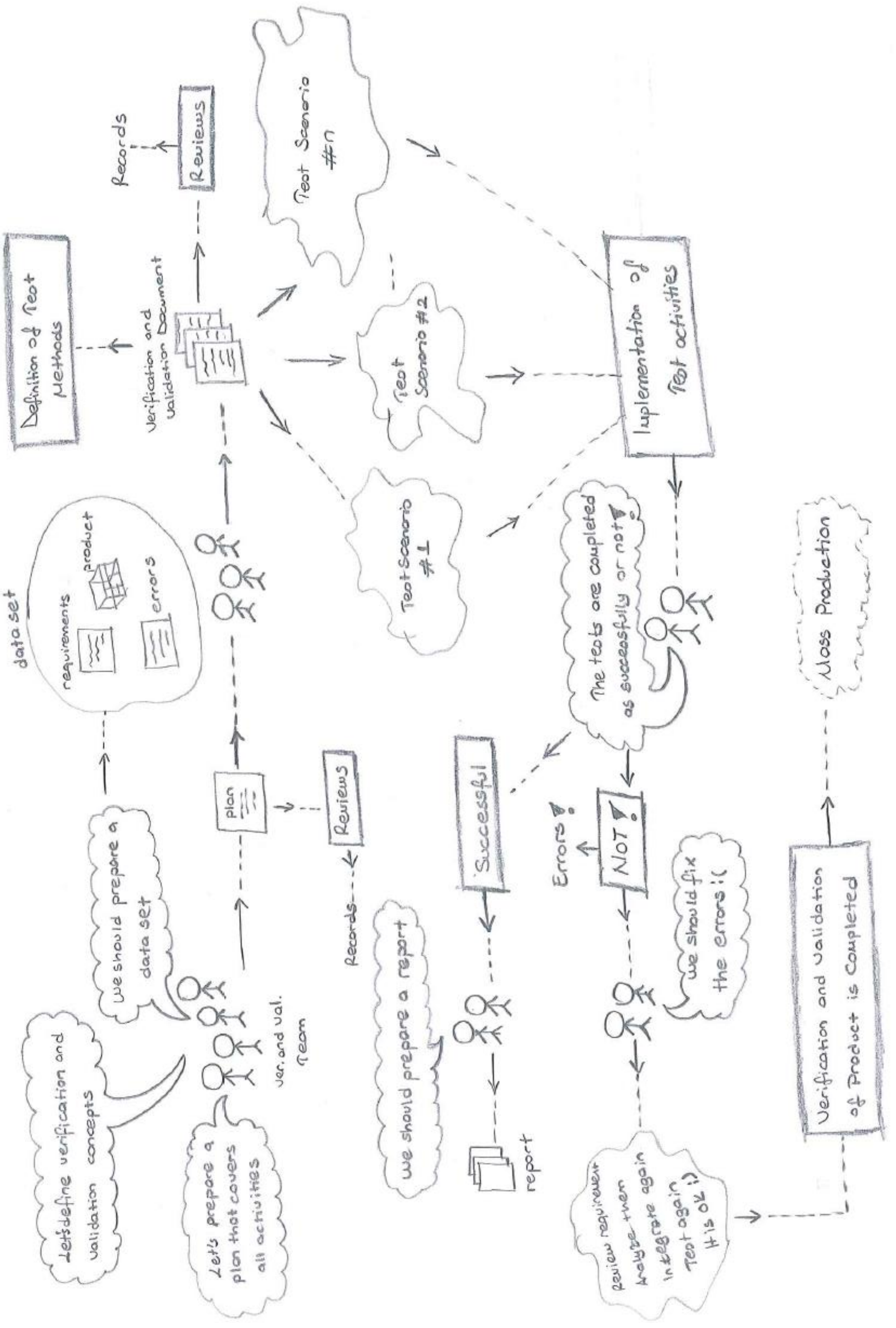

Figure 4.3.4.1: Rich Picture for Verification and Validation of Design

4.4 Stage 3: Formulate Root Definition of Relevant Systems

The root definition is used to describe the activity system that needed to be created in order to improve the defined situation in part 4.3. It is also the basis for building conceptual model of the system at the following part.

Root Definition is applied all problematic cases defined at 4.3 and for the creation of it, CATWOE rule is used and it is defined as follows.

Customers (C): The customers of this tranformation can be seen as a group of interested parties. These parties can be defined as the project team, the owners and participicants of the oher sub-process apart from the realted sub-process. Because the studies about a sub-process can be used as inputs for other sub-processes. Also it can be said that the end users of the design projects can be thought as customer indirectly. Because the communication between end users and the organization is generally defined over project team.

Actors (A): The people concerned with the transformation are the employees of the design group including the management. The other raleted parties can be thought as the owner of related sub-process and maybe training providers. Although the employees are not the drivers of change, they are the principal participants in whom the change process rests.

Transformation (T): The transformation is required to add or redefine some process steps that can be more applicable for employees. There is a defined sub process related with this case in the organization but the defined steps in the process do not cover every activities that are implemented by employees. New additional activities should be defined to have a well defined process approach.

Worldview or Weltenshauung (W): There are some worldviews to consider in this case and they can be aligned as employees, the related sub process owners and indirectly end users. Employees and the process owners are also participants of the process. Sometimes, end users can have some request in the project's concept to change the existing sub process practices. The employees are the most relevant view in achieving the necessary transformation.

Owners (O): The owners can be thought as people or institutes that creates the requirement management process definition and also provides some standarts, guidelines about how it can be applied for any organizations. The organizaiton's processes definitions are generally defined in accordance to standarts and guidelines.

Environment (E): The environment for change can be defined as office, work area, infrastructure and related tools. Office, work area and infrastructure are provided by organization. Tools are selected by employees and then organization supply the desired tools.

Table 4.4.1: The Root Definition Statement

Root Definition Statement:
Redefining of requirements management, technical solution, integration, verification and validation sub processes, generally defined in accordance to standards and quidelines, to improve the existing process, to become more applicable by employees in an environment that have enough infrastructure.

4.5 Stage 4: Build Conceptual Models

The creation of Root Definition is followed by a Conceptual Model in the Soft Systems Methodology. The Conceptual Model can be thought as a schematic representation of required activities for process improvement in the research study. The following Conceptual Models are defined to improve existing design processes and its' sub-processes in the organization.

4.5.1 Requirement Elicitation, Analysis, Management and Changes

Defined conceptual model that is given on Figure 4.5.1.1, identifies requirement management sub process that can be performed by all designers during design life cycle. It enables to product required outputs and save and increase institutional knowledge by recording and hiding the outputs. Also this process provides convenience about requirement traceability from contract level to validation level.

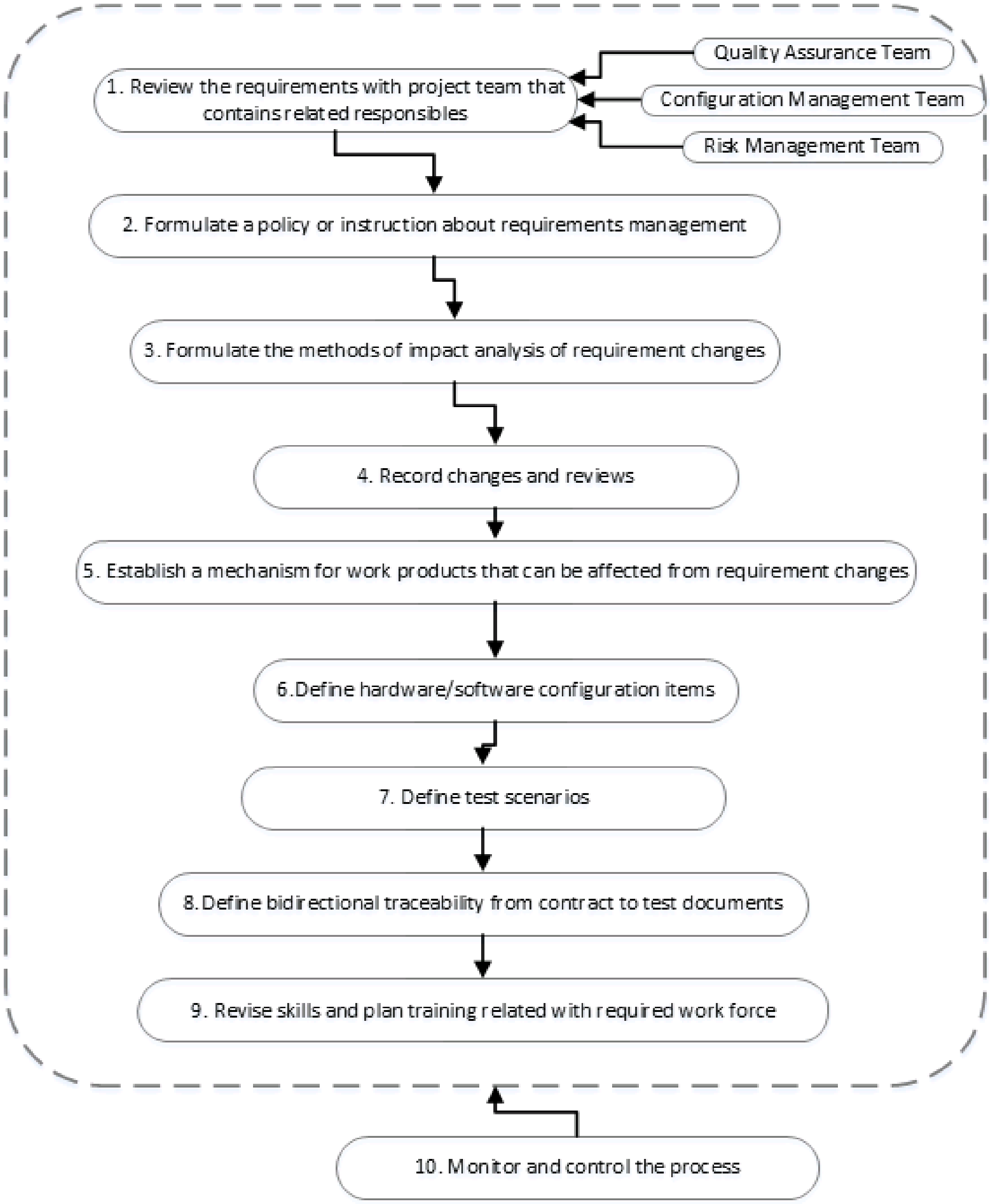

Figure 4.5.1.1: Conceptual Model of Requirement Elicitation, Analysis, Management and Changes

The elements of conceptual model are given at following table (Table 4.5.1.1)

Table 4.5.1.1: The Elements of Conceptual Model for Requirement Elicitation, Analysis, Management and Changes

The Elements of Conceptual Model *(Requirement Elicitation, Analysis, Management and Changes)*
Review the requirements with project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Formulate a policy or instruction about requirement management activities that covers all work instructions and existing process documents
Formulate the methods for impact analysis of requirement changes
Record changes and reviews.
Establish a mechanism for work products that can be affected from requirement changes
Define hardware/software configuration items
Define test scenarios
Define bidirectional traceability from contract to test documents
Revise skills and plan training related with required work force

4.5.2 Technical Analysis of Design

The conceptual model that is defined on Figure 4.5.2.1, identifies technical solution sub-process that can be performed by related hardware/software designers during design life cycle. It provides detailed information about design activities after completion of requirement management sub-process. It covers required activities for design and documentation of produced knowledge to reuse them later. Also this process provides convenience about requirement traceability from contract level to detailed design level.

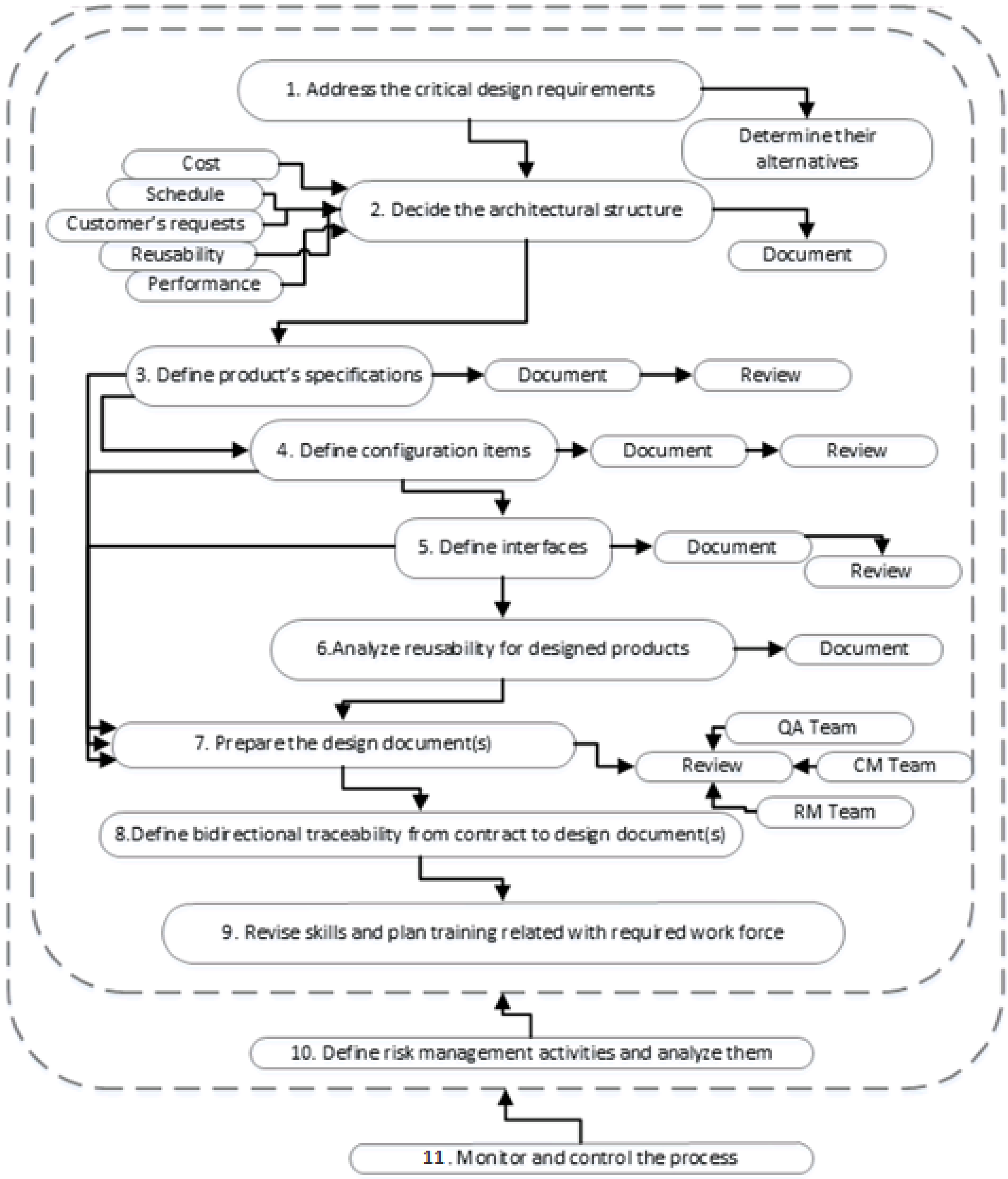

Figure 4.5.2.1: Conceptual Model for Technical Analysis of Design

The elements of conceptual model are given at following table (Table 4.5.2.1)

Table 4.5.2.1: The Elements of Conceptual Model for Technical Analysis of Design

The Elements of Conceptual Model *(Technical Analysis of Design)*
Address the critical design requirements by using derived requirements from requirement management sub-process and then determine their alternatives
Decide the architectural structure consisting cost, schedule, performance, reusability and customer's request parameters, document it.
Define the product's specifications, document and review them between team members.
Define the configuration items, document and review them between team members as software and hardware configuration items after being sure that the infrastructure enables to implement related configuration items.
Define the interfaces as physical, hardware and software, document and review them between team members.
Define and analyze reusability for the designed products and then document them.
Prepare the design document and review it with project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Define bidirectional traceability from contract to the design document that can cover the technical solution activities
Revise skills and plan training related with required work force

4.5.3 Integration of Designed Configuration Items

The conceptual model that is defined on Figure 4.5.3.1, identifies integration sub-process that can be performed by related hardware/software designers during design life cycle. It provides detailed information about integration activities after completion of technical solution sub-process. It covers required activities for integration and these activities can be basically named as planning, defining integration test concepts and documenting them, integration of configuration items and performing defined test activities in defined test environment. Also this process provides convenience about requirement traceability from contract level to integration level.

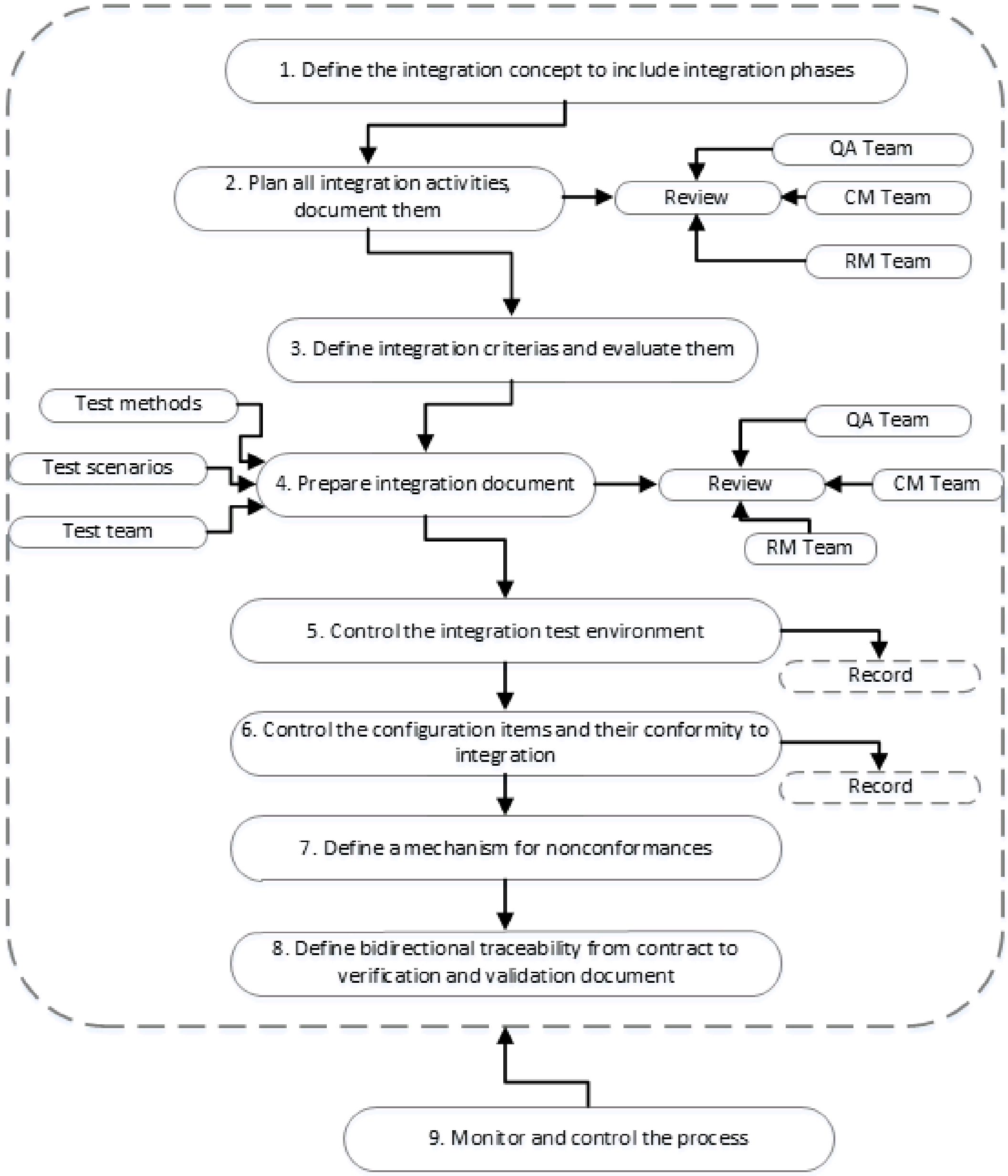

Figure 4.5.3.1: Conceptual Model for Integration of Designed Items

The elements of conceptual model are given at following table (Table 4.5.3.1).

Table 4.5.3.1: The Elements of Conceptual Model for Integration of Designed Configuration Items

The Elements of Conceptual Model *(Integration of Designed Configuration Items)*
Define the integration concept to include integration processes.
Plan all integration activities that are specified for integration concept, document it.
Review integration plan with designers of hardware and software configuration items and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Define integration criterias to perform a succesful integration activity and evaluate them.
Specify and document the integration test team, scenarios and methods about how to perform integration activities for configuration items and their interfaces. Review integration document with designers of hardware and software configuration items and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Control the integration environment and be sure that it is compatible with the integration document
Control the configuration items and their conformity to integration.
Define a mechanisim for nonconformancess and check the possibility that the nonconformances are solved in the integration period or not.
Define bidirectional traceability from contract to the integration document that can cover the integration activities

4.5.4 Verification and Validation of Design

The conceptual model that is defined on Figure 4.5.4.1, identifies technical solution sub-process that can be performed by related hardware/software designers during design life cycle. It provides detailed information about design activities after completion of requirement management sub-process. It covers required activities for design and documentation of produced knowledge to reuse them later. Also this process provides convenience about requirement traceability from contract level to detailed design level.

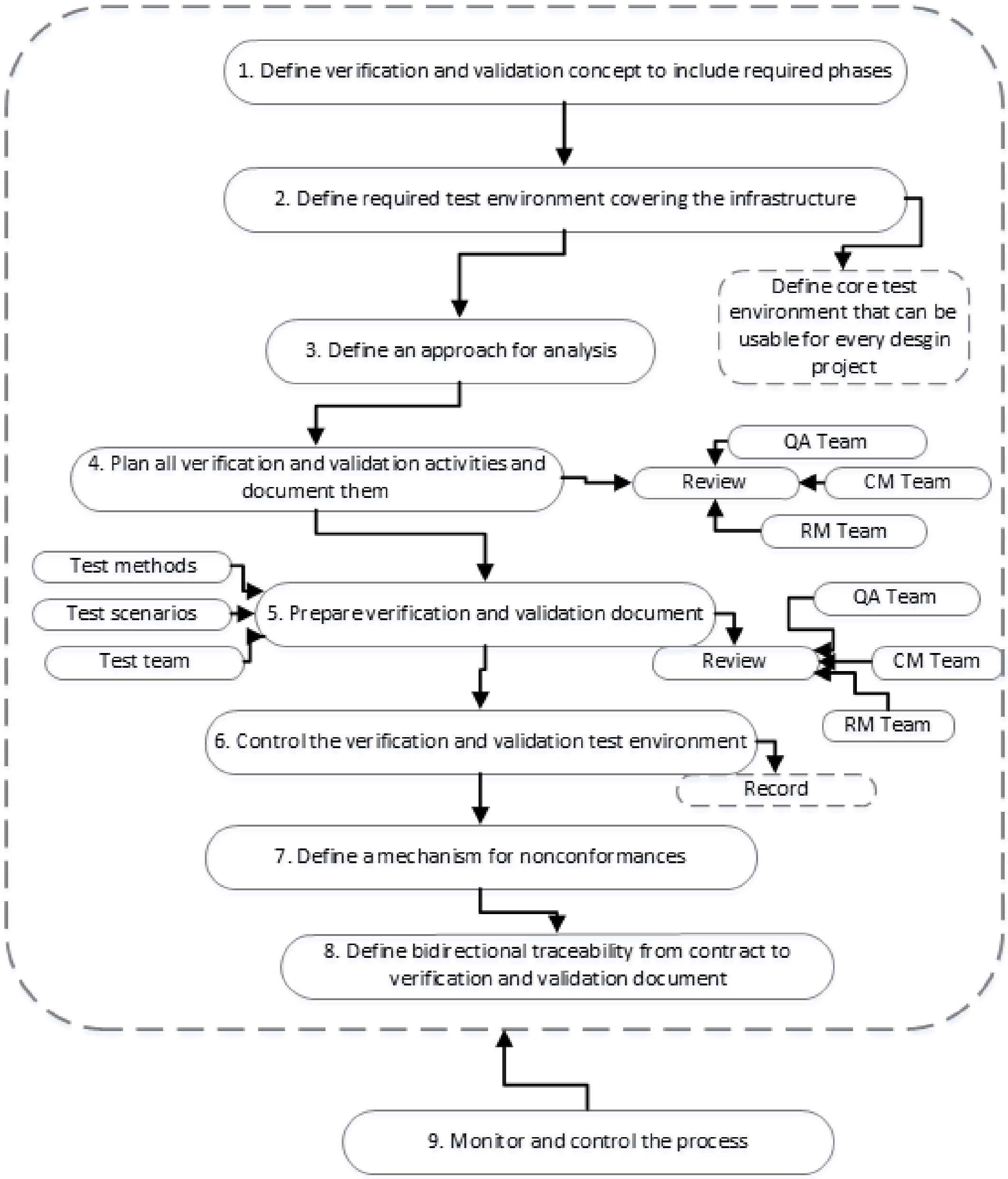

Figure 4.5.4.1: Conceptual Model for Verification and Validation of Design

The elements of conceptual model are given at following table (Table 4.5.4.1).

Table 4.5.4.1: The Elements of Conceptual Model for Verification and Validation of Design

The Elements of Conceptual Model *(Verification and Validation of Design)*
Define the verification and validation concept to include verification and validation phases.
Define required test environments covering the infrastructure and evaluate them.
Define core test environment that can be usable by every design project.
Define an approach for analysis that can be used for verification and validation activities.
Plan all verification and validation activities that are specified in verification/validaiton concept and document it.
Review verification and validation plan with designers and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Specify and document the verification and validation test team, scenarios and methods about how to perform required activities for integrated products and their interfaces. Review verfication and validation document with designers and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)
Control the verification and validation test environment and be sure that it is compatible with the verification and validation document
Define a mechanisim for nonconformancess and check the possibility that the nonconformances are solved in the verification and validation period or not.
Define bidirectional traceability from contract to the verification and validation document that can cover the related activities

4.6 Stage 5: Compare Conceptual Models with Real World

There are four ways of comparing the reality through the conceptual models (refer 2.3.5) and the first approach that is the most informal is preferred in the research study. It suggests using the conceptual model as a reference and locating the differences between it and the real world in order to choose which of differences will produce change in the problematical situation.

Compare models with real world part consists of four sub parts in accordance to problematical situations in the engineering design process. The related parts are detailed below.

4.6.1 Requirement Elicitation, Analysis, Management and Changes

The conceptual model that is determined (refer 4.5.1.1) facilitates a consideration of the requirement elicitation, analysis, management and change in order to find ways to improve it. After determining a conceptual model, the real world activities as illustrated in the rich picture are compared with the conceptual model. The details are given on Table 4.6.1.1.

Table 4.6.1.1: The Comparison between Conceptual Model and Real World for Requirement Elicitation, Analysis, Management and Changes

Conceptual Model Activities *(Requirement Elicitation, Analysis, Management and Changes)*	**Real World Activities**
Review the requirements with project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	Requirements are reviewed by desgin team but the other authorities (Quality Assurance Team, Configuration Management team and Risk Management team) are not involved.
Formulate a policy or instruction about requirement management activities that covers all work instructions and existing process documents	There are work instructions and process documents but they are disorganized
Formulate the methods of impact analysis of requirement changes	The methods are changeable from project to project.
Record changes and reviews.	Generally reviews are recorded but changes can be managed informally
Establish a mechanism for work products that can be affected from requirement changes	The affected work products are generally defined at reference parts in design documents.
Define hardware/software configuration items	The definition of hardware and software configuration items are usually defined but not always
Define test scenarios	Test scenarios are defined to verify and validate the requirements
Define bidirectional traceability from contract to test documents	It is not applied for all design projects.
Revise skills and plan training related with required work force	Tranings are planned but generally existing skills are not evaluated.

Conceptual Model Activities *(Requirement Elicitation, Analysis, Management and Changes)*	**Real World Activities**
Monitor and control the process	Performance criterias are defined but there is no measuring, monitoring and controlling mechanism.

4.6.2 Technical Analysis of Design

The conceptual model that is determined (refer 4.5.2.1) facilitates a consideration of the technical analysis of design in order to find ways to improve it. After determining a conceptual model, the real world activities as illustrated in the rich picture are compared with the conceptual model. The details are given on Table 4.6.2.1.

Table 4.6.2.1: The Comparison between Conceptual Model and Real World for Technical Analysis of Design

Conceptual Model Activities *(Technical Analysis of Design)*	**Real World Activities**
Address the critical design requirements by using derived requirements from requirements management sub-process and then determine their alternatives	The critical design requirements are addressed by using the outputs of requirements management sub-process but the alternatives of them are not defined in the concept of design project. If a problem occurs, the alternatives are evaluated, otherwise not.
Decide the architectural structure consisting cost, schedule, performance, reusability and customer's request parameters, document it.	While deciding to architectural structure, cost, schedule and performance parameters are evaluated but not documented. Reusability and customer's request should be added into parameters and also their evaluations shouuld be ocumented.
Define the product's specifications, document and review them between team members.	The product specifications are defined but not documented and reviewed between team members.
Define the configuration items, document and review them between team members as software and hardware configuration items after being sure that the infrastructure enables to implement	Generally,the configuration items are defined then the infrastructure is evaluated. This can cause loss of labor. On the other hand, the defined configuration items are not documented

Conceptual Model Activities *(Technical Analysis of Design)*	**Real World Activities**
related configuration items.	and reviewed.
Define the interfaces as physical, hardware and software, document and review them between team members.	The interfaces are defined as physical, hardware and software. Generally they are documented in design document.If there is a request by customer, they are documented as separately. The review activities are coordinated in the concept of the design document.
Define and analyze reusability for the designed products and then document them.	The reusability depends on the designer's experience.There are no record about reusability for existing projects.
Prepare the design document and review it with project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	Design document is prepared and then reviewed by desgin team but the other authorities (Quality Assurance Team, Configuration Management team and Risk Management team) are not involved.
Define bidirectional traceability from contract to the design document that can cover the technical solution activities	It is not applied for all design projects.
Revise skills and plan training related with required work force	Tranings are planned but generally existing skills are not evaluated.
Define risk management activities, analyze and document them.	There is no formal documentation for risk management activities in the concept of technical solution sub-process
Monitor and control the process	Performance criterias are defined but there is no measuring, monitoring and controlling mechanism.

4.6.3 Integration of Designed Configuration Items

The conceptual model that is determined (refer 4.5.3.1) facilitates a consideration of the integration of designed configuration items in order to find ways to improve it. After determining a conceptual model, the real world activities as illustrated in the rich picture are compared with the conceptual model. The details are given on Table 4.6.3.1.

Table 4.6.3.1: The Comparison between Conceptual Model and Real World for Integration of Designed Configuration Items

The Elements of Conceptual Model *(Integration of Designed Configuration Items)*	**Real World Activities**
Define the integration concept as including integration phases.	Integration concept is defined to include configuration items and their interfaces. Integration phases are not addressed directly.
Plan all integration activities that are specified for integration concept	All integration activities except from integration phases are planned and documented.
Review integration plan with designers of hardware and software configuration items and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	Integration plan is reviewed by only designer that have responsibilities about hardware/software configuration items and integration sub-process.
Define integration criterias to perform a succesful integration activity and evaluate them.	There is no such kind of activities in the existing integration sub- process
Specify and document the integration test team, scenarios and methods about how to perform integration activities for configuration items and their interfaces. Review integration document with designers of hardware and software configuration items and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	These activities are available in integration sub-process. But there is no detail about test team and its specification. There is no formal records about it. Integration document is reviewed by only designer that have responsibilities about hardware/software configuration items and integration sub-process.
Control the integration environment and be sure that it is compatible with the integration document.	The integration environment control is not applied to all design project. Therefore, it can be said that there is no formal record as defined in the integration sub-process.
Control the configuration items and their conformity to integration.	Configuration items and their conformity are checked but there is not any form or record for it.

The Elements of Conceptual Model *(Integration of Designed Configuration Items)*	**Real World Activities**
Define a mechanisim for nonconformances and check the possibility that the nonconformances are solved in the integration period or not	There is a policy for nonconformances that is prepared by Quality team but this policy is not applied for integration activities.
Define bidirectional traceability from contract to the integration document that can cover the integration activities	It is not applied for all design projects.
Define risk management activities, analyze and document them.	There is no formal documentation for risk management activities in the concept of technical solution sub-process
Monitor and control the process	Performance criterias are defined but there is no measuring, monitoring and controlling mechanism.

4.6.4 Verification and Validation of Design

The conceptual model that is determined (refer 4.5.4.1) facilitates a consideration of the verification and validation of designed product in order to find ways to improve it. After determining a conceptual model, the real world activities as illustrated in the rich picture are compared with the conceptual model. The details are given on Table 4.6.4.1.

Table 4.6.4.1: The Comparison between Conceptual Model and Real World for Verification and Validation of Design

The Elements of Conceptual Model *(Verification and Validation of Design)*	**Real World Activities**
Define the verification and validation concept to include verification and validation phases.	Verification and validation concept is defined to include all information about integrated products but the vericaiton and validation phases are not addressed directly.
Define required test environments covering the infrastructure and evaluate them.	Test scenarios are defined but the required test environments are not specialized and evaluated.
Define core test environment that can be usable by every design project.	Same test environments are not defined in the organization. They are built separately for every project. This can cause the loss of work force.

The Elements of Conceptual Model *(Verification and Validation of Design)*	**Real World Activities**
Define an approach for analysis that can be used for verification and validation activities.	Inspection, demo and test activities are formally defined for verification and validation sub-process in the organization's documentation. Analysis can be performed for some requirements' verification/validation. But there is no formal documentation of analysis.
Plan all verification and validation activities that are specified in verification/validaiton concept and document it.	All verification and validation activities except from their phases are planned and documented.
Review verification and validation plan with designers and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	Verification and validation plan is reviewed by only designer that have responsibilities at this suprocess
Specify and document the verification and validation test team, scenarios and methods about how to perform required activities for integrated products and their interfaces. Review verfication and validation document with designers and project team that contains related responsibilities (Quality Assurance Team, Configuration Management team and Risk Management team)	These activities are available in verification and validation sub-process. But there is no detail about test team and its specification. There is no formal records about it. Verification and validation document is reviewed by only designer that have responsibilities about integrated products.
Control the verification and validation test environment and be sure that it is compatible with the verification and validation document	The verification and validation test environment control is not applied to all design project. Therefore, it can be said that there is no formal record as defined in the verification and validation sub-process.
Define a mechanisim for nonconformancess and check the possibility that the nonconformances are solved in the verification and validation period or not.	There is a policy for nonconformances that is prepared by Quality team but this policy is not applied for verification and validation activities.
Define bidirectional traceability from contract to the verification and validation document that can cover the related activities	It is not applied for all design projects.

The Elements of Conceptual Model *(Verification and Validation of Design)*	**Real World Activities**
Define risk management activities, analyze and document them.	There is no formal documentation for risk management activities in the concept of technical solution sub-process
Monitor and control the process	Performance criterias are defined but there is no measuring, monitoring and controlling mechanism.

4.7 Stage 6: Define Proposed Changes

4.7.1 Requirement Elicitation, Analysis, Management and Changes

The proposed changes that will guide to Engineering Design Department to improve the requirement management sub process are addressed as follows:

- The definition of a new review mechanism that covers either design engineers or other responsibilities such as Quality Assurance, Configuration Management and Risk Management team.

- The implementation of review activities by generating related records.

- The definition of a new policy or instruction that should guide to requirement managament activities including all work instructions and existing process documents.

- The definition of impact analysis, methods and approach for requirement changes that can effect the final product directly or indirectly.

- The implementation of requirements changes after being reviewed the impact analysis by project team that inclues not only designers but also Quality Assurance, Configuration Management and Risk Management responsibles and generating related records for this review activity.

- The realization of a new approach about impact analysis not only designed product level but also system level because of having interrelations with other designed product.

- The improvement of an approach or policy about defining hardware and software configuration items at this sub-process phase and the completion of them.

- The selection of a tool for bidirectional traceability from contract to test documents and adding required information about this approach to the policy or instruction that will be defined.

- The definition of a new method for revision of employee’s skills and registration of them.

- The implementation of monitoring and controlling activities for requirement management sub-process by auditing and defining a method and/or performance criterias that can be measured.

4.7.2 Technical Analysis of Design

The proposed changes that will guide to Engineering Design Department to improve the technical solution sub process are addressed as follows:

- Determination of critical design requirements and their alternatives. While specify the critical design requirements and their alternatives, the methods and approaches that are used to verify and validate them, should be also taken into consideration.

- The decision mechanism for architectural structure. An instruction or policy should be prepared for this purpose and the criterias that are used for decision, should be defined in it. The required criterias are defined on conceptual model as cost, schedule, performance, reusability and customer’s requests. Generally, comparison approach is preferred for decision and the details can be defined on decision instruction/policy.

- The definition of product’s specification in accordance with the requirements that are defined on requirements management sub-process. This definition shoul include product’s circuit diagrams, product trees and (if requires or there is any risk) product’s alternatives. After definition is completed, this product’s sepcification should be documented. It should be also reviewed by design team.

- The determination of configuration items as software and hardware configuration items by taking into consideration the existing infrastructure. At this phase, evaluation of infrastructure has an importance for design implementation. If there is any deficiency, the project schedule can delay. The defined configuration items should be documented and reviwed by design team.

- The definition of interfaces as physical, hardware and software and then documentation of them. The documentation of interfaces has an importance for integration phase. Therefore, documentation activity should be performed for every design project. Review of the documentation should be performed by design team.

- The reusability analysis for components/architectural structure/product's specification and documentation of them. It can be said that reusability is an important manner for the organization because of serving similar porducts to the market. Therefore, it can be said that reusability can provide benefits to the organization. The reusability analysis should be performed for every projects.

- The generation of design document covering the information about architectural structure, products' specifications, configuration items, interfaces and reusability analysis. After documentation process, this document should be reviewed by not only design team but also responsibles like Quality Assurance, Configuration Management and Risk Management. Additionally, it can be suggested that interface documents should be prepared as separately from design document to be more functional.

- The selection of a tool for bidirectional traceability from contract to design document and adding required information about this approach to the policy or instruction that will be defined.

- The definition of a new method for revision of employee's skills and registration of them.

- The definition of a new policy or instruction that should guide to risk management activities for technical solution sub process. There are some critical points such as purchasing required components, defining alternative architectural structures and configuration items etc.If there is any problems about the defined risks, it can cause delays on schedule, over cost, low performance etc.

- The implementation of monitoring and controlling activities for technical solution sub-process by auditing and defining a method and/or performance criterias that can be measured.

4.7.3 Integration of Designed Configuration Items

The proposed changes that will guide to Engineering Design Department to improve the integration sub process are addressed as follows:

- The definition of integration phases that include knowledge about the integration order of related configuration items.The integration plan can be updated to cover it.

- The implementation of review activities generating required records.

- The definition of an appoach that enables the participation of other responsibilities like Quality Assurance team. Generally, these activities are performed by organization's employees and there is no participation by customer. Quality team can evaluate the integration status more objectively.

- The specification of performance criterias for integration to evaluate its success. These criterias should also provide a decision mechanism about completion status of it.

- The determination of a formal declarition record for integration test team. Generally test team can be changeable from test to test and this makes difficult to trace test sessions of integration. This declaration can be defined in integration document as responsibility topic.

- The definition of a new review mechanism that covers either design engineers or other responsibilities such as Quality Assurance, Configuration Management and Risk Management team.

- The determination of a checklist to control integration environment before starting to the integratin tests. This checklist should be produced as a formal record.

- The definition of a control mechanism that give information about relevance of integrated configuration items. Most of configuration items are developed at technical solution sub process and generally it is assumed that the developed configuration items are ready for integration. A formal record or checklist should be defined.

- The definition of a nonconformance system to trace errors/bugs that are identified during integration test session. There is a defined nonconformance system in the organization but it is not applied for integration activities. The existing nonconformance system should be updated as covering the integration activities.

- The selection of a tool for bidirectional traceability from contract to integration document and adding required information about this approach to the policy or instruction that will be defined.

- The definition of a new method for revision of employee's skills and registration of them.

- The definition of a new policy or instruction that should guide to risk management activities for integration sub process. There are some critical points such as planning integration activities, deciding the order of configuration items for integration, defining integration test scenarios, testing integration activities for configuration items and their interfaces.

- The implementation of monitoring and controlling activities for integration sub-process by auditing and defining a method and/or performance criterias that can be measured.

4.7.4 Verification and Validation of Design

The proposed changes that will guide to Engineering Design Department to improve verification and validation sub process are addressed as follows:

- The definition of verification and validation phases that include knowledge about verification and validation activities.The verification and validation plan can be updated to cover it.

- The specialization of required test environments for verification and validation test activities. Test scenarios are generally defined but the test enivronments are not defined and evaluated.

- The definition of core test activities that can be performed by all design project in the organizaiton. These test environments are built in a laboratory and can provide advantages about unnecessary rebuilding processes.

- The determination of analysis that can be preferred for verification and validation activities. Some analysis can be performed for design project but there is no formal approach for analysis.

- The implementation of review activities generating required records.

- The definition of an appoach that enables the participation of other responsibilities like Quality Assurance team to verificaiton and validation activities. Generally, these activities are performed by organization’s employees and there is no participation by customer. Quality team can evaluate the verification and validation status more objectively.

- The determination of a formal declarition record for verificaiton and validation test team. Generally test team can be changeable from test to test and this makes difficult to trace test sessions of verification and validation sub-process. This declaration can be added in verification and validation document as responsibility topic.

- The definition of a new review mechanism that covers either design engineers or other responsibilities such as Quality Assurance, Configuration Management and Risk Management team.

- The determination of a checklist to control verificaiton and validation test environments before starting to the integratin tests. This checklist should be produced as a formal record.

- The definition of a control mechanism that give information about relevance of integrated products to the test activities. Most of integrated products are the outputs of integration sub-process and generally it is assumed that the integrated products are ready for verification and validation. A formal record or checklist should be defined.

- The definition of a nonconformance system to trace errors/bugs that are identified during verification and validation test session. There is a defined nonconformance system in the organization but it is not applied for verification and validation activities. The existing nonconformance system should be updated as covering the verification and validation activities.

- The selection of a tool for bidirectional traceability from contract to verification and validation document and adding required information about this approach to the policy or instruction that will be defined.

- The definition of a new method for revision of employee’s skills and registration of them.

- The definition of a new policy or instruction that should guide to risk management activities for verification and validation sub process. There are some critical points such as planning verification and validation activities, controlling integrated produtcs, defining verification and validation test scenarios, testing integrated products and their interfaces.

- The implementation of monitoring and controlling activities for verification and validation sub-process by auditing and defining a method and/or performance criterias that can be measured.

4.8 Stage 7: Take Action to Improve the Problem Situation

Part 4 presents the findings of this research study which applied all stages of Soft Systems Methodology, except the implementation stage. The findings and proposed changes about them are shared with the organization.

CHAPTER 5

5. CONCLUSION

5.1 Discussion

Soft Systems Methodology (SSM) is derived after failure of hard systems approach in messy management problem situations and focuses on mainly human factors such as human beings involvement, human situations, and cultural-social considerations. This methodology enables breaking the problematical situations into smaller components and then analyzing each of them more detailed.

Toward the end of exploring the usefulness of SSM to improve design process, the findings related with research questions are detailed as follows.

The means of optimizing change in the organization’s design process can be identified and modelled consistently, using a soft systems approach. The semi-structured interview topics and the interview materials, that contain documents, policies, procedures, plans, reports, non-conformances related with sub-processes of design process, are used to define the rich pictures that provides the means of identifying pathways to the solutions for the problematical situations. By following the SSM of defining rich pictures, the root definitions of the required transformations are established. At this phase, the worldviews of the employees, employers and process owners are also used to define the organization culture. The representations of required activities for design process improvement are addressed on the conceptual models and compared with the real world activities. This comparison also gives the ideas about improvement cost to the process owners and managers. The root definitions and conceptual models that are built for sub-processes of the design process provide clear identification of the characteristics of the transformation and the path away to achieving the implementation.

The participants in semi-structured interviews have similar background at their education levels. The most of proposed changes are based on lack of some documentation about activities performed or not. There are documentation needs about requirements changes, impact analysis, definition of bidirectional traceability, revision of employee's skills, review mechanism, decision mechanism, reusability analysis, risk management activities, checklist, definition of integration phases, non-conformances' records and formal definition of test environments. These improvements can be implemented into design group with the supports of employees, process owners and managers within acceptable cost. In additionally, quality assurance team can have a supportive role for these improvements by checking or controlling the expectations of some standardization organizations.

In the concept of research study, the methodology is applied only the design process and its' sub-processes. During this study, it is proved that SSM is a fruitful in identifying various approaches for improvement. Interviews with employees, process owners and managers revealed that there are extensive lists of options for improvements in design process and its' sub-processes. The most of improvements, that are suggested, are addressed during interviews by questioning as to why things are processed the way they are. Therefore, this methodology can be applicable to other processes of the organization and also other organizations for improving existing processes and it seems to be an appropriate guiding methodology.

Besides the main findings of the study, the participants in the design process' focus group are the most stressed about meeting the customers' needs and the quality of designed products. These concerns effect also the motivation of the designers and sometimes causes the schedule's delays that can be concluded as not performing the required process activities that are defined. Therefore, some outputs such as plans, reports, non-conformances reports, checklists that have already existed in the processes are not produced or prepared.

5.2 Conclusion

In this research study, finding out the participants' desired characteristics for the design process and its sub-processes are aimed. This study considers four case studies related with design process and its sub-processes in an organization whose processes are generally defined in accordance to standards and guidelines and all facing problematic cases that require extensive processual changes are addressed. Soft Systems Methodology is applied to each sub-process of existing design process and its sub-processes to specialize an improvement approach for them. The data is gathered with semi-structured interviews by questioning the topics given in Appendix-A. Then the required analyzes in the concept of SSM are performed to generate outputs that can give information or clues about process improvement. Acceptable solutions are proposed after structuring the conceptual models and comparing them with real world activities. Consequently, the rate of changes about process improvement can be enhanced by the application of SSM stages.

From the interviews with participants, deeper knowledge about existing design process and its sub-processes are acquired. The results of this study show that the process can be improved in accordance to the defined proposed changes based on the rich pictures, root definition and conceptual models. Comparison of the conceptual models with the real world activities provides a learning cycle for evaluating the implementations of viable and desirable changes. It is realized that SSM has the following characteristics; the capability for understanding and modelling the problematic situations and the capability for learning.

5.3 Contribution to Learning

Although there are many applications for the extended use of Soft Systems Methodology in the literature, there is little evidence recorded about its use for improving design processes in the organizations. This research study concentrates four case studies related with design process for the applications of SSM stages. It shows that the process improvements can be determined by evaluating the existing processes with SSM. It also identifies the generation of creativity and innovation for the design process and its sub-processes.

5.4 Limitations of the Study

In this research study, the information provided is based on the semi-structured interviews with focus group of the organization and some documentation of concern could not be focused because of unavailability and restriction.

Although the models of sub-processes (refer Figure 4.1.2, 4.1.3, 4.1.4 and 4.1.5) are defined based on the gathered data, these models could not fully cover the real world activities. There may be some unseen activities that support other processes or activities and SSM could not focus on these unseen activities because of mainly focusing on the design process and its sub-processes.

The participants that contain employees, process owners and managers may not express their options openly that can cause to the inappropriate analysis. The design process and its sub-processes can be interpreted differently from employee to employee and therefore it complicates the understanding real world activities and building their conceptual models.

The process owner of integration sub-process went on leave for a long time. Therefore, the interviews were performed with only employees and managers (not the process owner of integration sub-process).

The stage seven of SSM is about taking action based on the conceptual models and this stage requires some resources. This stage is out of the scope but the methodology does not address by whom this action will be taken and how implementation of proposed changes will be carried out.

5.5 Delimination of the Study

There is no delamination in the concept of the study.

5.6 Implications for Practices

This study is a role model for all processes in the organization to develop and improve in accordance to their own needs for increasing the products' quality. SSM can be used by any organizations and other organizations to define the complex situations and their solution approaches. Proposed changes are determined based on the defined rich pictures, root definitions and conceptual models. The implementation of proposed changes without significant resistance from employees, management should support the improvements. This study reveals that SSM is a flexible tool and can be applicable to any processes of different organizations.

5.7 Recommendations for Future Research

This study was conducted in only improvement of design process and its sub-processes for an organization. The Soft Systems Methodology was applied and worked successfully in the chosen process. This research study has found the proposed changes for four sub-process of design process. It is known that the methodology would be successful in human factors, organizational cultures and observations where participants (employees, process owners and managers) are clear in expressing their own opinions and taking active roles during changing process.

The organization has many processes except from design process such as risk management, quality assurance, configuration management, project management, system engineering and so on. The all processes that exist in the organization can be analyzed with SSM and proposed changes can be determined in accordance to analysis' results. The common desired characteristics of an improved process stated by the participants could inform a future implementation in other processes with a similar interview design, organizational context and cultural background. Following changes and implementations that continue to define problematic cases and build conceptual models for processes, usability studies, performance and the products' quality should be improved continuously. This will also serve to ensure continuous improvements of the design process and other processes.

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APPENDICES

APPENDIX A

Interview Design

Target Interviewee: Design sub-processes owners, designers and their managers.

Nature of Interview: Group interview, face to face meetings.

Interview Type: Semi-Structured

Methods of Appointment: Personal Contact, Personal Visits, Emails and Telephone.

Themes: The themes that are given below, are determined from acquaintance meetings. The first meeting is coordinated to include participation of employees' representatives, process owners and the managers of the design engineers. The general knowledge about design process and its' sub-processes is obtained from this meeting. The collected data is categorized as themes and they are shared as follows.(All of collected data is not shared because of some restrictions/limitations for organization. In addition to Appendix A, the contents of interviews for sub-processes are summarized and given at Appendix B.)

Themes	**# of Themes Density** (*)	**Responsibilities of Employees Mentioned to Themes**
Process Documents	21	Employees, Sub-Process Owners, Managers
Flow Diagrams of Process and Sub-Processes	8	Generally sub-process owners
Procedures and Policies	20	Employees, Sub-Process Owners, Managers
Planning (Engineering Design Process)	11	Design team leaders
Effort and Cost Estimation	5	Managers and Design team leaders

Themes	**# of Themes Density** (*)	**Responsibilities of Employees Mentioned to Themes**
Risk (Identification and Categorization)	28	Sub-Process Owners and Managers
Requirements (Management/Changes/Traceability)	55	Employees, Sub-Process Owners, Managers
Changes (Request)	37	Employees, Sub-Process Owners, Managers
Architectural Structure of Design	17	Employees and Sub-Process Owners
Interface (Identification and Management)	39	Employees and Sub-Process Owners
Details (the Design Requirements)	23	Employees and Sub-Process Owners
Hardware	42	Employees and Sub-Process Owners
Software	40	Employees and Sub-Process Owners
Review (Related Documents, Plans and Records)	32	Employees and Sub-Process Owners
Test (Activities and Their Concepts)	53	Employees and Sub-Process Owners
Integration (Activities)	27	Employees and Sub-Process Owners
Verification (Activities)	21	Employees and Sub-Process Owners
Validation (Activities)	25	Employees and Sub-Process Owners
Prototype (Products)	8	Employees and Sub-Process Owners
Training	46	Employees and Sub-Process Owners
Non-conformances	13	Design team leaders, Employees and Sub-Process Owners
Configuration (Activities/Management Records)	15	Design team leaders, Employees and Sub-Process Owners
Traceability between Process and Sub-Processes	22	Design team leaders, Employees and Sub-Process Owners
Design Baselines	11	Design team leaders, Employees and Sub-Process

Themes	**# of Themes Density** (*)	**Responsibilities of Employees Mentioned to Themes**
		Owners
Process and Sub-Processes Evaluation	29	Managers, Design team leaders, Employees and Sub-Process Owners
Audits	5	Sub-Process Owners
Environment	11	Employees and Sub-Process Owners
Team (design, other responsibles)	29	Sub-Process Owners
Analysis	8	Design team leaders, Employees and Sub-Process Owners
Meetings	15	Design team leaders, Employees and Sub-Process Owners
Quality	13	Sub-Process Owners
*: The "number (#) of themes density" information for given themes is gathered from minutes of meetings that are prepared for first meeting (acquaitance meeting).		

APPENDIX B

Meeting #1 (General Evaluation of Design Process)

"…The deign process is defined on procedure, policy and process documents….Process documents contain the required details for the work that are performed……The flow diagrams are defined on process documents…..The flow diagrams gives detailed information about process and sub-processes….Procedures and policies may not be used sometimes because of some schedule delays….Generally, a life cycle is defined takin into account the project structure…. The life cycle can be defined on a document or not, there is no restriction or obligation about it…..The design activities are planned….The planned activities can provide inputs to the project planning…. There is obligation about providing inputs to project plans…. Efforts and cost are changeable from project to project… Generally, estimation about cost and effort are made…..This estimation is shared or not… This estimation are related with managers not employees…There can be risky topics at some projects…There is a risk manager in project team but he/she mainly concern with the project risks……It is thought that the risk related with design phases are principally related with design activities and so the preventive activities are defined by design team……There are sub-processes of design process and responsibilities changes in accordance to these sub-processes…..Generally, design activities starts with requirements….Requirements are generally defined by customers and system engineers….Generally, design activities starts after being signed the contract….Sometimes, customer requests may be changed…….The changes are informed via project team….There is a need to track requirements changes……..Some requirement changes may cause big problems….The requirements that are defined at contract may be high level requirements….Designers divide the requirements into low level….Traceability is very important for verification and validation activities……At some project, traceability is defined from contract level to equipment level, but this is not applicable for all projects…..Architectural structure has importance for design activities….The configuration items should be defined as hardware and software…..The interfaces between configuration items should be addressed……The interface definitions are very important for integration activities…..Generally, design documents are prepared that contain all design activities from requirements management to completion of verification and validation activities…..Test plans should be prepared….The documents and plans are usually prepared after the related activities are completed…….Test scenarios are defined for integration, verification and validation activities….. …Test scenarios are very important for verifying the requirements about meeting customers' needs………Primary design and then detailed design is implemented…..The prototype version of the design product is built by integration activities…… The prototype version is ready for tests…..Integration activities are implemented based on defined test scenarios…….The test can be repeated……There can be some non-conformances……Training is important but generally there is no time for training……There is schedule jam……The configuration items are defined but the other configuration activities may not be performed….The baselines are not defined or defined very late when it is compared with time to be…….There is generally no audits for design activities, design sub-process activities…..Traceability between process to sub-process are known by related employees not others……. The knowledge can be depend on employees…..Design baselines are defined very late as it should be…….The evaluation of design activities, design process and its sub-process are not performed because the schedule is very busy…….The audits can be performed for some projects but not all of them….There is need to define the activities that are performed….. Some activities are performed but not exist in the process…..There is some misunderstandings about the process flow….”

Meeting #2 (The Evaluation of Requirements Management Sub-Process)

"…The contract is used to derive the requirements…A responsible for design activities are defined…Sometimes, the responsible for sub-processes can be defined for the projects….There is information for design activities…Meetings can be organized with customers to provide a clear understanding about requirements and their details…..Project team has responsibility for the relationships with customers….Detailing the requirements are important to design…If requires, the technical researches are performed…The implementation techniques are evaluated with design team members…..The qualification of the requirements are evaluated while defining the implementation techniques….Some requirements may be high level…. Some requirements are divided into low level…. At these phases, the meetings can be organized in design team….. Project team can be invited or not….Meeting records are prepared from time to time…Designers have detailed requirements….Uncertainties are eliminated….At some cases, uncertainties cannot be realized….Unrealized uncertainties may not be eliminated up to validation phases…..There is no risk activity for unrealized uncertainties….Software and hardware requirements are classified….The hardware and software design team are defined….The related requirements are shared with hardware and software design team…..At some projects, the configuration items can be defined….Traceability is generally defined …..If there is any request about bidirectional traceability, it can be provided…..Generally, there is no formal bidirectional traceability mechanism to produce the required outcomes….After classification of requirements, the test scenarios are defined….How to verify these requirements?.....How to integrate these requirements?....Let's define the test environments….We should analyze the requirements by evaluating defined test scenarios…..There are some misunderstandings….There can be some uncertainties that are unrealized…..We should change the requirements…..Let's do the impact analysis of the changes….Generally, there is no formal records for impact analysis…. There can be some non-conformances….. Customer should be informed about requirements changes….Let's check the changes are required or not…..This should be evaluated on a meeting…..If customer attends to the meeting, a record should be noted….Generally, the customer wants to review the minutes of meetings…The changes are required….Let's update the design document….Generally, internal review are implemented….Generally, there is no need for the participation of project team to review updated design document…..There is no participation of quality team, configuration management team and risk management team….Updated design document can be shared with customers if there is any requests. …The updated design document is approved….Generally, requirements management activities contain elicitation, management and changes of requiremen…Trainting is important but generally there is no time for training…"

Meeting #3 (The Evaluation of Technical Solution Sub-Process)

"…..Requirements and their test scenarios are defined at requirements management sub-process…..the requirements can be categorized as low level and high level....There is need to define the critical requirements……The design specifications are defined based on the performed activities at requirements management sub-process….the design architecture should be defined… Generally, there is no formal bidirectional traceability mechanism to produce the required outcomes…...Product specifications are generally defined before integration sub-process…….The defined design architecture is used to define product architecture…...The configuration items are determined based on defined product's architecture…..The physical interfaces are determined….. The hardware and software interfaces and configuration items are specified……The qualification of interfaces are evaluated by related designers but there is generally no records related with it……If the interface definition are not enough, some changes should be implemented on requirements…….. the requirements changes triggers the schedule delays……….The qualification of hardware and software interfaces are evaluated……During evaluation phases, there are many meetings within designer not project team……..The required data, infrastructure, components are provided to implement hardware and software items…….The required tests are defined for designed hardware and software components… There can be some non-conformances……Training is important but generally there is no time for training…The coding activities are performed by software design engineers…..The integration of software and hardware is a very critical issue for integration phase but the interfaces between them are thought during technical sub-process……All activities that are performed at this phase are documented by designers……the design document are prepared and reviewed…..The review activities are generally implemented within design tea…..There is no participation of quality team, configuration management team and risk management team…. If customer have a request about reviewing design document, the document are shared with customer via project team…..The review activity is generally recorded….The test environments are also defined for software, hardware configuration items and their interfaces…..the defined test environments are also important for integration, verification and validation phases…….There is two review steps named as primary design review and critical design review at the procedure and policy……These review activities are important for the baselines of requirements that are used for the following sub-processes….."

Meeting #4 (The Evaluation of Integration Sub-Process)

"……Integrated items and their orders are defined……Before integration activities, it is evaluated that the configuration items are ready for integration…..The integration environment are evaluated and specified…….Integration steps are determined……The all activities that are defined in the concept of integration are documented on a plan…….Planning is important for project schedule…….The priorities can be also defined on this plan……This plan is documented……the plan is reviewed within designers (not containing the project team)……There is no participation of quality team, configuration management team and risk management team….After approval of the plan, the integration activities are documented in detail…..Integration document should cover the integration techniques and the methods how the activities are performed……..Design document can be used as an input for integration document because of containing the detailed information about designed items…..Generally, there is no formal bidirectional traceability mechanism to produce the required outcomes … ….Baselines are defined very late as it should be…….Also the integration test scenarios are defined in the integration document…….This document should be reviewed before starting to integration activities……the integration document generally is reviewed by designers (not including the project team)…….Integration activities are performed based on the order that is defined on the integration plan……The hardware and software items are integrated taking into account their interface specifications……The environment should be as defined on the integration document…….The integrated product is ready……The test are performed on the integrated product in defined test environment… There can be some non-conformances ..…Test report is prepared that summarizes the integration test activities….There some errors, bugs or non-conformances related with the integrated products…. Generally there are no formal records about these errors, bugs or non-conformances…... they are mixed and then the integration phase is completed……Training is important but generally there is no time for training…"

Meeting #5 (The Evaluation of Verification and Validation Sub-Process)

"…..The verification and validation concepts are defined…..a data set is required and therefore it is prepared……All of them are documented on a plan……the plan does not cover the detailed information about verification and validation activities…..The reviews of the plan is performed within design team……..There is no participation of quality team, configuration management team and risk management team….The data set is evaluated based on requirements, the designed products and their non-conformances that are realized at integration sub-process……..The test methods are defined…….test methods are documented that covers also the data set……the verification and validation document are prepared that contains the all activities that will be performed at this sub-process…….The verification and validation document is reviewed within design team (not include the project team)….Baselines are defined very late as it should be…….Generally, there is no formal bidirectional traceability mechanism to produce the required outcomes….…The test scenarios and test environment are built for verification and validation activities…..Test activities are implemented…….the schedule of the tests can be critical……The results of test activities are evaluated based on the non-conformances that are encountered during test activities…..If the activities are completed with successfully, a test report should be prepared…….If not, the errors should be fixed……There are some reverse loop for design sub-processes. The non-conformances can cause some requirements changes and this case also cause to repeat some design activities from the beginning……..After fixing the problems, errors, bugs and non-conformances, the designed product is ready for manufacturing process. The design process and its sub-process are completed with successfully……Training is important but generally there is no time for training…"