INTEGRATED PIPING ENGINEERING DESIGN MANAGEMENT MODEL FOR OIL & GAS INDUSTRY IN INDIA

By

DEBARUN DUTTA

COLLEGE OF MANAGEMENT AND ECONOMIC STUDIES
(DEPARTMENT OF OIL & GAS)

SUBMITTED

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

To

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
DEHRADUN, INDIA
August, 2015

Under the Guidance of

Name: Dr. Shailendra Kumar Pokhriyal
Designation: Professor & Head of the Department of Oil & Gas, CoMES
Institution: University of Petroleum and Energy Studies

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জয় মহারাজ

DEDICATION

I whole-heartedly dedicate my work to

God,

my great Gurudeb

Sri Sri Mohonananda Brahmachari Maharaj

and my Family, especially my Father

Mr. Deb Kumar Dutta,

my Mother

Mrs. Arundhati Dutta,

My Brother

Dr. Debanjan Dutta,

my Wife

Mrs. Amrita Dutta

and my Son

Master Debayan Dutta.

জয় মহারাজ

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ThankYou Lots & Lots

Yours Sincerely,
Debarun Dutta,
UPES Enrolment No.: 500013996,
Cell Phone No.: +601123503875 & +919874740089.

Declaration by the Research Scholar

This is to certify that this submission is my own work and that, to the best of my knowledge and belief, my thesis titled "Integrated Piping Engineering Design Management Model for Oil & Gas Industry in India" is a piece of original bona-fide research work done by me, in partial fulfilment of the requirements for the award of Doctor of Philosophy in Management (Oil & Gas) degree by University of Petroleum and Energy Studies (UPES), India. I hereby declare that this work has not been submitted in part or full to any other Institute or University, in India or abroad, for any degree or diploma, except where due acknowledgment has been made in the text. My indebtedness to other referred works has been duly acknowledged at the relevant places.

Debarun Dutta	20th August, 2015	Dehradun, India
(Researcher's Name)	(Date)	(Place)

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Thesis Completion Certificate

This is to certify that this thesis titled "Integrated Piping Engineering Design Management Model for Oil & Gas Industry in India" submitted by Mr. Debarun Dutta to University of Petroleum and Energy Studies (UPES), India, for the award of Doctor of Philosophy in Management (Oil & Gas) degree is a piece of original bona-fide research work done by him under my supervision and guidance. The contents of the thesis, in full or parts have not been submitted to any other Institute or University for the award of any other degree or diploma.

Dr. Shailendra Kumar Pokhriyal	24th AUGUST 2015	Dehradun, India
(Research Supervisor's Name)	(Date)	(Place)

BIDHOLI CAMPUS Energy Acres, PO Bidholi Via Prem Nagar, Dehradun 248007 (UK), INDIA, T +91-135-2102690/1, 2694201/3/8 F +91-135-2694204
KANDOLI CAMPUS Knowledge Acres, Vill. Kandoli, PO Bidholi Via Premnagar, Dehradun 248007 (UK), INDIA, T +91-135-2102647/2102760
CORPORATE OFFICE 2nd Floor, 210, Okhla Industrial Estate, Phase III, New Delhi-110020, INDIA, T +91-11-41730151-53 F +91-11-41730154

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Executive Summary

Effective management of Piping Engineering Design is indispensable to sustain the competitive advantage of any engineering company. Piping Engineering Design Management consists of two sides - Design Product Engineering Side & Design Process Side. Previous researches in this field in different industries have found out many challenges or issues that need to be taken care of in order to make an effective design management model. However, those researches have only concentrated on some issues on a particular side of the design management cycle while not addressing the others. So, the models that have been built so far did not provide integrated management of all the identified issues on both the sides of the design management cycle. But the future demands an efficient design management model that caters to all the identified issues on both the sides. This research takes the existing knowledge in this field a step further by highlighting the minimal aspects of a much needed model catering to all the identified issues plaguing the management of engineering design on both the product & process sides of engineering design management, a step that the previous studies have not uncovered.

Previous researches have evidenced that an integrated management model for managing engineering design is indispensably needed to aid design engineers in their design management decisions and to sustain the competitive edge of the company because efficient management of piping engineering design management cycle is crucial to sustain any company's competitive advantage, thereby preventing time loss, opportunity loss & revenue loss. The companies who do not have effective design management practices/models are much less successful in business than the ones having it. This is the business problem.

The existing studies have established that design management cycle comprises of Three Governing Levels:

Strategic Design Management,

Tactical Design Management,

Operational Design Management.

Some other researchers have established that at Each Level, design expertise can be effectively managed to produce an innovative solution through Three Layers:

Enabling Technology Layer,

Solution Layer,

Interface Layer.

The holistic Piping Engineering Design Management Cycle has Six Phases namely:

Establishing a Need Phase

Analysis of Task Phase,

Conceptual Design Phase,

Embodiment Design Phase,

Detailed Design Phase,

Implementation Phase.

The management of Piping Engineering Design has Two interfering Sides:

Design Product Engineering Side,

Design Process Side.

The three governing levels of design management run on both sides (Product side and Process Side) through each of the six phases of the design management cycle. Multiple issues have been found to be plaguing the design management cycle in each phase, on each side and through each governing level.

From the comprehensive reviews of over three hundred available relevant existing literatures, it has been found that there have been some researches in the broader field of Multidisciplinary Engineering Design Management. There have also been some researches in the Management of specifically Piping Engineering Design. It has been found that these studies have been done for Architecture, Civil, Construction, Electronics, Transportation industries; they are different among themselves and do not throw any light on the state of design management affairs in the oil & gas industry. Previous studies have also established that, engineering design thinking & corresponding design activities in different industries in differing situations have crucial differences.

Previous studies have established that an integrated management model for managing engineering design is indispensably needed. The previous studies have their respective limitations. Some researchers have focused only on the Product Side of Engineering Design Management and have so far found out three issues challenging the efficient management on engineering design on the Product Side. Whereas some other researchers have focused only on the Process Side of Engineering Design Management and have so far found out four issues challenging the efficient management on engineering design on the Process Side. Existing literature review has evidenced that engineering design management can be effectively managed if the identified issues are catered to. Previous studies for specifically piping engineering design management have focused only from a pure engineering point of view, ensuing a colossal dearth of focus on the management aspects in the product as well as the process sides of design management; the existing studies did neither focus on the piping enginering design management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides. Further, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. An extensive literature review covering over three hundred relevant available literatures yielded no references of any design approaches & models for oil & gas piping engineering design management in India. The previous studies neither throw any light on the design management in the global oil & gas industry nor on the design management issues of any industry in India. There has been no research to know how design is being managed in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. However, previous studies have established that design management roles, practices and activities significantly & crucially vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an integrated design management model and in India no research has focussed on engineering design management. The identified research gaps have not been addressed by any of the previous studies. This present research tries to answer these questions and thus address these dodged research gaps in a bid to improve engineering design management in India.

The present research objectives have been:

To Study the Existing Practices/Models of Piping Engineering Design Management that are being used in oil & gas industry in India.

To Identify the areas of improvements in order to develop a Model of Piping Engineering Design Management.

To solve the business problem, address the research gaps, answer the research questions and fulfill the research objectives, the existing practices of piping engineering design management that are being used in the piping engineering design department of India's largest oil & gas company have been studied, issues identified, compared with other researchers' finding, each research step has been deeply thought upon, profoundly analyzed, rigorously verified and an integrated model of piping engineering design management has been proposed as seriated through the following paragraphs.

After careful consideration of established methods & approaches, a descriptive qualitative case study with a grounded theory approach has been chosen as the philosophy of this research owing to the approach being the best suitable research mode for this particular study of the problem through the objectives. This is because the present research purpose has been descriptive (fact finding about a state of affairs), research process has been qualitative (for a phenomenon related to quality) and research approach has been a grounded outlook (to systematically generate theory from data through inductive thinking about a phenomenon of interest). Sample selection has been done in three stages, while decreasing sample size by using the Theory of Elimination and unit of analysis has been critically chosen in line with the research objectives. Detailed case study questionnaire has been developed in three steps so as to enable an appropriate research into the answers to the research questions. Data have been collected and analysed in line with the research philosophy and rationale. All evidences substantiating the case study have been archived and are being maintained with the researcher. The validity of the case study has been verified by employing a number of tactics. To ensure construct validity & internal validity, two tactics have been employed. First, two levels of analyses are undertaken during data analysis – conceptual and detailed. Secondly, the case study reports are reviewed by key informants and then their feedbacks have been incorporated in the final research. This present research study is expected to provide depth and so the study intended to provide an insight into the probable relationships suggested and therefore to generalize beyond this particular research area would require additional confirmation of results that is beyond the scope of this particular research and has been included as a further research scope. Although the research is limited to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India, however, a point to be noted here is - this research establishes that the seven challenges of design management identified outside India are applicable to the oil & gas industry in India plus there are some additional five challenges specific to the Indian oil & gas context and therefore, theoretically it can be inducted that most/all of the found out issues and their solution model proposed through this research shall be applicable to the other oil & gas companies as well (the researcher, through his previous work experiences, has also experientally observed these issues to be plaguing design management in some other oil & gas companies in India as well as abroad); further, external validity is beyond the scope of this particular research and is a future research arena. Reliability has been highly ensured through apt instruments, archival of all evidences and use of data analysis software Atlas.ti. This research employed a number of approaches to ensure high reliability while applying procedures for data collection and analysis. First, the case study protocol has been used to guide the research process as the protocol is a major tactic in increasing the reliability of a case study research and is intended to guide the researcher / investigator in carrying out the case study. The protocol has comprised of instruments as well as procedures and general rules that have been followed. This ensured consistency in the areas covered. Secondly, to reduce the likelihood of forgetting or misunderstanding the data and to allow independent data analysis by other researchers, interviews have been taped, transcribed and all original evidences are archived. Thirdly, the use of Atlas.ti qualitative analysis software allowed systematic & consistent analysis of the qualitative data and further increased the reliability of this research because procedures can be repeated. Fourthly, the field notes taken by the researcher have been also transcribed for future reference.

Different levels of coding, within case analysis (conceptual & detailed), theory triangulation, employment of case study protocol, use of software Atlas.ti, archival of all evidences, etc. have been carried out to ensure high quality (construct validity, internal validity & reliability) of the study.

Data analyses has been done through grounded theory approach involving process iterations for movements between existing theory and the collected interview data, observation data & interaction data. The coding approach has involved perspectives of the theoretical framework/lens, the existing constructs and search for any new finding, in tune with the research objectives. The present case data analysis can be represented in three steps or levels. The first step has been open coding, followed by the second & third steps. Both the second and third steps have been focussed/selective coding and used axial focussed as well as theoretical focussed coding techniques. The third step differed from the second step by focussing deeper into the underlying relationships among the codes, categories & concepts; the identified inter-relationships, intra-relationships, cross-relationships and contra/clashing-relationships are linked as a pertinent root causal function. It may be noted that in vivo coding has been used in all three steps. While the first & second steps helped the researcher in exploring & understanding the existing practices of piping engineering design management and the challenges/issues by developing the codes, categories & concepts, the third step helped the researcher understand the relationships of the codes to the challenges/issues that affect the design management output in the existing practices.

The case study has been done through various data collection methods including interviews, observations and interactions with the team members. This study focusses on reality as perceived by the researcher himself, in line with the ideology that reality is what & how we perceive any particular issue and as such, this study is one of the several probable theories of the business management problem. By limiting the study to a single organization, the researcher is able to examine the case in more detail and to thoroughly understand the interrelationships of isolated data; this is more relevant because it focusses on depth of insightful knowledge instead of generality promoted by others. This approach may be criticized as developing localized theory; however, this is still a useful contribution to existing knowledge since it establishes that the issues plaguing the management of piping engineering design in other industries in other countries, are also applicable to India and there are some additional issues in the Indian oil & gas scenario. Further, the relevance of this specific research in the Indian oil & gas context is bona fide.

The concepts/theories/solutions have been refined in a number of iterative stages leading to natural theory built-ups from the analysis. These refined concepts/solutions have been then again iteratively integrated to synthesise the final refined concepts/theory/solutions.

The existing practices have been described and challenges existing in the present practices have been identified and compared to the issues found by other researchers in other industries; it has been observed that all the seven issues from previous researches are existing and five additional issues are identified to be plaguing the efficient management of piping engineering design in the oil & gas Industry in India. Catering to all the identified issues, a conceptual new model (appositely named Doctonaut) has been proposed to systematically and judiciously manage piping engineering design management.

The research objectives & questions have always been borne in the mind of the researcher throughout the entire research process, with special emphasis during the data collection and analyses stages of the research. As a result, each step has been deeply thought upon, profoundly analysed, rigorously verified and then used in the research. At the later stages, it has been verified whether the findings do indeed answer the research questions and meet the objectives.

Neoteric Knowledge Advancement by this study is gravitated in this paragraph. This study has reviewed pertinent existing research knowledge and has built a new basic conceptual framework; after that data has been collected and analysed as per a critically chosen research design and the previous research knowledge has been compared to the findings; it has been found that all the earlier identified seven issues are applicable to the Indian oil & gas context and additionally five more issues are found to be plaguing the effective management of piping engineering design. Finally, in line with the research objectives and questions, from the analysed data a brand new model of piping engineering design management, appositely named Doctonaut, has been built encompassing the entire cycle throughout each of the bi-sided six phases; the initially built basic conceptual framework has been suitably modified, augmented and aptly included as a part of this new model Doctonaut through an Operator-Integrator sub-model; this integrated model Doctonaut has been built extensively catering to all the previous seven issues (from previous researches) that are found to be applicable in the present research context as well as the newly identified five issues (from this particular research), catering to a total of all the twelve issues/challenges; thus, this present study substantially adds & advances the existing knowledge in this field of Piping Engineering Design Management.

This research work's consistency with the research objectives and questions has been successfully verified. Further, a few salient advantages of the study's findings, especially the new model Doctonaut, have been highlighted; for e.g., sustaining & developing the competitive edge of a company, improving the safety of personnel, equipment, environment & other stake holders of the design group, etc. The limitations of the study & the elicited potential areas of future research have also been documented; for e.g. applicability of the new model in other industries, etc.

In short, the previous researches as well as existing practices of piping engineering design management have been analysed and a conceptual new model named Doctonaut has been built that takes the existing knowledge a step further by validating the presence of issues identified elsewhere plus additional issues to be applicable to the Indian oil & gas sector as well as by integrating inductive solutions systematically into each stage of the entire design management cycle; this has been an indispensable step that the previous researchers have not ventured into and a step that ensures that the full benefits of the research knowledge of this field permeate each step of the entire design management cycle, thus guaranteeing continuous improvement as well as safety of the company's competitive edge, that in turn shall positively contribute directly to the development of the company and indirectly to the country & the world.

List of Abbreviations

Sl. No.	Abbreviation	The Defined Acronym's Full Form
1	AHARP	As High As Reasonably Practicable
2	ALARP	As Low As Reasonably Practicable
3	AMC	Annual Maintenance Contract
4	ANo.	Answer Number
5	ASME	American Society of Mechanical Engineers
6	BSI	British Standards Institute
7	Codes/Standards	Engineering Codes/Engineering Standards
8	C-S-Q	Case-Study-Questionnaire
9	Doctonaut	Deb's Octo-Operated Nauticator
10	EDM	Engineering Design Management
11	H-I	Head-Inquests
12	IBR	Indian Boiler Regulations
13	I-I	Innovation-Integrator
14	I-O	Interdisciplinary-Optimizer
15	IS	Indian Standards
16	ISO	International Standards Organisation
17	M-B-I	Multiple-Basic-Inquests
18	M-C	Multi-integrative-Communicator
19	NA	Not Applicable
20	NORSOK	Norsk Sokkels Konkuranseposisjon
21	O-E	Objectivity-Ensurer
22	O-I	Operator-Integrator
23	OpM	Operational Management Level of Engineering Design
24	P-D	Professional-Developer
25	PEDM	Piping Engineering Design Management
26	P-I	Probing-Inquests
27	P&ID	Piping/Process and Instrumentation Diagram
28	QNo.	Question Number
29	R-M	Rework-Minimizer
30	StM	Strategic Management Level of Engineering Design
31	T-B	Transknowledge-Balancer
32	TcM	Tactical Management Level of Engineering Design
33	U-P	Uncertainty-Positiviser

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Chapter 1: Prelude

Chapter 1: Prelude

This Chapter puts up the precursory business management problem inspiring this research, and also appraises the reader of the basic keys to engineering design management.

1.1 Problem Statement

The companies who do not have effective design management practices/models are much less successful in business than the ones having it (Bruce, Cooper, & Vazquez, 1999).

1.2 Background & Motivation

"Engineering Design is a systematic & intelligent process in which designers focus skills & knowledge to generate, evaluate and specify concepts for devices, systems or processes whose form and function achieve clients' objectives or users' needs for an optimum engineering solution while satisfying a specified set of constraints" (Dym, Agogino, Eris, Frey, & Leifer, 2005; Dutta, 2013a). Piping Engineering Design is a domain of mechanical engineering design (Tsai, Yang, & Liao, 2011) that studies the efficient transport of fluid or pressure from one point to another (ASME, 2014). Project Management is the art of making the right decisions in a customer-oriented way when faced with an array of alternative choices (Virine & Trumper, 2008; Dutta, 2013a). "Engineering Design Project Management or Engineering Design Management is the business side of design involving the interfacing of Engineering Design and Management united with the common goal of creating optimum engineering solutions for a better tomorrow" (Acklin, 2010; Design Management Institute, 2012; Dutta, 2013a). Successful management of engineering design is critical to cost-effectiveness, timeliness and quality of any engineering project and competitive advantage of the company (Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010). *Previous* research has proven that the more effective the design management practices of a firm are, the more the firm is successful in business (Bruce, Cooper, & Vazquez, 1999).

Piping Engineering Design Management (PEDM) is the business side of piping design involving the *interfacing of Piping Engineering Design and Management united with the common goal of creating optimum engineering solutions* for a better tomorrow (Acklin, 2010; Design Management Institute, 2012).

Management of Engineering Design can be traced back to the need based quest for bridging the gap between engineering design & corresponding business management, and this led to the birth of Design Management in 1944, when warfare & industrial needs drove the development of the British Design Council - Council of Industrial Design with the objective of promoting business practicability of engineering design (Wolf, 1993).

Researches have time & again proved that the design engineering role is of centrally pivotal importance to organizations engaged in product development (Pahl, Beitz, & (Ed.) Wallace, 1996; ASME, 2013, 2014; BSI, 2014) particularly as ***80-90% of production costs are determined at the conceptual design stage*** (Barbeau, 1998).

The crucial importance of design management in any organization's capability development is a widely accepted research proven fact (Owen, 2006; Mozota, 2006; Mutanen, 2008).

The criticality of the management of piping engineering design lies in the fact that ***piping consumes more than 40% of any plant's design engineering activities*** (Sheremetov, Batyrshin, Chi, & Rosas, 2008). Piping is popularly compared to the arteries in human body and, the adage that piping study is 'half science and half art' is true, the art part is visualization and creativity while the science part refers to following the established norms (Prasad, 2009).

From a comprehensive review of existing literatures on the subject, it has been found that the entire cycle of design management consists of six phases (Howard, Culley, & Dekoninck, 2008) discussed later & each phase consists of *two main interfering sectors – 1. the Design Product Engineering Side consisting mostly of the actual engineering design execution activities like CAD, Computer Aided Engineering (CAE), design optimization & product quality assurance, and, 2. the Design Process Side consisting mostly of the management of the associated design activities of the design product* like design knowledge management, design cycle sequencing-controlling-monitoring, conflict management, interdisciplinary management, innovation integration, feedback integration, non-value adding activities' identification & elimination, design change order management, rework minimization & design project work management (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000; Dutta, 2013a).

From the review of existing literatures, it has been further found that although there have been some researches on the Product Side, however, no evidence of research has been found on the Process Side or on the Product-&-Process-Sides-Integrated-Cycle of Piping Engineering Design Management (Dutta, 2013a).

But, since effective management of engineering design is critical to the competitive advantage of any engineering company, hence the research scholar has been motivated to research in this arena (Integrated Cycle of Piping Engineering Design Management consisting both the Product & the Process Sides).

This is the theoretical reason why the researcher chose this particular research. In addition to this, a part of the researcher's inspiration for this research can be traced to his practical piping engineering design management experiences in top oil & gas companies of India and abroad. It all started when the researcher has been practising as a design engineer in the very early stages of his career. During the course of his work, he noticed that different design managers manage engineering design in their different unique styles. And each style has some advantages as well as some inherent managerial flaws that are specific to the individual design managers but these diverse flaws affect the design output in the same way. For example, biased subjectivity (instead of objectivity), innovation mismanagement, etc. & these affect the design output quality negatively. The researcher's further piping engineering experiences in different engineering companies (mainly oil & gas) working under different design managers only reinforces what he felt earlier thus making him experientally realize a Practical Gap: there is no well-defined system to manage piping engineering design, thus allowing human flaws or Managerial Flaws to negatively affect the design output. This is unlike the engineering/technical aspect of engineering design wherein Codes & Standards (for e.g. ASME, BSI, ISO, NORSOK, IS, IBR, etc.) ensure that Technical Flaws do not hamper the design output, at least to a basic extent.

All these discussed factors, tripled with the facts that piping engineering design management comprises of more than 40% of any plant's design engineering activities (Sheremetov, Batyrshin, Chi, & Rosas, 2008) and 80-90% of production costs are dependent on the design stages (Barbeau, 1998), have been a constant source of motivation for the research scholar, inspiring him in this research.

In this Chapter the inspiration for this research has been discussed along with some basic key understandings of engineering design management. The proceeding Chapter introduces the indispensable business need for this research and depicts the flow of chapters in this thesis.

Chapter 2: Introduction

Chapter 2: Introduction

This Chapter introduces the business need for the Integrated Piping Engineering Design Management Model. It may be noted here that this second chapter is the introduction to the topic describing the business need for an integrated model of piping engineering design management in India's oil & gas sector. While not going into the comprehensive literature review that is discussed in details in the third chapter, this second chapter lays the preamble need for the research and depicts the flow of chapters.

2.1 The Business Management Problem: Need for an Integrated Model of Piping Engineering Design Management

Ever since 1944, there have been some researches in this broader field of *Multidisciplinary Engineering Design Management for industries other than Oil & Gas* as seen from literature study; it has been found that these studies have been done for Architecture, Civil, Construction, Electronics, Transportation industries and do not throw any light on the state of design management affairs in the oil & gas industry. There have also been some researches in the *Management of specifically Piping Engineering Design in industries other than Oil & Gas* (as chronicled in Literature Review section); it has been found that these studies have been done for Architecture, Civil, Construction, Electronics, Transportation industries and do not throw any light on the state of design management affairs in the oil & gas industry.. However, these researches' findings may not hold true for oil & gas piping design management since design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, 2009).

From the comprehensive reviews of existing available literatures in piping engineering design management (discussed in Literature Review) it has been found that all *researches, except one (Sheremetov et al., 2008), focused on the product side of piping in industries other than oil & gas, and furthermore, all of these have focused only from a purely engineering point of view, leaving a colossal dearth of focus on the management aspects in the product as well as the process sides of design management*. The only one research found on *Oil & Gas Piping Engineering Design Management* has been done too purely from an engineering point of view outside India (Sheremetov, Batyrshin, Chi, & Rosas, 2008); Sheremetov et al.'s (2008) research has been focused on only 1 issue (integrating piping analysis like stresses and flexibility with piping design like layouts, etc. discussed later) of oil & gas piping engineering design management but this research's engineering recommendations too may not be applicable to India since *design management practices vary from country to country* (Sun, Williams, & Evans, 2011). Moreover, any available literature of research into Multidisciplinary Engineering Design Management or Piping Engineering Design Management approaches & models in India have not been found. Further, from the extensive reviews of existing literatures, no evidence of research has been found on the Process Side or on the Product-&-Process-Sides-Integrated-Cycle of Piping Engineering Design Management (Dutta, 2013a). In the available *researches, it has been found that all of these have focused only from a purely engineering point of view, ensuing a prodigious paucity of focus on the management aspects in the product as well as the process sides of design management*.

The researcher's extensive literature reviews of over three hundred available publications on the subject yielded some issues plaguing effective design management (discussed in Literature Review). But, design management practices vary from industry to industry (Visser, 2009) as well as country to country (Sun, Williams, & Evans, 2011) as discussed with examples in Chapters 3 & 4. As a result, identified issues, undertaken in other industries & also outside India, are uncertain in terms of their applicability to the oil & gas industries as well as to India and there has been no research on their applicability to either the oil & gas industry or to India. Moreover, previous researchers have stressed the growing & indispensable need for a comprehensive design management model and there has been no research on engineering design management in India. Therefore, this research, sought to address these omissions by reporting a qualitative study of oil & gas piping design management practices & non-integrated models that are presently in vogue in India and, this study has used a novel and effective research method in order to identify the issues & arrive at or compile an integrated model of Oil & Gas Piping Engineering Design Management as detailed in relevant Chapters. In this introductory Chapter, let us take a deeper look at the business management problem.

In order to sustain the competitive advantage of the company effective design management is indispensable (Bruce, Cooper, & Vazquez, 1999; Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010). Effective design management is also required to *prevent time loss* (e.g. reworks from a variety of causes, conflicts, etc.), *opportunity loss* (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) and *revenue loss* (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). For example, practical site requirements may vary in quite many aspects from the theoretical conditions considered in design and thus not communicating with end users can cause a lot of rework in the later urgent stages leading to time & manhour wastage;

interdisciplnary conflicts, arising from interfacing disciplines not interacting with each other to understand other disciplines' specific requirements may have conflicts at later stages, again leading to time loss; haphazard management of design lowers cycle efficiency leading to excessive work pressure, decreased job satisfaction that causes higher attrition as well as loss of competitive edge which, in turn decreases the business opportunities for the company; all these issues plague the mangement of engineering design management cycle and reduce the company's revenue in the long run (Visser, 1996; Lee, Sause, & Hong, 1998; Kiwan & Munns, 1996; Case & Lu, 1996; Kim, Liebich, & Maver, 1997; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Chapman, 1998; Swink, 2000; Dutta, 2013a). *Previous research has proven that the more effective the design management practices of a firm are, the more the firm is successful in business* (Bruce, Cooper, & Vazquez, 1999). The researcher's extensive literature reviews of over three hundred publications on the subject yielded some issues plaguing effective design management (discussed in Literature Review). But, design management practices vary from industry to industry as well as country to country that are discussed with examples in Chapters 3 & 4. As a result, issues identified in other industries & also outside India, are uncertain in terms of their applicability to the oil & gas industries as well as to India and there has been no research on their applicability to either the oil & gas industry or to India. Moreover, previous researchers have stressed the growing & indispensable need for a comprehensive design management model and there has been no research on engineering design management in India at all.

In addition to the preceding, the following widely accepted research proven facts are highlighted: *80-90% of production costs are determined at the conceptual design stage* (Barbeau, 1998), *piping consumes more than 40% of any plant's design engineering activities* (Sheremetov, Batyrshin, Chi, & Rosas, 2008), *engineering design management is of crucial importance in any* *organization's capability development* (Owen, 2006; Mozota, 2006; Mutanen, 2008)*, in order to sustain the competitive advantage of the company effective design management is indispensable* (Bruce, Cooper, & Vazquez, 1999; Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010).

Research has proven that ***the companies who do not have effective engineering design management practices/models are much less successful in business than the ones having it*** (Bruce, Cooper, & Vazquez, 1999) as the absence of an effective design management model induces loss of competitive edge of the company in terms of time loss, opportunity loss & revenue loss (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011). Previous research has further proven that a model for integratively catering to all identified issues/challenges becomes innately effective in flourishing the competitive advantage of any company (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Bruce, Cooper, & Vazquez, 1999, Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011). Thus the ***business management problem*** is:

An ***integrated model for managing engineering design*** is indispensably needed to aid design engineers/managers in their management decisions and to sustain the ***competitive advantage of the company***.

To solve this business problem, address the research gaps, answer the research questions and fulfill the research objectives, the existing practices of piping engineering design management that are being used in the piping engineering design department of India's largest oil & gas company have been studied, issues identified, compared with other researchers' finding, each research step has been deeply thought upon, profoundly analyzed, rigorously verified and an integrated model of piping engineering design management has been proposed.

Now that an introduction to the business management problem has been discussed, a deeper delve into the review of existing literatures that give rise to the Research Gap, Research Problem, Research Questions and Research Objectives have been detailed in following Chapter 3.

2.2 Breviloquent Vista of Research Gaps

From the review of existing literatures two research gaps emerged as follows:

Extensive literature review yielded no references of any *design approaches & models for oil & gas piping engineering design management in India.* There has been no research to know how design is being managed in India.

From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Further, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

Previous studies have established that an integrated management model for managing engineering design is indispensably needed. The previous studies have their respective limitations. Some researchers have focused only on the Product Side of Engineering Design Management and have so far found out three issues challenging the efficient management on engineering design on the Product Side. Whereas some other researchers have focused only on the Process Side of Engineering Design Management and have so far found out four issues challenging the efficient management on engineering design on the Process Side. Existing literature review has evidenced that engineering design management can be effectively managed if the identified issues are catered to. Previous studies for specifically piping engineering design management have focused only from a pure engineering point of view, ensuing a colossal dearth of focus on the management aspects in the product as well as the process sides of design management; the existing studies did neither focus on the piping enginering design management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides. Further, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. An extensive literature review covering over three hundred relevant available literatures yielded no references of any design approaches & models for oil & gas piping engineering design management in India. The previous studies neither throw any light on the design management in the global oil & gas industry nor on the design management issues of any industry in India. There has been no research to know how design is being managed in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. However, previous studies have established that design management roles, practices and activities significantly & crucially vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an integrated design management model and in India no research has focussed on engineering design management. The identified research gaps have not been addressed by any of the previous studies. This present research tries to answer these questions and thus address these dodged research gaps in a bid to improve engineering design management in India.

2.3 Laconic Overview of Research Design

The detailed research design has been described in a dedicated Chapter 4; however a concise overview is presented in this section as an introduction. On careful consideration of established methods & approaches, a descriptive qualitative case study with a grounded theory approach has been chosen as the philosophy of this research owing to the approach being the best suitable research mode for this particular study of the problem through the objectives. This is because the present research purpose has been descriptive (fact finding about a state of affairs), research process has been qualitative (for a phenomenon related to quality) and research approach has been a grounded outlook (to systematically generate theory from data through inductive thinking about a phenomenon of interest). Sample selection has been done in three stages, while decreasing sample size by using the Theory of Elimination and unit of analysis has been critically chosen in line with the research objectives. Detailed case study questionnaire has been developed in three steps so as to enable an appropriate research into the answers to the research questions. Data have been collected and analysed in line with the research philosophy and rationale. All evidences substantiating the case study have been archived and are being maintained with the researcher. The validity of the case study has been verified by employing a number of tactics. To ensure construct validity & internal validity, two tactics have been employed.

First, two levels of analyses are undertaken during data analysis – conceptual and detailed. Secondly, the case study reports are reviewed by key informants and then their feedbacks have been incorporated in the final research. This present research study is expected to provide depth and so the study intended to provide an insight into the probable relationships suggested and therefore to generalize beyond this particular research area would require additional confirmation of results that is beyond the scope of this particular research and has been included as a further research scope. Although the research is limited to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India, however, a point to be noted here is - this research establishes that the seven challenges of design management identified outside India are applicable to the oil & gas industry in India plus there are some additional five challenges specific to the Indian oil & gas context and therefore, theoretically it can be inducted that most/all of the found out issues and their solution model proposed through this research shall be applicable to the other oil & gas companies as well (the researcher, through his previous work experiences, has also experientially observed these issues to be plaguing design management in some other oil & gas companies in India as well as abroad); further, external validity is beyond the scope of this particular research and is a future research arena. Reliability has been highly ensured through apt instruments, archival of all evidences and use of data analysis software Atlas.ti. This research employed a number of approaches to ensure high reliability while applying procedures for data collection and analysis. First, the case study protocol has been used to guide the research process as the protocol is a major tactic in increasing the reliability of a case study research and is intended to guide the researcher / investigator in carrying out the case study. The protocol has comprised of instruments as well as procedures and general rules that have been followed. This ensured consistency in the areas covered. Secondly, to reduce the likelihood of forgetting or misunderstanding the data and to allow independent data analysis by other researchers, interviews have been taped, transcribed and all original evidences are archived. Thirdly, the use of Atlas.ti qualitative analysis software allowed systematic & consistent analysis of the qualitative data and further increased the reliability of this research because procedures can be repeated. Fourthly, the field notes taken by the researcher have been also transcribed for future reference. Different levels of coding, within case analysis (conceptual & detailed), theory triangulation, employment of case study protocol, use of software Atlas.ti, archival of all evidences, etc. have been carried out to ensure high quality (construct validity, internal validity & reliability) of the study.

2.4 Chapter Flow

This thesis consists of **eight chapters**.

The **invaluable contributions** of all the associated stakeholders in this research are graced before the first Chapter as well as referenced in relevant sections.

The **first chapter** is the **problem statement** and the **background** of the research.

The **second chapter** is the **introduction** to the topic describing the **business need for an integrated model of piping engineering design management in India's oil & gas sector**. While not going into the comprehensive literature review that is discussed in the third chapter, this second chapter lays the preamble need for the research. For example, in order to *sustain the competitive advantage of the company,* effective design management is indispensable. Effective design management is also required to prevent time loss (e.g. reworks from a variety of causes, conflicts, etc.), opportunity loss (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) & revenue loss (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). *Previous research has proven that the more effective the design management practices of a firm are, the more the firm is successful in business*. The researcher's extensive literature reviews of over three hundred publications on the subject yielded some issues plaguing effective design management (discussed in Literature Review). But, design management practices vary from industry to industry as well as country to country that are discussed with examples in Chapters 3 & 4. As a result, issues identified in other industries & also outside India, are uncertain in terms of their applicability to the oil & gas industries as well as to India and there has been no research on their applicability to either the oil & gas industry or to India. Moreover, previous researchers have stressed the growing & indispensable need for a comprehensive design management model and there has been no research on engineering design management in India at all.

The **third chapter** is the **review of existing literatures** that identified the existing research gap, research problem, research objectives & research questions, and lays the **conceptual framework** for the study.

The **fourth chapter** explains the **research design**, the **research methodology**, **rationale** of the study, **quality** ensurance, **scope** of this research work, **case selection, data collection plan** and the **data analyses strategy & rationale**.

The **fifth chapter** discusses the **actions taken in the case study** as per the research design or plan & the **findings**; it comprises of **detailed case study protocol** used, **data collection process** employed in the study, **analysis methods** applied, **tools as well as** the **findings** from the case study along with the **inductive analyses**.

The **sixth chapter** describes the **modelling techniques,** the workable **ingredients** of the new model and verification of **fulfillment of the research objectives**.

The **seventh chapter** depicts the **new model of piping engineering design management for the oil & gas industry in India named Doctonaut** and its **integrated working**.

The **eighth chapter Conclusion** presents a brief touchup of the **main points in this research**, the salient **features & advantages of the new model Doctonaut,** the **limitations** of this research and the **recommendations on further research scopes**.

Finally the **Bibliography & Appendices (Appendices A, B, C, D, E, F, G & H)** are presented for reference.

In this Chapter the precursory business need for this research and the flow of chapters have been depicted. The proceeding Chapter lays out the conceptual framework for the study that is developed from the review of existing literatures.

Chapter 3: Literature Review:

Conceptual Framework

Chapter 3: Literature Review: Conceptual Framework

This Chapter portrays the findings from previous researches and explains the fundamental knowledge including the developed conceptual frames on which this research is based upon. This chapter also entails the gaps in the previous researches, the research problem, the research questions and the research objectives.

3.1 Review of Existing Literature

The researcher's extensive literature review covered over three hundred published literatures (referenced in Bibliography section) relevant on the subject. Based on the need for the research discussed earlier, the review of the existing literatures have been under **two main themes –**

I) Existing Researches/Models/Practices in multidisciplinary Engineering Design Management that cover management of different engineering designs including mechanical/piping designs, &

II) Existing Researches/Models/Practices in Piping Engineering Design Management that cover specific management of piping engineering designs only.

The theme-wise reviews of the subject existing literatures are discussed in the following paragraphs.

I. Existing Researches/Models/Practices in Multidisciplinary Engineering Design Management:

Research in discipline independent or multidisciplinary engineering design management reveals that Design Engineers suffer from *decision dilemmas* leading to degradation of product quality (Turner, 1985; Owen, 2006) and limiting design management excellence which in turn lowers competitive advantage and this calls for an effectively efficient design management model (Ughanwa, 1988; Mozota & Kim, 2009).

Engineering Design has so far been managed by various designers in several differing methods & ways *devoid of any formal management model guiding the processes* (Zanella & Gubian, 1996). Some researchers have identified this gap, researched & built some management models that are discussed in the following paragraphs.

The development of the first formal design management model can be traced back to the Waterfall Model (Royce, 1970) wherein sequential management of seven engineering steps are considered in a top-down approach. This model has been based on an assumption that all activities of a particular step would get completed before moving on to the next step & that there has been no provision of two-way interaction between the steps, and hence, this model suffered widespread criticism from its researcher himself & others (Royce, 1970; Parnas, 1986; McConnell, 2004).

Some researchers identified the problem of managing engineering design data that is a part of the design process and built an engineering data management system for Computer Aided Design or CAD (Heerema & Hedel, 1983; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000). This system is not for managing the entire design process but only one part of it. A *real management* *system for managing all the processes of engineering design* has been felt though subsequent research studies (Turner, 1985). Research in the management of CAD processes in ship-building also highlighted similar problems (Beames, 1987). Research in search for design management excellence unearthed the weaknesses existing in design management practices leading to gradual erosion of competitive edge and highlighted the need for integrating the design management functions (Ughanwa, 1988). Design data handling & interactions with the other processes of construction have also been researched & modeled but the integrated model does cater to the management of the internal design processes (Brown, et al., 1995). The need to provide support decisions throughout the design process is a worldwide acclaimed fact requiring the systematic integration of CAD tools into the design management process (Sharpe, 1995; Twigg, 1995). Konemann (2011) stressed the need to integrate design decision support systems into the processes of software engineering design management (Konemann, 2011). The integration of early & late process design stages have been researched upon purely from an engineering point of view and a framework has been developed (Karcanias, 1995). Karcanias' (1995) research however does not touch upon the design decision-making problems inherent in the design processes, from a management side as have been highlighted by others.

NASA (National Aeronautics and Space Administration, USA) follows an eight step design process that is custom build for only the aeronautical & space industry– Identify the Problem, Identify Criteria & Constraints, Brainstorm Possible Solutions, Generate Ideas, Explore Possibilities, Select an Approach, Build a Model or Prototype, and Refine the Design (NASA, 2012). Researchers at the University of Cambridge have identified four basic phases of the design process namely Clarification of the Task involving problem, criteria & constraints identification, Conceptual Design involving brainstorming possible solutions, generating ideas, exploring possibilities & selecting san approach, Embodiment Design involving building a model or prototype, and Detail Design involving refining the design (Wallace & Burgess, 1995). Other researches also recognized these four basic phases of the design cycle (Erden, 2004). The Cambridge researchers have also substantiated the business need for switching from the traditional design method of relying on the experience & insight of talented designers to a validated/verified design method/model that manages the design processes fully. CAD systems tend to focus on the design product from an engineering point of view only thus leaving the remaining design processes' decision dilemma with the design manager. To address this gap, these researchers have created an Integrated Design Framework which however, is limited by its applicability to the Aerospace, Transportation & Medical Equipment industries only (Wallace & Burgess, 1995). Some other researchers have identified "*six detailed phases of the design process namely:*

1. *Establishing a Need Phase* involving the idea, proposal, etc.,

2. *Analysis of Task Phase* involving investigation of the need, specification, task clarification, etc.,

3. *Conceptual Design Phase* involving possible concept synthesis, product principle, etc.,

4. *Embodiment Design Phase* involving basic product design, feasibility testing, etc.,

5. *Detailed Design Phase* involving feasible alternatives & detailed solutions, detailed design, detailed specifications, etc., &

6. *Implementation Phase* involving testing & refinement, commercialization, etc.," and, highlighted the links between engineering design process and creative process from a cognitive psychology approach that is all encompassive (Howard, Culley, & Dekoninck, 2008; Dutta, 2013a).

Some researchers have built a framework to support management decisions in the strategic design of the distribution system, applicable to the logistic system in the automotive sector (Manzini & Bindi, 2009).

Since the 1980s, CAD tools have been developed that simplify only some of the tasks of the design process (like product modeling & product analysis) whereas *integration with the other tasks is through ad hoc manual processes* (Zanella & Gubian, 1996). Moreover, the importance of *dynamic feedback* in knowledge management is well recognized (Dearnley & Smith, 1995). Catering to these needs, some scholars have proposed a conceptual design management model built by eliminating the *design manager's problems of incremental changes, dynamic checks & feedbacks, design project organization, control of CAD, design methodology, co-ordination of large sets of design data and maintenance of design rules & integrity* (Zanella & Gubian, 1996). However, this research has assumed the design manager as a syntactic controller in an intelligent CAD software and hence the research results cannot be flatly applied in solving the problems of a human design manager. Also this research is in the electronics design industry and the research model's applicability to other industries' design management has not been validated. However, the abstractions of the problems are applicable to present day multidisciplinary design management (Zanella & Gubian, 1996).

Some researchers have built a Neutral Object Data Model that classifies & codifies design information for structuring design data in a conceptual data model applicable only to the building construction / architectural industry (Kiwan & Munns, 1996). Some other researchers built a Database Infrastructure framework for design history information as an augmentation to the Standard for the Technical Exchange of Product Model Data or STEP in terms of supporting design process models (Shah, Jean, Urban, Bliznakov, & Rogers, 1996). Research has substantiated the *need for design process interdependency based conflict areas,* which has been catered to by the Discourse Model that treats assertions as facts & not as conflict (Case & Lu, 1996). This model manages the assertions of design engineers through a specified closely-coupled interaction module that explicitly detects conflicts, facilitates rationalization/negotiation through increased interaction and finally the opinioned solution subject to review & revisions. However, this research model is applicable specifically for the architectural industry (Case & Lu, 1996).

Visser (1996) has qualitatively researched into the functions of analogical reasoning in design problem solving (Visser, 1996). Visser used a cognitive-psychology approach in observational studies of professional designers & identified two types – a. *Action-Execution (AE) Analogies & b. Action-Management (AM) Analogies*, in which, AE types are the ones normally employed by designers in a specific design problem-solving whereas *AM types are the ones employed after the designer gets the solution for the AE types and these AM types are used for managing the specific design problem solution most-economically in the context of the global design problem, of which, the specific design problem is just a part* (Visser, 1996).These findings give an insightful direction in the development of systems for managing engineering design, an area of future research (Visser, 1996).

Design process involves a lot of interactions between the target design user & the design expert and hence is crucial to an efficient design management system. Research on this using semantic discourse analysis and rhetorical techniques undertaken by Parent (1997) identified a classification scheme in the form of a question-answering mechanism consisting of 5 main categories – Elaboration, Enablement, Validation-Current-Model, Validation-Future-Model and Clarification through different question types to facilitate communications between the end-user (client) & domain-expert (designer). Parent (1997) also validated this question answering mechanism & opened up the further research area for studying the design management dialogue process (Parent, 1997).

Design management in an integrated CAD environment has been studied from a data management approach & a research model has been built that connects the different design data applications which improve the design management process in the architectural industry (Kim, Liebich, & Maver, 1997). The importance of engineering design knowledge sharing as a part of the design management process has been recognized and an information system for improving the sharing has been built which however does not cater to the other processes of design management (Jokinen, 1997; Dong & Agogino, 1998; Herder & Weijnen, 1999).

Previous qualitative research work substantiates the *neglect & absence of systematic feedback to the engineering design management processes* leading to a design output that is much inferior to what could have been achieved through structured feedback management (Busby, 1998). Chen, Frame, & Maver's (1998) research shows us how the *human-level interactions among multidisciplinary design teams have been ignored & left to be managed by differing human opinions leading to designing bottlenecks* that can be removed through an efficient studio environment managing the human interactions within design teams in architectural industry (Chen, Frame, & Maver, 1998). As seen, there have been quite a number of researches & models on Design Management in the architectural/building/construction industry, all substantiating the *design manager's problems of multidisciplinary collaboration, non-value adding activities, reworks, data management & conflicts,* and proposing some improvements on the existing practices (Kiwan & Munns, 1996; Case & Lu, 1996; Kim, Liebich, & Maver, 1997; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Chua & Tyagi, 2001). It can also be seen that there have been considerable research in design data/archive management since that plays an important role in a design engineer's task of referencing (Heerema & Hedel, 1983; Brown, et al., 1995; Zanella & Gubian, 1996; Kiwan & Munns, 1996; Kim, Liebich, & Maver, 1997; Dowlatshahi & Nagaraj, 1998; Willaert, Graaf, & Minderhoud, 1998; Peng & Trappey, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000;

Tiwana & Ramesh, 2001) (Concheri & Milanese, 2001; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Hicks, Culley, Allen, & Mullineux, 2002).

Research in collaborative engineering has highlighted that documentation of design decisions are typically made after the project ends which leads to unwanted leaving out of steps that are crucial to retrieve the design processes of that project later on & hence this calls for an indispensable need for *full documentation of the design decisions during the design product development itself* (Willaert, Graaf, & Minderhoud, 1998). The ever-increasing challenge of companies to remain competitive in today's extremely volatile market calls for *systematic innovation alongwith optimization of cost, quality & flexibility* (Willaert, Graaf, & Minderhoud, 1998; Walton, 2004; Stark, et al., 2010). "Despite the obvious importance of systems innovation to continued organisational existence, research suggests that *innovative efforts are ineffectively managed*, cumulating in over half failing to achieve their goals" (Dooley & Sullivan, 2003; Li, Li, Wang, & Liu, 2010; Xu, Houssin, Caillaud, & Gardoni, 2011; Dutta, A Theoretical Model of Innovation Integrated Engineering Design Management, 2013). *Lack of time, poor planning & management of engineering design have been found to be the main limiters to innovation, necessitating structured management techniques to integrate systematic innovation into the design management cycle* in order to sustain firm's competitive advantage (Salter & Gann, 2003). Xu et al. (2011) showed how design innovation can be integrated into knowledge management through 4 characteristics of *explicitness, novelty, importance & usability* with due regards to traceability & trustworthiness of knowledge for fostering continuous innovation (Xu, Houssin, Caillaud, & Gardoni, 2011). Artificial intelligence technology still lacks basic theory about human creative thinking and decision mechanism and so existing design software systems have creative limitations, and thus human-based creativity for product innovation appears to be the most pragmatic approach (Liu, Li, Pan, & Li, 2011).

More democracy in organizational structure leads to less blockages to innovation (Shoham, EranVigoda-Gadot, AyallaRuvio, & NitzaSchwabsky, 2012).

The ISO Standard STEP provides a technology to solve product data exchange problems but *does not support semantic communication between the design engineering processes* (Martino, Falcidieno, & Habinger, 1998). Poor management of engineering design in USA has created 10 major problems/concerns of the design management firms - *(1) making a profit, budget, (2) meeting schedules and deadlines; (3) change order and/or scope management; (4) internal communications; (5) quality control; (6) client communication; (7) lack of experienced engineers; (8) low fees/determining fees; (9) planning/scheduling and (10) time management* (Ogunlana, Lim, & Saeed, 1998). These problems have been shown to be depreciated by the use of an efficient design management model that has been built by the researchers with the aim of addressing these concerns but the research has been limited to civil engineering design only (Ogunlana, Lim, & Saeed, 1998).

A review of how information management is dealt with in today's design management departments shows that the existing practices are *mostly manual with some semi-automated processes (for example CAD outputs) devoid of any formal management model to facilitate seamless collaboration & concurrency control* in creative multidisciplinary engineering design (Jacobsen, Eastman, & Jeng, 1997). A review of engineering change management shows that *engineering change is predominantly seen as a problem rather than an opportunity to cause incremental product development* thus necessitating effective design management practices (Wright, 1997).

Lee, Sause, & Hong's (1998) research into Design Management highlights two concurrent models – a Product Model for managing the information created during the design process and a Process Model for managing the associated design activities. For an *improved understanding & implementation of design, indispensable is the need for a design management model that caters to the whole of the design process* (Lee, Sause, & Hong, 1998). Hence, Lee et al. build an entity based sequentially integrated model that uses product entities and process entities to represent design information and design activities, respectively. This model has been validated in building structural design only & has not been validated for other engineering design systems (Lee, Sause, & Hong, 1998).

Liu, Tang, & Frazer (2004) presented a software based design management framework using hierarchical multi-agent system architecture to systematically manage the design activities. This framework aids multidisciplinary collaboration but does not solve the design manager's other problems like non-value adding activities, reworks, data management & conflicts, dynamic checks & feedbacks & systematic innovation integration as have been highlighted by other researchers discussed earlier. Also this framework is an intermediate one requiring further research & development of the software in order to be able to cater to the full range of integrated design cycle activities (Liu, Tang, & Frazer, 2004). Komoto & Tomiyama (2012) developed a similar framework for mechatronics products (Komoto & Tomiyama, 2012).

The *requirement of collaborative design negotiation environment for conflict resolution* is a research proven fact (Case & Lu, 1996; Pena-Mora & Hussein, 1998; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002) that traditional meeting environment does not cater to owing to its inherent human constraints like poor communication in either quality, quantity or form (Pena-Mora & Hussein, 1998). Conflicts are barriers to design management excellence, conflicts originate in interfacing points and conflicts can be effectively handled by shared understanding through efficient design project management (Kleinsmann & Valkenburg, 2008). Design conflicts occur between designers of same discipline (Ouertani, 2008), between disciplines (Case & Lu, 1996) and between design teams & client (Wong, Lam, & Chan, 2009).

Engineering design has been traditionally & most-widely been managed in a top-down approach but recent trends suggest a movement towards a *flatter structure of design teams consisting of a balance between top-down & bottom-up management methods that enables more effective design management products* (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003).

In any managerial task, if the difficulty level is high, *broad-scope information is required continuously to help the manager understand difficult tasks more clearly* (Choe, 1998). Under high task uncertainty as in the case of design engineering (Lee, Sause, & Hong, 1998), *aggregated and timely information through high user participation is positively related to high performance* (Choe, 1998). Currently, there is a *lack of holistic approach to the management of design* (Chapman, 1998). Besides poor design management, the problem of design project duration overrun has now been attributed to the *loss of key personnel (attrition) resulting in disruptive communications, reworks, excessive work pressure on existing employees and decreased morale* which need to be recognized & systematically taken care of by a proactive design management system (Chapman, 1998). Another major reason of design project overruns is *underestimation of the design effort* for which the existing methods like PERT/CPM (Program Evaluation & Review Technique/Critical Path Method) have been found to be ineffective (Bashir & Thomson, 1999) since they do not have feedback & iteration that is very common to design (Smith & Morrow, 1999) but methods using metrics to estimate design effort & time are found to be more suitable which however, is a subject of further research (Bashir & Thomson, 1999; Bashir & Thomson, 2001; Xijuan, Yinglin, & Shouwei, 2003).

In order to sustain the competitive advantage of the company effective design management is indispensable (Bruce, Cooper, & Vazquez, 1999; Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010). Effective design management is also required to *prevent time loss* (e.g. reworks from a variety of causes, conflicts, etc.), *opportunity loss* (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) and *revenue loss* (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). Effective design management is also required to *prevent time loss* (e.g. reworks from a variety of causes, conflicts, etc.), *opportunity loss* (e.g. job dissatisfaction of employees leading to higher attrition, product quality lowering leading to lower customer satisfaction and loss of market to better competitors, etc.) and *revenue loss* (e.g. shrinking market share, the various effects of time & opportunity losses on the revenue, etc.). For example, practical site requirements may vary in quite many aspects from the theoretical conditions considered in design and thus not communicating with end users can cause a lot of rework in the later urgent stages leading to time & manhour wastage; interdisciplnary conflicts, arising from interfacing disciplines not interacting with each other to understand other disciplines' specific requirements may have conflicts at later stages, again leading to time loss; haphazard management of design lowers cycle efficiency leading to excessive work pressure, decreased job satisfaction that causes higher attrition as well as loss of competitive edge which, in turn decreases the business opportunities for the company; all these issues plague the management of engineering design management cycle and reduce the company's revenue in the long run (Visser, 1996; Lee, Sause, & Hong, 1998; Kiwan & Munns, 1996; Case & Lu, 1996; Kim, Liebich, & Maver, 1997; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Chapman, 1998; Swink, 2000; Dutta, 2013a).

Research has proven that the companies who do not have effective engineering design management practices/models are much less successful in business than the ones having it (Bruce, Cooper, & Vazquez, 1999) as the absence of an effective design management model induces loss of competitive edge of the company in terms of time loss, opportunity loss & revenue loss (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011). Previous research has further proven that a model for integratively catering to all identified issues/challenges becomes innately effective in flourishing the competitive advantage of any company (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996; Bruce, Cooper, & Vazquez, 1999, Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011).

Research in large & medium sized mechanical engineering design firms shows lack of design management control and recognizes the *need for an efficient design management system that empowers designers to actively influence existing practices, involves them in consultations about the overall strategy and creates a sense of identity with the products they design* (Lauche, 2005).

Team decision making has been proven to be more effective by *increasing simultaneity of the product development processes* through concurrent engineering methods (Moffat, 1998; Roemer & Ahmadi, 2010) and this can be suitably managed through an efficient design management system (Willaert, Graaf, & Minderhoud, 1998). Previous research has also shown that the *design problem of making the best design decision is more for senior design engineers compared to the lesser experienced ones* since the senior engineers have a lot more design alternatives to choose from than their juniors (Atman, Chimka, Bursic, & Nachtmann, 1999). Also *losing these senior engineers due to any* *unanticipated event like employee dissatisfaction, low work morale, etc. proved to be very harmful to design project quality & completion schedule* (Chapman, 1998). Inspite of worldwide recognized engineering standards (for example ASME, BS, ISO, etc.) governing the design of products, a recent survey conducted by the UK Design Council concluded that an average product could be redesigned to reduce manufacturing costs by 24% and to improve market demand by 29% thereby challenging the existing products' designs and invariably opening the gates for *research on design management for better design products* (Hurst, 1999).

Crafts knowledge or practical manufacturing/production/construction knowledge has been seen to augment and sometimes modify the engineering design practices for the common goal of making a better designed product & hence the *integration of this two way feedback loop between the design department & the manufacturing/production/construction department in the design management process* has been considered to be of paramount importance (Yair, Tomes, & Press, 1999). Design management in small businesses have been studied in terms of sourcing the designer, briefing the designer & evaluation of design, and, the research proved that *the more effective the design management practices of a firm are, the more the firm is successful in business* (Bruce, Cooper, & Vazquez, 1999). Design involves a lot of interdisciplinary as well as intradisciplinary negotiations that are best managed through an ergonomic approach (Owens, 2000; Detienne, Martin, & Lavigne, 2005). Research has proved that ergonomic criteria is often neglected in design leading to product's quality of usability being compromised and this calls for *integration of the ergonomic criteria into the design management process* itself (Wulff, Westgaard, & Rasmussen, 1998; Karwowski, 2005).

It has been observed that engineering researchers have typically focused on formal structures involved in engineering design decisions (Pahl, Beitz, &

(Ed.) Wallace, 1996; Smith & Morrow, 1999), while management research has concentrated on the myriad organizational issues involved in product development (Brown & Eisenhardt, 1995; Smith & Morrow, 1999). Both research traditions have value to the engineering design management researcher. Some researches identify the common goal of Engineering Design & Management Research as building tested knowledge for use, and, portray *future management research as design science* in contrast to the present conception of management research as an explanatory science, where both academics could thrive and managers could have confidence (Tranfield, 2002). The growing invasion of nature by humans today necessitates an ecological engineering approach to serve as one of the bases of engineering management (Xu & Li, 2012).

A review of the different design management models like AIDA (Harary, Jessop, Stringer, & Luckman, 1965), Q-GERT (Taylor & Moore, 1980), DSM (Steward, 1981), Petri net (Bretschneider & Lagger, 1992), Parallel scheduling (AitSahlia, Johnson, & Will, 1995) & WTM (Smith & Eppinger, 1998) reveal that these models focus either on *development lead time or development cost or product specifications* i.e. these models focus only on one aspect of the design management process and on top of it, these models *lack practical applicabilities since these models have been developed from a purely academic context & not by people engaged in design engineering activities* (Smith & Morrow, 1999). Thus, Smith & Morrow's research reinstates Bruce et al.'s research highlighting need for practical crafts knowledge integrated design management model. Some other researchers have proposed a web based design management framework that reduces some of the design manager's problems of sequencing processes, monitoring flow, controlling flow & displaying results of a multidisciplinary design project at the macro level, but does not cater to the other design management problems (Rogers & Salas, 1999) like incremental changes, dynamic feedbacks, innovation integration, etc. already discussed.

Cho & Eppinger (2005) have built a process model that uses design structure matrix (DSM) representation to capture the information flows between tasks and a simulation-based analysis to account for many realistic aspects of design process behavior which are not possible in previous analytical models (Cho & Eppinger, 2005). This model although facilitates better design project planning & control, but suffers from inaccuracy since it assumes that *processing time of each task is independent of those of other tasks whereas in practice it is not* and also, this model does not consider *bi-directional information exchange* that is very common in design practices (Cho & Eppinger, 2005). A design management model specifically applicable for remote & environmentally sensitive sites have been developed by researchers through two case studies catering to the construction sector (Kestle & London, Towards the Development of a Conceptual Design Management Model for Remote Sites, 2002; Kestle, Remote Site Design Management, 2009). Researchers Choo, Hammond, Tommelein, Austine, & Ballardd (2003) built a design management model applicable only for the detailed designing phase not the basic engineering or other phases of the design management cycle (Choo, Hammond, Tommelein, Austine, & Ballardd, 2003). *Designers lack knowledge of management concepts leads to ineffective management of engineering design by the design engineers and this necessitates an efficient model* of engineering design management (Mozota, The Four Powers of Design: A Value Model in Design, 2006). Mozota built a conceptual framework of design management based on four powers of design namely Design as Differentiator, Design as Integrator, Design as Transformer and Design as Good Business that reduces the designer’s difficulty in implementing a value model in their everyday practice, but the framework, however, does not consider the relationships among the processes of product design cycle (Mozota, 2006). Some other researchers used an object oriented approach to build an integrated model of engineering design management named CoMoDe that may well form the basis for developing an integrated software model of design management (Gonnet, Henning, & Leone, 2007) but does not facilitate innovation integration or dynamic feedbacks that are indispensable to make design management proactively successful in today's competitive world as envisaged by other researches discussed earlier.

Some researchers presented a model for managing the design processes limited only to the conceptual or front-end design phase (Brunettia & Golob, 2000; Tzortzopoulos, Cooper, Chan, & Kagioglou, 2006). Some other researchers studied electronics engineering design teams to develop a human-centred soft system method based on ethnography to facilitate design team's performance but the research is also limited only to the early & conceptual design phases in electronics design projects (Jagodzinski, Reid, Culverhouse, Parsons, & Phillips, 2000). A study of aerospace design teams defines *engineering design as complex, elaborate socially-mediated activity much of which is tacit* and shows how *ethnographic approach is indispensable to study teamwork in design teams* (Baird, Moore, & Jagodzinski, 2000). Lloyd (2000) has also studied engineering design teams from an ethnographic approach involving mainly qualitative data and found that *storytelling as a common language in design teams* that facilitated better design (Lloyd, 2000). Research has proven that information strategies applied to the design process substantially improves project performance (Moreau & Back, 2000). Owens' (2000) research establishes the current trend towards *flatter & looser structures in design teams so that it empowers team members* to assert their own expertise when needed (Owens, 2000). Owens' research also shows that the *primary mechanism for decision making in design teams is through informal negotiations*. Research on role of engineering design in innovation has identified *that design acts as an agent of innovation and two ways are identified as innovation integrator & innovation broker,* whereas other ways of applying design activities to promote innovation require further research (Bertola & Teixeira, 2003).

A qualitative research on future design engineering competency requirements forecasts that although *technical competencies will remain equally important in the future, their relative importance will decline as a consequence of the emerging importance of non-technical competencies like design project management in order to cater to the increased business need for incremental innovation* (Robinson, Sparrow, Clegg, & Birdi, 2005). The design engineer's position in the product development process allows them to bridge the gap between market conceptualization and the realities of production and hence research shows that in addition to more rigorous technical skills to perform their engineering work, the design engineer's job has enlarged from technical specialist to participating member of a cross-functional team where *communication and cooperation* are key success factors (Hong, Vonderembse, Doll, & Nahm, 2005). A *good design leader must have open attitude, objectivity, block removing capacity, proactive appreciation for passion & creativity and an understanding nature* (Lee & Cassidy, 2007). Today's increasing need of flexibility calls for a management system that allows reformulations of project objectives along the way (Lenfle, 2008).

Another research reinstates previous research work that *systematic design management positively impacts internal internal quality outcomes such as scrap, rework, defects, performance, and external quality outcomes such as complaints, warranty, litigation, market share* (Ahire & Dreyfus, 2000). Swink's (2000) research also recognizes other researchers' views that an design integration is a co-ordination of product & process design activities performed in design teams & reinstates the *need for holistic design management integration together with innovation aided by top management* (Swink, 2000). Another research in electronics engineering design teams *reinstates the design management dilemmas of design co-ordination & team integration* highlighted by other researches discussed earlier & points towards the *need for a flexible & dynamic design* *management system* (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000).

For large and complex design-processes traditional ad-hoc approaches to process design do not suffice (Moody, 2005; Aken, 2005). Prescriptive knowledge models' practice in process design is still too limited owing to the reasons that the potential of professional process design to produce effective and efficient design processes is still underestimated as well as the potential of prescriptive design knowledge to support that professional process design (Aken, 2005). Design effectiveness, in recent years, has become subjective instead of being objective, and this necessitates the need for automation in the design management in order to expand horizons (Woudhuysen, 2006).

Design is positioned at the point where art & science meet and so design focuses on possibilities & opportunities in an imaginative way (Rieple, 2004). Although there are lots of evidences that innovation induces economic success, senior managers tend to block innovation since innovation has uncertain predictability that may risk shareholders' returns from their investments (Rieple, 2004). Neufville (2004) shows that this uncertainty can be actively managed & exploited by a profound positive shift in our mindset & attitude towards *uncertainty meaning the entire distribution of possible outcomes* instead of just the general synonym for risk and, this shift is powerful enough to drive the greatest innovative opportunities (Neufville, 2004). On the flip side of uncertainty is imprecision that can also be managed through imprecise probabilities that reduce to precise probabilities when the available information is extensive (Aughenbaugh, 2006).

The *indispensable need for systematic management of engineering design* has time & again been proven by a number of researches in various engineering sectors as well (Royce, 1970; Turner, 1985; Sim, 1985; Parnas, 1986; Applegate, Konsynski, & Nunamaker, 1986; Lewis, 1988; Ughanwa, 1988; Twigg, 1995; Zanella & Gubian, 1996; Eastman C. M., 1996; Saad & Maher, 1996; Wright, 1997; Mcdermott, 2003; Peng & Trappey, 1999; Owens, 2000; Chua & Tyagi, 2001; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Goonetillake, Carnduff, & Gray, 2002; Nagl, Westfechtel, & Schneider, 2003; Mozota, 2003a; Choo, Hammond, Tommelein, Austine, & Ballardd, 2003; Joshua, 2004; Conley, 2004; Rieple, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2004; Marquardt & Nagl, 2004; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Moody, 2005; Siddiqui, 2005; Moody, 2005; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Sanchez, 2006; Owen, 2006; Mozota, 2006; Baxter, et al., 2008; Mozota & Kim, 2009; Kestle, Remote Site Design Management, 2009; Mozota, 2010; Acklin, 2011; Ping, Keung, & Ramanathan, 2011; Dutta, 2013a).

Today's fast paced competition needs engineering designs to be optimized but this optimization can only be managed through an *efficient design management system that limits the optimization in a particular discipline based on its dependant disciplines' limitations* in a multidisciplinary design environment (Rodriguez, Renaud, Wujek, & Tappeta, 2000). Today's sophisticated "state of the art" CAD systems require much more proactive design management system than actually practiced (Malhotra, Heine, & Grover, 2001). *Management functionality that enables experimenting with a dynamic environment that supports decision making & management of future outcomes, rather than dictating well designed activities*, is the need of the hour (Artto, Lehtonen, & Saranen, 2001).

Balanced Scorecard is a management instrument developed to measure business performance, originally created at Analog Devices in the 1980s, that be used to assess activity performance of an organization based on four perspectives, namely (i) financial, (ii) customer, (iii) internal business and (iv) innovation and learning (Kaplan & Norton, 1996; Wong, Lam, & Chan, 2009). The problems of design quality commonly arise due to divergent goals between the client and the design team who have different aspirations and perceptions (Colander, 2003). Wong, Lam, & Chan (2009) showed how design objectives, optimized by using balanced scorecard approach using *the four typical design objectives, i.e. Aesthetics, Functionality, Buildability and Economics,* can successfully manage the conflicts between the client and the design team in order to *ensure the optimum product quality* in building design industry (Wong, Lam, & Chan, 2009).

The "entire cycle of design management consists of six phases" (Howard, Culley, & Dekoninck, 2008; Dutta, Findings from a Review of Existing Approaches and Models of Engineering Design Management, 2013; Dutta, A Theoretical Model of Innovation Integrated Engineering Design Management, 2013) discussed earlier & "each phase consists of *two main interfering sectors – 1. the Design Product Engineering Side consisting mostly of the actual engineering design execution activities like CAD, Computer Aided Engineering (CAE), design optimization & product quality assurance, and, 2. the Design Process Side consisting mostly of the management of the associated design activities of the design product* like design knowledge management, design cycle sequencing-controlling-monitoring, conflict management, interdisciplinary management, innovation integration, feedback integration, non-value adding activities' identification & elimination, design change order management, rework minimization & design project work management" (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000; Dutta, 2013a, 2013b).

Sheu & Chen (2007) researched on the product side of design management to propose a framework facilitating feedback-guided backward design engineering analysis & cross-functional design (Sheu & Chen, 2007) but does not address the problems on the process side like innovation integration, non-value adding activities' identification & elimination, change order management, etc. highlighted by other researchers discussed earlier. Plant Design Management

System or PDMS® is one of the most widely used leading CAD tools for modeling plants pertaining to a wide range of industries. But *it caters to only the product side & not to the process side of design management* (AVEVA, 2012). *That too, on the product side it caters specifically to the creation & management of drawings & databases whereas the creation & management of the engineering design analyses are left for the design manager through manual or other CAD methods* (AVEVA, 2012). Plant Design System or PDS® is another software similar to PDMS® (Intergraph, 2012). Other popular CAD softwares such as AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, AutoCAD®, Autodesk Streamline®, etc. do not offer any tool for real-time management of the collaborative design process (Wang, Tang, Song, & Jiang, 2009). Wang et al. built a software based Collaborative Design Process Model (CDPM) that interacts with the CAD software & other communication softwares to facilitate data management, collaboration, design changes and conflict management but does not, however, cater to the other problems on the process side like innovation integration and non-value adding activities' identification & elimination highlighted by other researchers discussed earlier. Acklin (2009) developed a Design-Driven Innovation Process Model that systematically integrates innovation into the design process but the model has not been validated (Acklin, 2009). Acklin's model also does not cater to the design manager's problems of multidisciplinary collaboration, non-value adding activities, reworks, data management & conflicts observed by other researchers discussed earlier. Some researchers built a process model that aids innovation in conceptual design but does not cater to the other stages of the design cycle and the other problems of design management (Li, Li, Wang, & Liu, 2010). Research has recognized the importance of *design audits* for design product quality assurance (Sung & You, 2007). Researchers built a tool named TracED that allows the capturing & tracing of the engineering design processes limited only to the software & chemical engineering design domains (Roldan, Gonnet, & Leone, 2010). Taylor (2007) found that for combating design errors a combination of more than one analysis type is more effective like *Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in multiple stages and Mechanical Audits* (Taylor J. R., 2007).

Design engineers rate technical work as more satisfying than non-technical social work but ironically, research suggests that 50% or more of each design engineer's time is used for work of a less or non-technical nature especially project management involving motivation, communication & leadership (Robinson, How design engineers spend their time: Job content and task satisfaction, 2012). Researches also showed that design engineers are aware of this increasing importance & prevalence of non-technical work over technical work and this is a cause of tension for design engineers which in turn reduces their job satisfaction & this calls for an efficient & effective management system that aids the design engineers in their increasingly prevalent non-technical work & project management so as to combat their falling satisfaction levels (Robinson, 2012).

From the reviews of the existing literatures, it is seen that many researches have concentrated either upon *only some aspects of the product side* (Pahl, Beitz, & (Ed.) Wallace, 1984; Beames, 1987; French, 1992; Beitz, 1994; Karcanias, 1995; Pahl, Beitz, & (Ed.) Wallace, 1996; Brunettia & Golob, 2000; Jagodzinski, Reid, Culverhouse, Parsons, & Phillips, 2000; Zha & Du, 2002; Roy & Bharadwaj, 2002; Gabbar, Suzuki, & Shimada, 2003; Su, Chen, & Lin, 2003; Halachmi, Simon, Guetta, & Hallerman, 2005; Yang & Han, 2006; Tan & Vonderembse, 2006; Sung & You, 2007; Taylor J. R., 2007; Sheu & Chen, 2007; Young, 2008; Shen, Hao, & Li, 2008; Roy, Hinduja, & Teti, 2008; Sung, et al., 2009; Bracewell, Wallace, Moss, & Knott, 2009; Dellino, Lino, Meloni, & Rizzo, 2009; Sakao, Shimomura, Sundin, & Comstock, 2009; Bock, Zha, Suh, & Lee, 2010; Smith & Ierapepritou, 2011; Linfeng, Qiang, & Lin, 2011; Hsiao, Hsu, & Lee, 2012; Chen, Gao, Yang, & Zhang, 2012; Adhikari, Aste, & Manfren, 2012;

Xiaoyan, 2012; McIntosh, et al., 2012; Du, Mo, Li, & Li, 2012; Raine & Walker, n.d.; AVEVA, 2012; Intergraph, 2012a) or *only some aspects of the process side* (Harary, Jessop, Stringer, & Luckman, 1965; Taylor & Moore, 1980; Steward, 1981; Heerema & Hedel, 1983; Bretschneider & Lagger, 1992; AitSahlia, Johnson, & Will, 1995; Brown, et al., 1995; Dearnley & Smith, 1995; Kiwan & Munns, 1996; Shah, Jean, Urban, Bliznakov, & Rogers, 1996; Case & Lu, 1996; Wagner, Castanotto, & Goldberg, 1997; Parent, 1997; Kim, Liebich, & Maver, 1997; Jokinen, 1997; Busby, 1998; Smith & Eppinger, 1998; Dong & Agogino, 1998; Chen, Frame, & Maver, 1998; Kalay, Khemlani, & Choi, 1998; Dowlatshahi & Nagaraj, 1998; Willaert, Graaf, & Minderhoud, 1998; Moffat, 1998; Pena-Mora & Hussein, 1998; Martino, Falcidieno, & Habinger, 1998; Peng & Trappey, 1999; Yair, Tomes, & Press, 1999; Atman, Chimka, Bursic, & Nachtmann, 1999; Herder & Weijnen, 1999; Hurst, 1999; Rogers & Salas, 1999; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000; Lloyd, 2000; Moreau & Back, 2000; Baird, Moore, & Jagodzinski, 2000; Owens, 2000; Rodriguez, Renaud, Wujek, & Tappeta, 2000; Tiwana & Ramesh, 2001; Artto, Lehtonen, & Saranen, 2001; Concheri & Milanese, 2001; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Hicks, Culley, Allen, & Mullineux, 2002; Wang, Mills, & Devarajan, 2002; Hislop, Lacroix, & Moeller, 2002; Bertola & Teixeira, 2003; Rouibah & Caskey, 2003; Koh, Ha, Kim, Rho, & Lee, 2003; Hsu & Hwang, 2004; Lowe, McMahon, & Culley, 2004; Merlo & Girard, 2004; Carnduff & Goonetillake, 2004; Wu & Sarma, 2004; Chen, Chen, Wang, Chu, & Tsai, 2005; Wu & Sarma, 2005; Wu, Hsieh, & Cheng, 2005; Liao, 2005; Ozkaya & Akin, 2006; Hicks, Culley, & McMahon, 2006; Girard & Robin, 2006; Lombard & Yesilbas, 2006; Sung & You, 2007; Robin, Rose, & Girard, 2007; Zdrahal, Mulholland, Valasek, & Bernardi, 2007; Baxter, et al., 2008; Shiau & Wee, 2008; Bordoloi & Guerrero, 2008; Zeng, 2008; Serror, Inoue, Adachi, & Fujino, 2008; Giess, Wild, & McMahon, 2008; Nunes, Santoro, & Borges, 2009; Wu J.-H. , 2009; Eilouti, 2009; Ahlemann, 2009; Mahdjoub, Monticolo, Gomes, & Sagot, 2010; Pirro, Mastroianni, & Talia, 2010; Kocar & Akgunduz, 2010; Bai, Gao, Tang, Liu, & Guo, 2010; Pitiot, ThierryCoudert, Geneste, & Baron, 2010; Tang, Zhu, Tang, Xu, & He, 2010; Shen, et al., 2010; Bowen, Edwards, Cattell, & Jay, 2010; Chua & Hossain, 2011; Berends, Reymen, L., & Eindhoven, 2011; Eastman & Shirley, n.d.; Kim & Kim, 2011; Luo, Shen, Fan, & Xue, 2011; Lau, 2011; Park, 2011; Xu, Houssin, Caillaud, & Gardoni, 2011; Liu, Li, Pan, & Li, 2011; Artto, Kulvik, Poskela, & Turkulainen, 2011; Lehoux, Hivon, Williams-Jones, & Urbach, 2011; Dongmin, Dachao, Yuchun, & Hong, 2012; Mukhtar, Ismail, & Yahya, 2012; Hermans, Naber, & Enserink, 2012; Kumar & Yao, 2012; Quintana, Rivest, Pellerin, & Kheddouci, 2012; Wang, Johnson, & Bracewell, 2012) of design management, not holistically.

The *need for a design management model that fully covers the entire design management cycle including the product as well as the process sides has been recognized by design engineers & researchers worldwide for quite some time now* (Royce, 1970; Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Sharpe, 1995; Twigg, 1995; Zanella & Gubian, 1996; Visser, 1996; Ogunlana, Lim, & Saeed, 1998; Lee, Sause, & Hong, 1998; Chapman, 1998; Smith & Morrow, 1999; Swink, 2000; Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Malhotra, Heine, & Grover, 2001; Pike & Chaney, 2001; Lang, Dickinson, & Buchal, 2002; Kestle & London, 2002; Choo, Hammond, Tommelein, Austine, & Ballardd, 2003; Heller & Westfechtel, 2003; Nagl, Westfechtel, & Schneider, 2003; Andersen, Nycyk, Jolly, & Radcliffe, 2004; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Gabbar, Aoyama, & Naka, 2004; Lardeur & Longueville, 2004; Liu, Tang, & Frazer, 2004; Marquardt & Nagl, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Cho & Eppinger, 2005; Seshasai, Gupta, & Kumar, 2005; Pektas & Pultar, 2006; Klashner & Sabet, 2007; Mozota & Kim, 2009; Girard & Doumeingts, 2010; Parent, 1997; Tzortzopoulos, Cooper, Chan, & Kagioglou, 2006; Vermaas & Dorst, 2007; Gonnet, Henning, & Leone, 2007; Acklin & Hugentobler, 2007; Chiva & Alegre, 2007; Danilovic & Browning, 2007; Young, 2008; Wang, Tang, Song, & Jiang, 2009; Manzini & Bindi, 2009; Juuti & Lehtonen, 2010) (Pitiot, ThierryCoudert, Geneste, & Baron, 2010; Roldan, Gonnet, & Leone, 2010; Charnley, Lemon, & Evans, 2011; Tonkinwise, 2011; Ping, Keung, & Ramanathan, 2011; Cipriani, M.Wieland, M.Grobmann, & D.Nicklas, 2011). However, as it has been seen in the preceding discussions, *holistic design management models have so far been built for the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries only*. From the preceding discussions it has also been seen that a few models have been built that are applicable to any engineering design management but do not solve the *design manager's problems of innovation integration and non-value adding activities' identification & elimination*. The integration of the product side involving tools & the process side involving management towards a fuller model of design management that is efficient yet flexible, *is still lacking*, inspite of the fact that *without integration, data and information needs to be manually transferred between tools adding to the cognitive load of design engineers, disrupting creative thought processes and leading to the possibility of misinterpretation or loss of design information* (Lang, Dickinson, & Buchal, 2002).

Design Management has three main ranges or governing levels –

i. *Strategic Design Management,*
ii. *Tactical Design Management &*
iii. *Operational Design Management* (Mozota, 2003b; Sun, Williams, & Evans, 2011).

The three governing levels of design management run on both sides (Product Side and Process Side discussed earlier) through each of the six phases of the design management cycle. The broad business goals for each phase and the piping design management philosophy are created in Strategic Design Management level and flow to Tactical Design Management level. Resources required for piping design and management, conducive conditions and implementation logics flow from Tactical Design Management level to Operational Design Management level. The practical implementation consisting of the actual design of the piping system and its management is controlled in the Operational Design Management level and hence this Operational Design Management level also produces necessary improvement feedbacks to the higher governing levels besides yielding the optimal design output, thus completing the piping design management cycle for that phase on each side (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000; Mozota, 2003b; Conley, 2004; Howard, Culley, & Dekoninck, 2008; Dutta, 2013a).

Conley (2004) illustrated how design expertise can be effectively managed to produce an innovative solution through three layers –

a. *Enabling Technology Layer,*
b. *Solution Layer and*
c. *Interface Layer* (Conley, 2004).

Sanchez's (2006) research stressed the integration of design & management at the strategic level (Sanchez, 2006). Acklin & Hugentobler's (2007) research into the issue of innovation integration in design management of SMEs only at the Strategic level finds that design is not yet an integral part of company's mindset which can be addressed by an innovation integrated model of design management (Acklin & Hugentobler, 2007). Thurston-Chartraw's (2006) research, besides supporting innovation integration at the strategic level, also highlights the need to integrate innovation into the tactical level (Thurston-Chartraw, 2006). There are other researchers who highlighted the need to *integrate innovation systematically into all the levels of design management* (Willaert, Graaf, & Minderhoud, 1998; Bertola & Teixeira, 2003; Salter & Gann, 2003; Rieple, 2004) as chronicled in the preceding paragraphs.

"The case study method is a favoured method to study practices of design management" (Svengren, 1993) because the research inquiries include a concern for how to integrate design with other business functions, which is a process of change" (Svengren, 1993; Kothari, 2004) and enables an in-depth, and detailed examination of a subject of study (the case) relevant under contextual conditions in order to reach the basic causal relations (Kothari, 2004). Green, Kennedy, & McGown (2002) have researched into the existing four case study based research methods in engineering design namely Protocol Studies, Ethnographic Observation, Historical Analysis & Experiental Analysis and have found that a Multi-Method research approach, that complementarily uses the four methods as per suitability, is best in terms of interpretability & recognition of research (Green, Kennedy, & McGown, 2002). Protocol Studies are concerned with constraining or equalizing variables of the research equation (Dorst, 1995). When designers work for real such rational constructs do not apply leading to the research being less representative of the actual design process (Dwarakanath & Wallace, 1995; Green, Kennedy, & McGown, 2002). With the growing recent recognition of engineering as essentially a human activity, Ethnographic Studies, wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, prove to be more useful in helping to understand how and why design happens (Wallace & Hales, 1989; Kennedy, 1997; Green, Kennedy, & McGown, 2002). Historical Analysis is used for comparing new design products to past one or learning from past design (Green, Kennedy, & McGown, 2002). Some design researchers have used Experiental Analysis to draw on their own designing experiences to explain the aspects of the design process (Green, Kennedy, & McGown, 2002). French studied engineering design from product side "through his experience of design" (French, 1992). Pahl and Beitz also put up a similar study (Pahl, Beitz, & (Ed.) 1984). "Design researchers are also rightly concerned about the lack of acceptance of their ideas by practising designers" (Cross, 1993; Beitz, 1994; Green, Kennedy, & McGown, 2002). "By *involving designers in the research as* *equal partners* it is more likely that the outcome of the research will be taken up because of the shared ownership of the knowledge produced by the research" (Green, Kennedy, & McGown, 2002). A Multi-Method research approach combines the advantages of the four methods complementarily to negate the disadvantages of each, thus leading to enhanced recognition of the research (Green, Kennedy, & McGown, 2002). In the study of design process, the adoption of a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011).

Design thinking & corresponding *design activities in different industries in differing situations not only have significant similarities but also have crucial differences* (Visser, 2009). For example - design activity in all industries involes problem solving, reuse of knowledge, etc. thus having similar traits; but Architects use ad hoc strategies to integrate partial solutions into global ones, whereas Electronic & Mechanical Design Engineers use predetermined procedures to integrate interactions between parts of a VLSI circuit or mechanical assembly respectively, etc. thus having crucial differences (Akin, 2001; Visser, 2009). So the previously discussed *design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries* and there has been no research on their applicability to the oil & gas industry. Some scholars identified through research that Design Management roles & practices vary from country to country, region to region and they recommended *region-specific design management* remits (Sun, Williams, & Evans, 2011). For example, although design management as a subject is both academically prevalent in the UK & the USA, however, whereas spotty applications of existing design management knowledge can be found in the UK but existing design management knowledge is not being out to practice in the US companies; further, the existing design management activities (for example, design approach, workflow management, design knowledge management, etc.)

significantly vary from US to UK to China – while US follows a restrictive (design by rule/analysis) approach, UK follows a risk based (safety case) approach whereas China follows both restrictive as well as risk based approaches depending on their particular Client's requirement, thus, rendering the design management activities differ significantly from country to country (Bruce, 1998; Jonson, 2006; Biddle, 2007; Chen et al., 2007; HSE, 2008; Hugentobler, 2008; Patrick, 2008; Ashton and Ye Deng, 2008; O'Brien et al., 2009; ASME 2013, 2014; BSI, 2010, 2014; DS, 2010; Sun, Williams, & Evans, 2011), So the previously discussed *design management studies, undertaken elsewhere, are uncertain in terms of their applicability to India and in India no research has been done in engineering design management*. Sun et al. (2011) also defined design management as the "management of the interface between design and the other stakeholders within the industry" and identified five key design management roles – Line Management of Design Teams, Management of Knowledge Input, Management of Design Output, Managing the Interface with Substitute Design Products, and Managing & Redefining Entry Barriers. Sun, et al. also stressed the growing & *indispensable need for a comprehensive design management system/model, however no research has been done on engineering design management in India*.

The issues that have emerged from the preceding reviews of existing literatures on multidisciplinary engineering design management are as follows in Emergence E:

Emergence: E

1. *An integrated management model for managing engineering design is indispensably needed* to aid design engineers in their design management decisions and *to sustain the competitive edge* of the company (Turner, 1985; Ughanwa, 1988; Wallace & Burgess, 1995; Kiwan & Munns, 1996;

Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Sun, Williams, & Evans, 2011) *and hence the companies who do not have effective design management practices/models are much less successful in business that the ones having it* (Bruce, Cooper, & Vazquez, 1999). Effective management of engineering design is also needed *to increase job satisfaction of design engineers* (Ahire & Dreyfus, 2000; Rieple, 2004; Robinson, 2012).

2. Design Management has three levels - *Strategic Design Management, Tactical Design Management & Operational Design Management* (Mozota, 2003b; Sun, Williams, & Evans, 2011). In each level, design expertise can be effectively managed to produce an innovative solution through three layers – *Enabling Technology Layer, Solution Layer and Interface Layer* (Conley, 2004).

3. The entire cycle of engineering design management consists of six phases (Howard, Culley, & Dekoninck, 2008) & each phase consists of has *two interfering sides – the Design Product Engineering Side & the Design Process Side* (Visser, 1996; Lee, Sause, & Hong, 1998; Swink, 2000).

4. Many researchers have focused only on the issues of the product side. The *issues of design management on the product side* are – (i) design philosophy needs to be *objective* instead of being subjective (Woudhuysen, 2006), (ii) designers need to *exploit the positive side of uncertainty* rather than focusing just on the negative side (Neufville, 2004), (iii) *design optimization needs to be based on the limitations of its dependant disciplines* (Rodriguez, Renaud, Wujek, & Tappeta, 2000), (iv) judicious management of the *four design objectives of Aesthetics, Functionality, Buildability and Economics between the client and the design team, that is needed in order to ensure optimum product quality*

(Wong, Lam, & Chan, 2009) and (v) effective *combating of design errors through a combination of more than one analysis type* like Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in multiple stages and Mechanical Audits (Taylor J. R., 2007).

5. Many researchers have focused only on the issues of the process side. *The issues of design management on the process side* are – (i) *design knowledge management* (Heerema & Hedel, 1983; Kiwan & Munns, 1996; Zanella & Gubian, 1996; Jokinen, 1997; Kim, Liebich, & Maver, 1997; Martino, Falcidieno, & Habinger, 1998; Herder & Weijnen, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000), (ii) *management of the six phases namely Establishing a Need Phase, Analysis of Task Phase, Conceptual Design Phase, Embodiment Design Phase, Detailed Design Phase, Implementation Phase, of the design cycle*, through sequencing-controlling-monitoring (Visser, 1996; Lee, Sause, & Hong, 1998; Rogers & Salas, 1999; Howard, Culley, & Dekoninck, 2008), (iii) *conflict management* & collaborative resolution by shared understanding & treating assertions as facts (Case & Lu, 1996; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Pena-Mora & Hussein, 1998; Kleinsmann & Valkenburg, 2008), (iv) *interdisciplinary management* involving collaborative coordination & team integration (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Liu, Tang, & Frazer, 2004), (v) *systematic innovation integration* in all the three management levels of design management using 4 characteristics of Explicitness, Novelty, Importance & Usability (Willaert, Graaf, & Minderhoud, 1998; Swink, 2000; Salter & Gann, 2003; Bertola & Teixeira, 2003; Rieple, 2004; Xu, Houssin, Caillaud, & Gardoni, 2011) through three management layers – Enabling Technology Layer, Solution Layer and Interface Layer (Conley, 2004), (vi) dynamic *bi-directional feedback integration* (Dearnley & Smith, 1995; Zanella & Gubian, 1996;

Busby, 1998; Sheu & Chen, 2007), (vii) *non-value adding activities' identification & elimination* (Chua & Tyagi, 2001), (viii) *design change order management* (Wright, 1997; Ogunlana, Lim, & Saeed, 1998; Wang, Tang, Song, & Jiang, 2009), (ix) *rework minimization* (Ahire & Dreyfus, 2000; Chua & Tyagi, 2001), (x) *effective communication* that is needed between the client & the design team, which can be facilitated through a question-answering mechanism consisting of different questions on 5 main categories – Elaboration, Enablement, Validation-Current-Model, Validation-Future-Model & Clarification (Parent, 1997) and (xi) *design project management maintaining a balance between top-down & bottom-up management* methods to enable more effective design management products (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003).

6. Popular CAD softwares such as PDMS®, AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, PDS®, AutoCAD®, Autodesk Streamline®, etc. cater only to the product side and do not offer any tool for real-time holistic management of the design process (Wang, Tang, Song, & Jiang, 2009; Intergraph, 2012b; AVEVA, 2012).

7. Integrated design management frameworks & models, that have so far been built, are applicable only to the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries (Wallace & Burgess, 1995; Kiwan & Munns, 1996; Case & Lu, 1996; Zanella & Gubian, 1996; Lee, Sause, & Hong, 1998; Chua & Tyagi, 2001; Kestle & London, 2002; Liu, Tang, & Frazer, 2004; Roldan, Gonnet, & Leone, 2010; Komoto & Tomiyama, 2012). For the oil & gas industry, no integrated multidisciplinary engineering design management model can be found that caters to the issues of the product & the process sides.

8. A study of the design process, employing a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011). Ethnographic Studies, wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, have been found to be more useful in helping to understand how and why design happens, and teamwork in design teams (Wallace & Hales, 1989; Kennedy, 1997; Baird, Moore, & Jagodzinski, 2000; Green, Kennedy, & McGown, 2002). Researchers have found that the qualitative case study method is a favoured method to study & analyze practices of design management (Svengren, 1993) and a Multi-Method research approach, that complementarily uses the four case study based methods, namely Protocol Studies, Ethnographic Observation, Historical Analysis & Experiental Analysis, as per suitability, is best in terms of interpretability & recognition of research (Green, Kennedy, & McGown, 2002).

9. Design thinking & corresponding *design activities in different industries in differing situations not only have significant similarities but also have crucial differences* (Visser, 2009).

10. Design Management roles & practices vary from country to country, region to region (Sun, Williams, & Evans, 2011).

II. Existing Researches/Models/Practices in Piping Engineering Design Management:

Piping Engineering Design is a domain of mechanical engineering design (Tsai, Yang, & Liao, 2011) that studies the efficient transport of fluid or pressure from one point to another (ASME, 2014) and hence, naturally consists of six phases (Howard, Culley, & Dekoninck, 2008) where each phase consists of a

a. Design Product Engineering Side, &

b. Design Process Side as have been discussed for multidisciplinary engineering design management in the preceding paragraphs. Subsequently, the earlier discussed design management problems of multidisciplinary engineering design management are also naturally inherent in piping engineering design management. The criticality of piping design engineering management lies in the fact that piping consumes *more than 40% of any plant's design engineering activities* (Sheremetov, Batyrshin, Chi, & Rosas, 2008). "Piping is popularly compared to the arteries in human body and, the adage that piping study is 'half science and half art' is true, the art part is visualization and creativity while the science part refers to following the established norms" (Prasad, 2009; Dutta, 2013a, 2013b).

The preceding discussed multidisciplinary "design management models that have so far been built, are applicable for the Architecture, Civil, Construction, Electronics, Mechatronics, Aerospace, Transportation / Automotive, Medical, Software, Chemical Engineering Design Industries only. And, *since design thinking & corresponding design activities in different industries in differing situations not only have significant_similarities but also have crucial differences* (Visser, 2009)", therfore the previously discussed *design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries* and there has been no research on their applicability to the oil & gas industry (Dutta, 2013a, 2013b).

Guzy (1987) undertook a research on dynamic load capacity testing of piping in the nuclear industry (Guzy, 1987). Some researchers developed an integrated piping design system focusing purely on the product side of only small bore piping design applicable only to the nuclear industry (Mo, 1994). Some other undertook a similar research but applicable to all bore piping and built a Nuclear Piping Integrity Expert System (NPIES) focusing purely on the product side of piping design applicable only to the nuclear industry (Kim, Suh, Jun, Park, & Choi, 1997). Fleming (2004) focused on the product side & applied Markov models for predicting nuclear industry piping reliability (Fleming, 2004). All of these researchers have been focused on the product side of engineering design from purely an engineering point of view, without any consideration for the managerial aspects in design management, that too for industries other than oil & gas outside India but design management varies from industry to industry (Visser, 2009) as well as country to country (Sun, Williams, & Evans, 2011) and the previous researchers neither focussed on design management in oil & gas industry nor on design management in India.

Researchers found that piping design is one of the most significant cost drivers in any plant but piping engineering management methods are still imprecise necessitating a project management type model for piping (Pulkkinen, Vainio-Mattila, & Riitahuhta, 1997). These researchers built a model for capturing the piping design process applicable only to the power plant industry (Pulkkinen, Vainio-Mattila, & Riitahuhta, 1997). Some other scholars focused purely on one of the aspects of the product side of piping design, the optimal shortest route problem and found that by using a power multiplication method subsequent to basic CAD system an optimally short piping route can be obtained in a power plant (Yamada & Teraoka, 1998).

Revesz focused on the stress aspect of the product engineering side of piping design management & developed Piping Analysis and Interactive Design (PAID) software that do not cater to the management of the process side (Revesz, 1985). Water hammer produces large dynamic forces that damage piping. Some researchers focused on this aspect of piping engineering to recommend the influencing of fluid dynamic conditions & other dynamic variations to minimize the effects (Gillessen & Lange, 1988). Some scholars developed Integrity Assessment Expert System of In-service Pressure Piping Containing Flaws (IAESPP-SINTAP) that assesses piping defects based of computing stress intensification factors (Lin & Xie, 2006). IAESPP-SINTAP, like its predecessors, caters only to one aspect of piping design engineering and not to the holistic (integrated product & process sides) management of piping engineering design. Some other researchers developed a method to aid the designer develop a 3D piping model piping applicable to ship design focused purely on the product engineering side of piping design (Roh, Lee, & Choi, 2007).

The product side of piping design engineering has two main components – 1. the Design Drawing Part (for e.g. developing the 2D plans, elevations, bill of quantities or the 3D model of the plant, etc.) and 2. The Design Engineering Part (for e.g. doing the calculations for deciding upon the pipe thicknesses, materials, stress effects, flexibilities, supports, etc.) for which respective softwares are there (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Wang, Tang, Song, & Jiang, 2009), as follows –

1. *Design Drawing Softwares* - PDMS®, AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, PDS®, AutoCAD®, Autodesk Streamline®, etc. (Wang, Tang, Song, & Jiang, 2009; Intergraph, 2012b; AVEVA, 2012).

2. *Design Engineering Softwares* - Caesar II®, CAEPIPE®, ROHR2®, AutoPIPE®, PetroPipe®, etc. (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Sigma, 2012; Bentley, 2012; Solutions, 2012; PetroStreet, 2012; Intergraph, 2012a).

The latest software tools for Part 1 do not have the capabilities of those of Part 2 and vice-versa, & this hampers of collaboration & concurrency of the product development process leading to increased human errors & man-hours (Sheremetov, Batyrshin, Chi, & Rosas, 2008). In order to combat this problem, Sheremetov et al. (2008) built a framework for stress-layout collaborative engineering design of oil & gas industry piping systems. This framework facilitates seamless data exchange between the two parts by employing an interoperability architecture thus facilitating the needs of the piping design engineers. Sheremetov et al. (2008) however focused only on the product side of piping design from an engineering point of view and hence did not take care of the *management problems troubling the Design Managers on both the product as well as the process sides of piping engineering design management*, as discussed in the preceding paragraphs.

Some researchers concentrated on the piping network design optimization of a geothermal heating system (Yildirim, Toksoy, & Gokcen, 2010) while some others studied the standard inspections techniques in vogue for cross-country pipeline's integrity (Kishawy & Gabbar, 2010) but both the researches concentrated upon the piping from a purely engineering point of view. Tsai et al. (2011) showed *that increasing the concurrency of the conceptual stages through a management model can reduce the project duration as well as the cost* & built a model for foam firefighting piping system for the construction industry (Tsai, Yang, & Liao, 2011).

Plant Design Management System (PDMS®) is the most widely used popular software in its category, but can be used only for the Design Drawing Part (Part 1 discussed earlier) on the product engineering side of piping design (Parisher & Rhea, 2012; AVEVA, 2012) just like other drawing softwares - PDS® (Intergraph, Intergraph PDS, 2012), AutoCAD®, Autodesk Inventor®, Solidworks®, Pro/Engineer®, AutoCAD®, Autodesk Streamline®, etc. (Wang, Tang, Song, & Jiang, 2009).

Caesar II® is the most widely used popular software in its category, but can be used only for the Design Engineering Part (Part 2 discussed earlier) on the product engineering side of piping design (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Intergraph, 2012a) just like other piping engineering softwares - CAEPIPE®, ROHR2®, AutoPIPE®, PetroPipe®, etc. (Sheremetov, Batyrshin, Chi, & Rosas, 2008; Sigma, 2012; Bentley, 2012; Solutions, 2012; PetroStreet, 2012).

As it has been seen from the preceding reviews of available existing literatures, The existing studies did *neither focus on the management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides*. However, previous studies have established that *design management roles, practices & activities significantly vary from industry to industry* (Visser, 2009) *and from country to country* (Sun, Williams, & Evans, 2011). Further, the previous studies neither throw a*ny light on the oil & gas industry nor on the design management issues*. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

Piping engineering being under the domain of mechanical engineering design (Tsai, Yang, & Liao, 2011) naturally has the same management problems on the product & the process sides as discussed in Emergence: E points 4 & 5 earlier. Also *piping design management has three levels - Strategic Design Management, Tactical Design Management & Operational Design Management* (Mozota, 2003a, 2003b, 2009; Sun, Williams, & Evans, 2011) and in each level, design expertise can be effectively managed to produce an innovative solution through *three layers – Enabling Technology Layer, Solution Layer and Interface Layer* (Conley, 2004).

The researcher, a mechanical engineer, on working in the piping engineering design departments of different multinational & Fortune 100 companies during the last ten plus years, have also *experientially observed all the preceding discussed findings (especially the issues/challenges in Emergence: E points 1, 4 & 5) from the existing literatures, plaguing the management of piping engineering design in actual practice, and have deeply felt the indispensable need for an integrated management model for efficiently managing the design product engineering side as well as the design process side.* As such, the researcher's experience reinforces the earlier observations from the available existing literatures. Hence, the researcher aspired to use the knowledge substantiated by scholars discussed in the earlier Emergence: E points and the research methods enlightened by Charnley et al. (2011) discussed in the Emergence: E point 8, to understand the existing oil & gas piping design management practices in India, identify the areas of improvements and build an ***Integrated Piping Engineering Design Management Model for Oil & Gas Industry in India*** because design improves the competitive edge of a country in international competitions (Ughanwa et al., 1988; Mozota, 2003a, 2003b; Dutta, 2013a).

3.2 Conceptual Frames

The preceding literature review discussions formed the conceptual frames for this study on the various issues plaguing the piping engineering design management cycle. The aphoristic *key highlights* are as follows.

Previous researchers have established that design management cycle comprises of *Three Governing Levels –*

i. Strategic Design Management,

ii. Tactical Design Management &

iii. Operational Design Management (Mozota, 2003a, 2003b, 2009; Sun et al., 2011)

and some other researchers have established that *at Each Level*, design expertise can be effectively managed to produce an innovative solution through *Three Layers –*

a. Enabling Technology Layer,

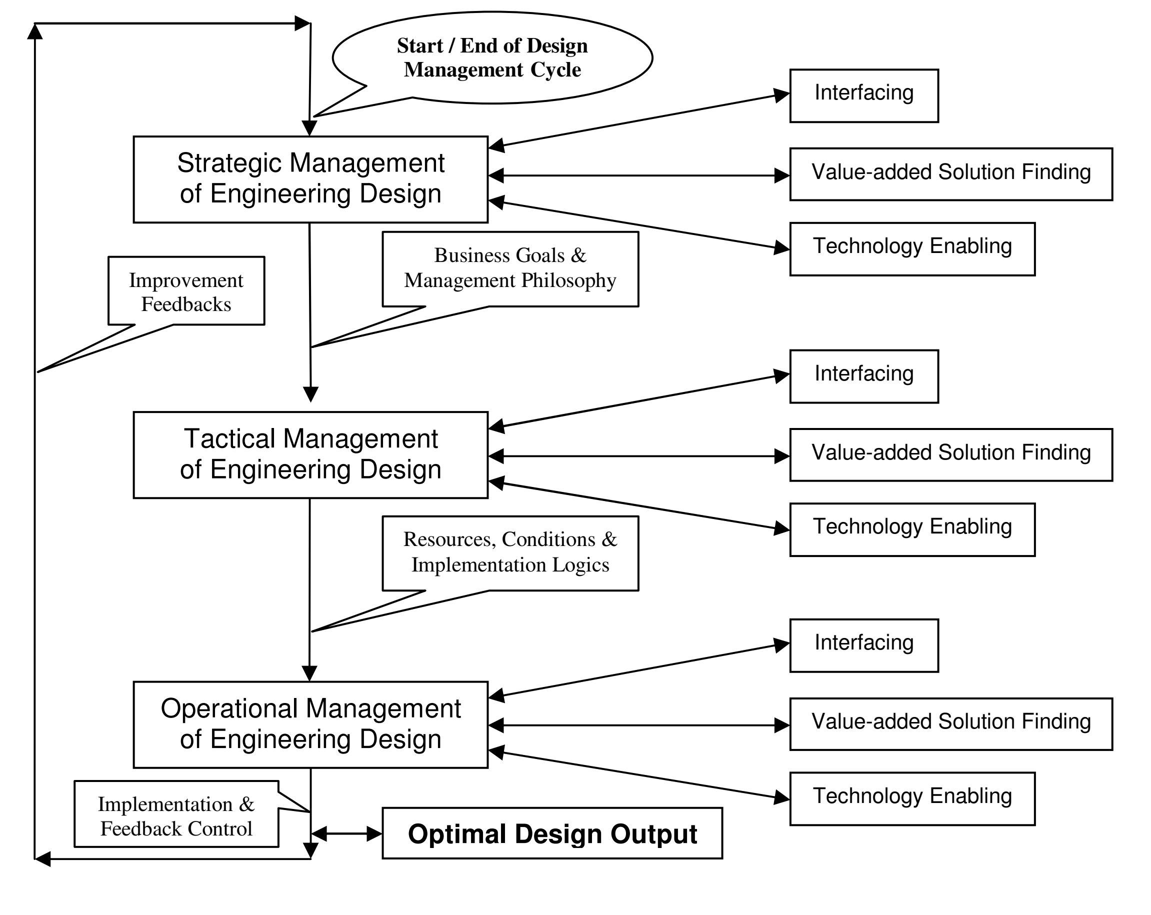
b. Solution Layer and

c. Interface Layer (Conley, 2004).

From the review of existing literatures, the *basic theoretical framework* of the proposed model has been derived as follows. It may be noted here that the Figure 31, described in the subsequent paragraphs, can be treated as a built-up *conceptual lens which has been deployed in the research process,* how this is employed in the present research process has been appositely discussed in pertinent sections (refer Sections 4.1, 4.2, 5.1 & 7.1).

(Figure 3.1 follows in next page)

Figure 3.1: Basic Theoretical Framework



The **Figure 3.1** framework has been proposed by the researcher by integrating his findings from the reviews of existing literatures. Previous researchers have established that design management cycle comprises of *Three Governing Levels –*

i. Strategic Design Management,

ii. Tactical Design Management &

iii. Operational Design Management

(Mozota, 2003a, 2003b, 2009; Sun et al., 2011) and some other researchers have established that *at Each Level*, design expertise can be effectively managed to produce an innovative solution through *Three Layers –*

a. *Enabling Technology Layer,*

b. *Solution Layer and*

c. *Interface Layer* (Conley, 2004).

The researcher has integrated these findings from the existing literatures for proposing this basic theoretical framework of an efficient engineering design management cycle. Further, from data collection and analyses findings, it has been one of the tasks of this research to build up on this Figure 3.1 framework the product-process sides integrated model of piping engineering design management for the oil & gas industry in India.

The Figure 3.1 cycle has the Basic Flow of Activities as follows: the broad business goals for each phase and the piping design management philosophy are created in Strategic Design Management level and flow to Tactical Design Management level, resources required for piping design and management, conducive conditions and implementation logics flow from Tactical Design Management level to Operational Design Management level, the practical implementation consisting of the actual design of the piping system and its management is controlled in the Operational Design Management level and hence this Operational Design Management level also produces necessary improvement feedbacks to the higher governing levels besides yielding the optimal design output, thus completing the piping design management cycle for that phase (Conley, 2004; Howard, Culley, & Dekoninck, 2008).

For systematic & effective innovation integration in each step, the present research uses this knowledge of three layers (Conley, 2004) into each of the three ranges or governing levels of design management and as such, each of the governing levels (1, 2 & 3) are modelled to consist of three core layers – (I) Interfacing, (II) Value-added Solution Finding, and, (III) Technology Enabling. In Interfacing layer, the work problem relevant to that governing level is discussed upon among team members to identify what are the areas of improvement and how can things be further improved. In the Value-added Solution Finding layer, team members brainstorm to find innovative improvements, appraise the emerging innovative ideas in terms of economics & practicability and finally approve the effective innovations. In Technology Enabling layer, the approved innovations are technologically enabled so as to put them into actual practice within the cycle.

The holistic Piping Engineering Design Management Cycle has *Six Phases* namely:

1. Establishing a Need Phase,
2. Analysis of Task Phase,
3. Conceptual Design Phase,
4. Embodiment Design Phase,
5. Detailed Design Phase &
6. Implementation Phase (Howard, Culley, & Dekoninck, 2008).

The management of Piping Engineering Design has *two interfering Sides:*

a. Design Product Engineering Side &

b. Design Process Side (Visser, 1996; Lee et al., 1998; Swink, 2000).

The three governing levels of design management run on both sides (Product as well as Process sides discussed earlier) through each of the six phases of the design management cycle.

Multiple issues are found to be plaguing the design management cycle as seen in all the preceding discussions; the factors plaguing the effective management of engineering design are hereby named issues or challenges; these issues/challenges can be grouped into seven categorical issues and an effective Piping Engineering Design Management Model can be built if these seven issues can be taken care of, as depicted in *Table 3.1: Issues* (can also be called the *constructs); further details on how these constructs have been used* have been described in the later chapters.

Table 3.1: Issues

Sl. No.	**Issues**	
1	Design Product Engineering Side	***Objectivity*** in Design Philosophy (Woudhuysen, 2006) based on ***Aesthetics, Functionality, Buildability and Economics*** (Wong, Lam, & Chan, 2009).
2		Exploitation of the ***Positive Side of Uncertainty*** (Neufville, 2004).
3		***Interdiscipline-Dependancy*** based Design Optimization (Rodriguez, Renaud, Wujek, & Tappeta, 2000) employing a combination *of* ***more than one analysis type*** like Hazard Identification & Operability (HAZOP) Studies, Design & Drawing Reviews in Multiple Stages and Mechanical Audits (Taylor, 2007).

Sl. No.	Issues	
4	Design Process Side	***Transparent Management** of **Design Knowledge*** (Heerema & Hedel, 1983; Kiwan & Munns, 1996; Zanella & Gubian, 1996; Jokinen, 1997; Kim, Liebich, & Maver, 1997; Martino, Falcidieno, & Habinger, 1998; Herder & Weijnen, 1999; Miles, Gray, Carnduff, Santoyridis, & Faulconbridge, 2000; Sheremetov, Batyrshin, Chi, & Rosas, 2008) including Design Change Orders (Wright, 1997; Ogunlana, Lim, & Saeed, 1998; Wang et al., 2009) maintaining a ***Balance between Top-Down & Bottom-Up*** management methods (Owens, 2000; Dias, Subrahmanian, & Monarch, 2003) ***in each of the Six Phases*** of the design cycle, ***through Sequencing-Controlling-Monitoring*** *(*Visser, 1996; Lee et al., 1998; Rogers & Salas, 1999; Howard et al., 2008).
5		***Effective Communication*** for - Conflict Resolution *by **Shared Understanding & treating Assertions as Facts*** (Case & Lu, 1996; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002; Pena-Mora & Hussein, 1998; Kleinsmann & Valkenburg, 2008), ***Dynamic Bi-Directional Feedback Integration*** (Dearnley & Smith, 1995; Zanella & Gubian, 1996; Busby, 1998; Sheu & Chen, 2007*),* ***Team Integration*** (Reid, Culverhouse, Jagodzinski, Parsons, & Burningham, 2000; Liu, Tang, & Frazer, 2004) & ***Client-Designer Agreements*** (Parent, 1997).

Sl. No.	**Issues**	
6		***Systematic Innovation Integration*** in the Three Governing Levels existing in each of the Six Phases ***through Three Management Layers*** **–** i. Enabling Technology Layer, ii. Solution Layer & iii. Interface Layer (Conley, 2004), ***by analysing Explicitness, Novelty, Importance & Usability*** of each innovative suggestion/practice (Willaert, Graaf, & Minderhoud, 1998; Swink, 2000; Salter & Gann, 2003; Bertola & Teixeira, 2003; Rieple, 2004; Xu, Houssin, Caillaud, & Gardoni, 2011).
7		Rework Minimization (Ahire & Dreyfus, 2000; Chua & Tyagi, 2001) by ***Identification & Elimination of Non-value adding activities*** (Chua & Tyagi, 2001).

Researches in many countries, none of which has focused on India, so far have identified that *an Effective Model for integrated Design Management can be built if these 3 issues on product side & 4 issues on process side are taken care of*. However, previous research has proven that engineering design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, 2009) as exemplified in earlier Chapters and therefore, the earlier discussed design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries and no research has been done on their applicability to the oil & gas industries. Furthur, previous research has proven that *design management roles & practices vary from country to country* (Sun et al., 2011) as discussed earlier. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Further, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focused on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

From the comprehensive reviews of existing literatures, it is found that there have been some researches in this broader field of *Multidisciplinary Engineering Design Management for industries other than Oil & Gas*. There have also been some researches in the *Management of specifically Piping Engineering Design in industries other than Oil & Gas* as discussed earlier. However, engineering design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, 2009) as discussed with examples in earlier paragraphs.

It has been found that all *researches, except one (Sheremetov, Batyrshin, Chi, & Rosas, 2008), focused on the product side of piping in industries other than oil & gas; however, all of these have focused only from a purely engineering point of view, leaving a colossal dearth of focus on the management aspects in the product as well as the process sides of design management*. The only one research found on *Oil & Gas Piping Engineering Design Management* has been done too purely from an engineering point of view outside India (Sheremetov, Batyrshin, Chi, & Rosas, 2008); Sheremetov et al.'s (2008) research has been focused on only one modelling aspect - integrating piping analysis like stresses and flexibility with piping design like layouts, etc. of oil & gas piping engineering design management but this research's engineering recommendations too may not be applicable to India since *design management practices vary from country to country* (Sun, Williams, & Evans, 2011). The only one research found on *Oil & Gas Piping Engineering Design Management* has been done too purely from an engineering point of view (Sheremetov, Batyrshin, Chi, & Rosas, 2008) and *may or may not be applicable in the Indian context because design management practices vary from country to country and no study has focussed on engineering design management in India.*

The existing studies did *neither focus on the management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides*. However, previous studies have established that *design management roles, practices & activities significantly vary from industry to industry (Visser, 2009) and from country to country* (Sun, Williams, & Evans, 2011) as exemplified in the earlier paragraphs. Further, the previous studies *neither throw any light on the oil & gas industry nor on the design management issues*. Therefore the identified seven issues, that have all emerged from research in other industries in other countries, may or may not be applicable to India. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a comprehensive design management model and in India no research has focussed on engineering design management.

It may be noted here that this particular Chapter reviews & discusses the relevant existing literature. All the findings from the existing literature review led to the development of the conceptual lens and the constructs, as chronicled in the next Chapter 4: Research Design.

The findings from the preceding discussions led to the research questions of how piping engineering design is being managed in the Indian context, with/without any existing model, what are the issues there and how those can be catered to through a model of piping engineering design management.

From all the preceding detailed discourses, the business management problem, research gaps, research problems, research questions & research objectives are summed up as follows.

3.3 Business Problem

The business management problem is:

An ***integrated model for managing engineering design*** is indispensably needed to aid design engineers/managers in their management decisions and to sustain the ***competitive advantage of the company***.

To solve this business problem, address the research gaps, answer the research questions and fulfill the research objectives, the existing practices of piping engineering design management that are being used in the piping engineering design department of India's largest oil & gas company have been studied, issues identified, compared with other researchers' finding, each research step has been deeply thought upon, profoundly analyzed, rigorously verified and an integrated model of piping engineering design management has been proposed as discussed in the following Chapters.

3.4 Research Gaps

The emerged research gaps are:

Extensive literature review yielded no references of any *design approaches & models for oil & gas piping engineering design management in India.* There has been no research to know how design is being managed in India.

From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary crucially from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an *integrated design management model* and in India no research has focussed on engineering design management.

Previous studies have established that an integrated management model for managing engineering design is indispensably needed. The previous studies have their respective limitations. Some researchers have focused only on the Product Side of Engineering Design Management and have so far found out three issues challenging the efficient management on engineering design on the Product Side. Whereas some other researchers have focused only on the Process Side of Engineering Design Management and have so far found out four issues challenging the efficient management on engineering design on the Process Side. Existing literature review has evidenced that engineering design management can be effectively managed if the identified issues are catered to. Previous studies for specifically piping engineering design management have focused only from a pure engineering point of view, ensuing a colossal dearth of focus on the management aspects in the product as well as the process sides of design management; the existing studies did neither focus on the piping enginering design management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides. Further, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. An extensive literature review covering over three hundred relevant available literatures yielded no references of any design approaches & models for oil & gas piping engineering design management in India. The previous studies neither throw any light on the design management in the global oil & gas industry nor on the design management issues of any industry in India. There has been no research to know how design is being managed in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. However, previous studies have established that design management roles, practices and activities significantly & crucially vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an integrated design management model and in India no research has focussed on engineering design management. The identified research gaps have not been addressed by any of the previous studies. This present research tries to answer these questions and thus address these dodged research gaps in a bid to improve engineering design management in India.

3.5 Research Problems

The two research problems are:

The Existing Practices/Models of Piping Engineering Design Management that are being used in Oil & Gas Industry in India are unknown, although are indispensably needed to be known in order to sustain the competitive advantage of the company.

The Areas of Improvements or Issues, that are needed to be identified in order to develop a Model of Piping Engineering Design Management, are also unknown.

3.6 Research Questions

The two research questions are:

HOW Piping Engineering Design is being managed in oil & gas industry in India?

WHAT are the areas of improvements in the existing practices/models and *HOW those areas can be catered to through a Model* of Piping Engineering Design Management?

3.7 Research Objectives

The two research objectives are:

To Study the Existing Practices/Models of Piping Engineering Design Management that are being used in oil & gas industry in India.

To Identify the areas of improvements in order to develop a Model of Piping Engineering Design Management.

In this Chapter the connate conceptual framework has been discussed. The proceeding Chapter describes the research design that is the basic plan for doing this research study.

Chapter 4: Research Design

Chapter 4: Research Design

This Chapter paints the basic design of the research itself; it depicts the plan including methodologies, rationales & philosophies for application in this study.

4.1 Research Methodology

Researches can be classified into multiple types based on the *research purpose, research process and research approach.*

From a *purpose* viewpoint, researches can be broadly classified into five types –

(a) Descriptive: for fact finding about a present state of affairs,

(b) Analytical/Historical/Correlational: for critical evaluation of already found facts to find relationships,

(c) Fundamental/Conceptual: to create new theory / abstract ideas,

(d)Exploratory/Empirical/Experiental/Predictive/Applied: to clarify/verify already available concepts or assess their applicability,

(e) Case Study: for an in-depth, and detailed examination of a subject of study (the case) relevant under contextual conditions in order to reach the basic causal relations (Kothari, 2004).

From a *process* viewpoint, researches can be broadly classified into four types –

(f) Qualitative: based on a phenomenon relating to quality (the researcher is an object of interview/survey),

(g) Quantitative: based on measurement of quantity (can be statistical, the researcher is an observer),

(h) Experimental: to evaluate whether a concept/program had the intended causal effect on the relevant participants (the researcher carries out the research process and is an observer),

(i) Action/Participatory: involving social action to solve an immediate problem or group action for progressive problem solving (the researcher directs & facilitates the research process, the participant is an observer) (Kothari, 2004; Denscombe, 2010).

There are many types of research approaches that are generally specific to the particular purpose &/or the particular process of the research. From an *approach* viewpoint, qualitative researches can be broadly classified into four types –

(j) Grounded Theory: to systematically generate theory from data through inductive thinking about a phenomenon of interest (Glaser & Strauss, 1967; Charmaz, 2006; Creswell, 2007),

(k) Phenomological/Protocol/Heuristic: to understand how a phenomenon is subjectively perceived & commonly interpreted by people (Creswell, 2007),

(l) Ethnological: to understand the shared patterns of a phenomenon in a common culture group or ethnicity (Creswell, 2007),

(m) Hermeneutic/Narrative/Discourse: to interpret narrations by individuals about a particular phenomenon (Creswell, 2007).

Out of these 13 [points 4.1 (a) to 4.1 (m)] broad types of research, it is noted that most researches generally comprise of a combination of these different methods (Kothari, 2004; Creswell, 2006). These thirteen broad types of research are presented in Table 4.1.

The present research objectives (refer Section 3.7) are to find ***facts about the present state of affairs*** in Piping Engineering Design Management (PEDM) that **matches with *4.1 (a)***; then, as the research objectives & research questions require to find the existing challenges and how to overcome those, this research calls for an ***in-depth and detailed examination of the facts*** in order to reach the basic causal relations & as such this **matches with *4.1 (e)***; and a ***detailed examination of a phenomenon*** (PEDM & its challenges) is the most suitable, thus **matching with *4.1 (f)***; further, in line with the research objective of building an integrated model of PEDM to overcome the identified challenges, the ***systematic generation of theory from data through inductive thinking, as in 4.1 (j)***, is the most applicable approach of analysis; hence, categorically the present research required:

4.1 (a) + 4.1 (e) + 4.1 (f) + 4.1 (j) => descriptive qualitative case study with a grounded theory approach

Therefore a ***descriptive qualitative case study with a grounded theory approach*** has been chosen for this particular research. This mixed approach is further detailed in the subsequent sections.

(Table 4.1 follows in next page)

Table 4.1: Types of Researches

Viewpoint	Tag	Research Type	Description
Research Purpose	a	Descriptive	For fact finding about a present state of affairs (Kothari, 2004)
	b	Analytical/Historical/ Correlational	for critical evaluation of already found facts to find relationships (Kothari, 2004)
	c	Fundamental/ Conceptual	to create new theory / abstract ideas (Kothari, 2004)
	d	Exploratory/Empirical /Experiental/ Predictive/Applied	to clarify/verify already available concepts or assess their applicability (Kothari, 2004)
	e	Case Study	For an in-depth & detailed examination of a subject of study (the case) relevant under contextual conditions in order to reach the basic causal relations (Kothari, 2004)
Research Process	f	Qualitative	Based on a phenomenon relating to quality (Kothari, 2004; Denscombe, 2010)
	g	Quantitative	Based on measurement of quantity (Kothari, 2004; Denscombe, 2010)
	h	Experimental	To evaluate whether a concept/program had the intended causal effect on the relevant participants (Kothari, 2004; Denscombe, 2010)
	i	Action/Participatory	Involving social action to solve an immediate problem or group action for progressive problem solving (Kothari, 2004; Denscombe, 2010)

Viewpoint	Tag	Research Type	Description
Research Approach	j	Grounded Theory	To systematically generate theory from data through inductive thinking about a phenomenon of interest (Glaser & Strauss, 1967; Charmaz, 2006; Creswell, 2007)
	k	Phenomological/ Protocol/Heuristic	To understand how a phenomenon is subjectively perceived & commonly interpreted by people (Creswell, 2007)
	l	Ethnological	To understand the shared patterns of a phenomenon in a common culture group or ethnicity (Creswell, 2007)
	m	Hermeneutic/ Narrative/Discourse	To interpret narrations by individuals about a particular phenomenon (Creswell, 2007)

"The case study method is a favoured method to study practices of design management" (Svengren, 1993) because the research inquiries include a concern for how to integrate design with other business functions, which is a process of change" (Svengren, 1993; Kothari, 2004) and enables an in-depth, and detailed examination of a subject of study (the case) relevant under contextual conditions in order to reach the basic causal relations (Kothari, 2004). Green, Kennedy, & McGown (2002) have researched into the existing four case study based research methods in engineering design namely Protocol Studies, Ethnographic Observation, Historical Analysis & Experiental Analysis and have found that a Multi-Method research approach, that complementarily uses the four methods as per suitability, is best in terms of interpretability & recognition of research (Green, Kennedy, & McGown, 2002). Protocol Studies are concerned with constraining or equalizing variables of the research equation (Dorst, 1995). When designers work for real such rational constructs do not apply leading to the research being less representative of the actual design process (Dwarakanath & Wallace, 1995; Green, Kennedy, & McGown, 2002). "With the growing recent recognition of engineering as essentially a human activity, Ethnographic Studies, wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, prove to be more useful in helping to understand how and why design happens" (Wallace & Hales, 1989; Kennedy, 1997; Green, Kennedy, & McGown, 2002). Historical Analysis is used for comparing new design products to past one or learning from past design (Green, Kennedy, & McGown, 2002). Some design researchers have used Experiental Analysis to draw on their own designing experiences to explain the aspects of the design process (Green, Kennedy, & McGown, 2002). French studied engineering design from product side through his experience of design (French, 1992). Pahl and Beitz also put up a similar study (Pahl, Beitz, & (Ed.) Wallace, 1984). "Design researchers are also rightly concerned about the lack of acceptance of their ideas by practising designers" (Cross, 1993; Beitz, 1994; Green, Kennedy, & McGown, 2002). "By *involving designers in the research as equal partners* it is more likely that the outcome of the research will be taken up because of the shared ownership of the knowledge produced by the research" (Green, Kennedy, & McGown, 2002). A Multi-Method research approach combines the advantages of the four methods complementarily to negate the disadvantages of each, thus leading to enhanced recognition of the research (Green, Kennedy, & McGown, 2002). In the study of design process, the adoption of a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011).

Among the different established processes to do a research, the qualitative & quantitative research processes are most widely used. The qualitative case study with a grounded theory approach chosen for this research is further supported by previous researches on qualitative research & its quantitative counterpart, as presented in following Table 4.2 (Maxwell & Loomis, 2003):

Table 4.2: Qualitative vs. Quantitative Research (Maxwell & Loomis, 2003)

RESEARCH / FEATURES	QUANTITATIVE RESEARCH	QUALITATIVE RESEARCH
RESEARCH ARENA		
Purpose	- Precise measurements & variable comparisons - Relations among variables - Inferencing from sample to population	- Meaning, Context and Process - Discovering unanticipated events, conditions and effects - Understanding of single cases - Induction based development of
Conceptual Framework	- Variance theories	- Process theories
Research Questions	- Variance questions: truth of proposition, absence or presence, amount or degree, correlation - Testing of hypothesis - Causality: factual	- Process questions: how & why - Meaning - Context: holistic - Conceptual framework works as hypothesis
RESEARCH METHODS		
Relationship	- Objectivity / influence reduction: researcher as an extraneous variable	- Use of influence as a tool for Understanding: researcher as a part
Sampling	- Probability sampling - Establishing valid comparisons	- Purposeful sampling
Data Collection	- Prior development of instruments - Standardization - Measurement / testing: quantitative / categorical	- Inductive development of strategies - Adapting to particular situation - Collection of textual or visual material

RESEARCH / FEATURES	QUANTITATIVE RESEARCH	QUALITATIVE RESEARCH
Data Analysis	- Numerical descriptive analysis statistics, correlation - Estimation of population variables - Statistical hypothesis testing - Textual data conversion into many categories	- Textual analysis: memos, coding, connecting - Grounded theory - Narrative approaches
RESEARCH VALIDITY		
Internal Validity	- Statistical conclusion validity - Construct validity - Causal validity: control of extraneous variables	- Descriptive validity - Interpretive validity - Construct validity - Causal validity: identification and assessment of alternative explanations
External Validity	- External generalizability or comparability	- Transferability - Generalizing to theory

To sum up the discussion, a ***descriptive qualitative case study with a grounded theory approach*** is chosen for this particular research since the research objectives defined in Section 3.7 do get catered only by *4.1 (a): D*escriptive (to find facts & challenges on the present state of affairs in PEDM), *4.1 (f): Qualitative (*a detailed examination of PEDM & its challenges), *4.1 (e): Case Study* (for an in-depth and detailed examination of the facts in order to reach the basic causal relations in challenges); further, in line with the research objective of building an integrated model of PEDM to overcome the identified challenges, the systematic theory generation from data through inductive thinking, as in *4.1 (j)*: Grounded Theory Approach is the most appropriate method of analysis for this qualitative research. Moreover, it is noted that this present case (Descriptive Qualitative Case Study with a Grounded Theory Approach) is for reaching the basic causal relations (Table 4.1 point-e: Case Study) leading to theory formulation only and is –

Neither: the verification or testing of generated theory/concepts to ascertain applicability (Table 4.1 point-d: Exploratory or point-h: Experimental),

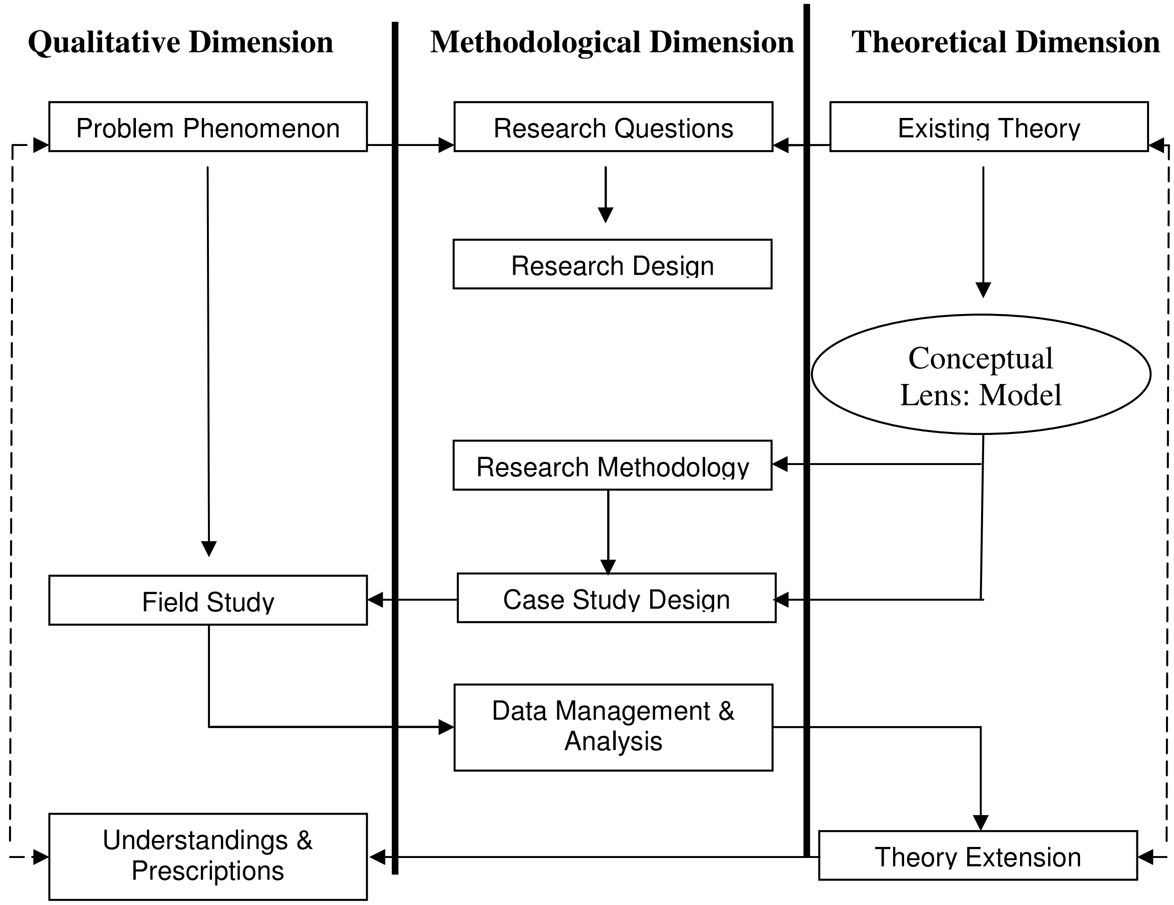
Nor: ‘sample to population’ (Table 4.2 Purpose) or ‘Testing of hypothesis’ (Table 4.2 Research Questions) or ‘External generalizability’ (Table 4.2 External Validity).

This descriptive qualitative case study with a grounded theory approach is further detailed in the subsequent sections.

4.1.1 Overall Approach

In the case of management research, the research scholar is intrigued with a particular problem / system / phenomenon in practice, that the researcher wants to understand and explore (Maxwell, 1996). After that he/she develops the research questions & a research design to understand systematically this problem / system. In the next step, existing theory is explored and integrated by using the theory development methodology to develop the conceptual lens in order to study the problem. This conceptual lens together with the research questions then lead to the development of qualitative research design and data analysis approach. Next the researcher enters the qualitative world and notes his/her observations in there & collects the data. After that, this data is managed as well as analyzed in accordance with the basic conceptual lens and qualitative research design that leads to findings. These findings then possibly lead to existing theory extension and help to understand and prescribe the identified problem. Figure 4.1 portrays this overall research process design.

Figure 4.1: Overall Research Process



With this background & keeping in view the research questions, as discussed earlier, it has been decided to undertake a process study (***descriptive qualitative case study***) in the piping engineering design management department of the largest oil & gas company in India. This is in contrast to a typical variance study (Crowston, 2000) and implied a focus on how events, organizational members and context interact and unfold (Pettigrew, 1997) rather than on the relationships between dependent and independent variables and subsequent results. In support of this approach, interpretive case study method has been used as research method. The assumptions underlying this choice and the rationale for adopting this approach are described in the following sections.

4.1.2 Philosophical Assumptions & Rationale

All research is based on some underlying assumptions about the nature of reality, what constitutes valid research and which research methods are appropriate (Myers, 1997). These philosophical assumptions consist of a stance toward the nature of the reality (ontology), how the researcher knows what he/she knows (epistemology), the role of values (axiology), the language of research (rhetoric), and the methods used in the process (methodology) (Creswell, 2003, 2007). In the present research all these assumptions have been used and Table 4.3 summarizes these *assumptions* as related to this research, duly highlighting their implications on this research.

Table 4.3: Philosophical Assumptions & Implications (Creswell, 2007)

ASSUMPTIONS	QUESTION	CHARACTERISTICS	IMPLICATIONS FOR THIS RESEARCH
Ontological	What is the nature of reality?	Reality is subjective and multiple, as seen by participants in study	The researcher has used themes in words of participants and provided evidence of different perspectives
Epistemological	What is the relationship between the researcher and that being researched	Researcher attempts to lessen distance between himself and that being researched	The researcher has spent almost two years in the PEDM Department and has worked actively with the team on their projects

ASSUMPTIONS	QUESTION	CHARACTERISTICS	IMPLICATIONS FOR THIS RESEARCH
Axiological	What is the role of values?	Researcher acknowledges that research is value laden and that biases may be present	The researcher has included his interpretations in conjunction with the interpretations of participants
Rhetorical	What is the language of research?	Researcher states in a literary and informal style while using personal voice and uses qualitative terms & limited definitions	The researcher has used first person pronoun in this research, and has tried to provide rich description of the phenomenon
Methodological	What is the process of research?	Researcher uses inductive logic, studies the topic within its context and uses an emerging design	The researcher has described the context of the project teams in detail, and revised the conceptual lens based on the findings from case studies

These ***assumptions*** cast a particular ***stance / paradigm / worldview*** that generally researchers make when choosing qualitative research methods. Various authors have suggested various classifications for these paradigms. The present study uses interpretive paradigm as advocated by Orlikowski and Baroudi (1991) because the research objectives & questions (Chapter 3) match with an interpretive stance, mainly since interpretive methods of research are "aimed at producing an understanding of the context of the problem, and the process whereby the problem influences and is influenced by the context" (Walsham, 1995) and, its two processes, discovering & emerging, are understood as covering a meticulous interpretative process in which the resulting concepts and eventually theory is constructed. This approach does not seek the truth as universal and lasting, but the research product is seen as a rendering or one interpretation among multiple interpretations of a shared or individual reality (Charmaz, 2006). Further details are discussed in the following paragraphs.

Interpretive Paradigm:

Creswell gives four paradigms as postpositivism, constructivism, advocacy/participatory, and pragmatism (Creswell, 2003, , 2007). Orlikowski and Baroudi suggest three categories: positivism, interpretive and critical (Orlikowski & Baroudi, 1991).

Positivism grew and matured in natural sciences research, therefore it has features more suitable for conducting natural science research. Positivists generally assume that reality is objectively given and can be described by measurable properties which are independent of the observer (researcher) and his instruments (Myers, 1997). Positivist studies generally attempt to test theory, which is normally stated in terms of hypothesis, in an attempt to increase the predictive understanding of phenomena. A research can be classified as positivist if there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing, and the drawing of inferences about a phenomenon from the sample to a stated population (Orlikowski & Baroudi, 1991).

Critical research paradigm has the assumption that social reality is historically constituted and that it is produced and reproduced by people. Although people can consciously act to change their social and economic circumstances, critical researchers recognize that their ability to do so is constrained by various forms of social, cultural and political domination (Myers, 1997). The main task of critical research is doing social critique, whereby the restrictive and alienating conditions of the status quo are brought to light. Critical research focuses on the oppositions, conflicts and contradictions in contemporary society, and seeks to be emancipatory i.e. it should help to eliminate the causes of alienation and domination. This research does not seek to explore the alienation and domination conditions, and because it wants to emphasize the socially constructedness of reality, an interpretive approach is selected for this research.

The philosophical base of interpretive approach is hermeneutics and phenomenology (Myers, 1997). The assumption underlying interpretive research is that access to reality (given or socially constructed) is only through social constructions such as language, consciousness and shared meanings. Typically, interpretive studies try to understand phenomenon through the meanings that people assign to that and interpretive methods of research are "aimed at producing an understanding of the context of the problem, and the process whereby the problem influences and is influenced by the context" (Walsham, 1995). Furthermore, the research study adopts a social constructivist point of view for reality, which implies that reality is socially constructed by the observer (Berger and Luckmann, 1967). The other social point of view can be an objectivist viewpoint. "The focus of the interview and the specific questions asked likely differs depending on whether the interviewer adopts a more constructivist, or more objectivist approach. A constructivist would emphasize eliciting the participant's definitions of terms, situations, and events and try to tap his or her assumptions, implicit meanings, and tacit rules. An objectivist would be concerned with obtaining information about chronology, events, settings, and behaviors" (Charmaz, 2006). While all social studies involve a mix of both viewpoints, a study which has more constructivist viewpoint can be said to have a constructivist grounded theory approach while the other can be said to have an objectivist grounded theory approach (Charmaz, 2006). Specifically, since this research study objectives require more of "participant's definitions of terms, situations, and events and try to tap his or her assumptions, implicit meanings, and tacit rules" (Charmaz, 2006) and less about chronology, settings or behaviors, therefore this research study employs the adapted version of the grounded theory (Glaser and Strauss, 1967), also referred to as the constructivist grounded theory (Charmaz, 2006). Its two processes, discovering and emerging, are understood as covering a meticulous interpretative process in which the resulting concepts eventually theory is constructed. This approach does not seek the truth as universal and lasting, but the research product is seen as a rendering or one interpretation among multiple interpretations of a shared or individual reality (Charmaz, 2006).

4.1.3 Quality of the Qualitative Study

It may be noted here that this section describes the plan for maintenance of high quality in the study. How these practices have been carried out are detailed in Section 5.1 of the next Chapter.

This study focusses on reality as perceived by the *researcher*, in line with the ideology that reality is what & how we perceive any particular issue and as such, the study is one of the several probable theories of the business management problem. *By limiting the study to a single organization, the researcher is able to examine the case in more detail and to thoroughly understand the interrelationships of isolated data; this is more relevant because it* ***focusses on depth of insightful knowledge instead of generality*** *promoted by others (Yin, 2003). This approach may be criticized as developing localized theory; however, this is still a useful contribution to existing knowledge (Hughes & Jones, 2003). Further, the relevance of this specific research in the Indian oil & gas context, as already argued earlier (refer to Section 2.1) is bona fide (Sun, Williams, & Evans, 2011). The subject study elicits the "in-vogue scenario of piping engineering design management, directly from the people practising it. This will help present &/or future researchers to get a direct feel of the existing scenario and thus will* *help them in identifying & analysing further ways to improve the present system of managing piping engineering design in the Indian oil & gas industry" (*Dutta, Piping Engineering Design Management Scenario in a Top Oil & Gas Company, 2013). *Further, the developed model, if put into use, has the potential to overcome the existing identified flaws in the system & thus accelerate the competitive advantage of the company, that in turn can substantially contribute to the country's economic growth.*

As can be seen in Table 4.2, for qualitative research, validity can be established in any one or more of the given approaches, in terms of suitability of that particular approach for the specific research. The different options in context of the present research are discussed in the following paragraphs. Four relevant tests are there for evaluating quality of any research study: construct validity, internal validity, external validity & reliability (Yin, 2003). These are further discussed in the following paragraphs.

Construct Validity:

Construct validity refers to establishing the correct or apt measures for concepts that are being studied (Yin, 2003). The constructs as well as all data & new findings have been analysed through the conceptual lens (discussed earlier in literature review Section 3.8). To ensure construct validity, two tactics are employed. First, *two levels of analyses* are undertaken during data analysis – conceptual and detailed, by triangulation of perspectives (also called theory triangulation) on the same set of data (Patton, 1990). The conceptual analysis findings are intrinsically descriptive whereas the detailed analysis findings are naturally prescriptive leading to solutions (Tsang, 1997) through the multidimensional causal relations, from which the results/theory/solutions naturally emerged. Secondly, the *case study reports are reviewed by key* *informants* as advocated by Yin (2003) and their feedbacks are incorporated in the final research. Further details on how the construct validity has been ensured can be found in the pertinent Section 5.1.4, Chapter 5 that is the pertinent chapter for the case study research actions & findings.

Internal Validity:

Internal validity is obtained by “establishing a causal relationship, wherein certain conditions are found to lead to other conditions, as distinguished from spurious relationships” (Yin, 2003). Internal validity includes interpretive and causal validity apart from the validity of other aspects (methods, data transcription, etc.). The problem associated with internal validity is that of spurious effects when there may be other determinative factors apart from those identified in this particular research design. In order to overcome this problem & improve internal validity, a number of tactics have been employed. First, during case analysis the same data set has been *analysed from different perspectives/phases* – on conceptual as well as detailed levels. This is done as one of the methods to improve quality by triangulation of perspectives (also called theory triangulation) on the same set of data (Patton, 1990) through the multidimensional causal relations, from which the results/theory/solutions naturally emerged. The conceptual analysis findings are intrinsically descriptive whereas the detailed analysis findings are naturally prescriptive leading to solutions (Tsang, 1997). Secondly, the key participants have been requested to appraise, *review & comment on the case reports and their comments are incorporated in the final research*. All these steps ensured the identification & assessment of alternative explanations in order to ensure the causal validity. To ensure internal validity the researcher has been focused on the understanding as well as the interpretation of the processes that can be represented as causal relationships between concepts: one concept (or a cause) leads to another concept (or an effect). Moreover, review by the respondents and incorporations of their comments have ensured elimination of any flaws in the detection & analyses, thus up-keeping the interpretive validity. Further details on how the internal validity has been ensured in this study are described in the next Chapter.

External Validity:

External validity is the ability to extend the research findings to a more general Case (Yin, 2003). This present research is intended to provide an insight into the probable relationships suggested. As discussed in Section 4.1, a case study methodology is expected to provide depth and not external generalizability. This research should then lead to additional valid research to confirm the relationships using measures that provide the necessary confidence in the results for generalizing. Therefore to generalize beyond this particular research area would require additional confirmation of results that is beyond the scope of this particular research and has been included as a *further research scope* in the concluding chapter. As such, external validity is beyond the scope of this particular research and is a future research arena.

Reliability:

Reliability test in a case study research implies that if any other research scholar does the same procedures, as employed by the previous researcher for conducting the same case study, he/she shall arrive at the same findings & conclusions (Yin, 2003). In this particular research a number of tactics have been employed to ensure consistency while applying the data collection & analyses procedures. First, the case study protocol has been used to guide the research process. The *protocol is a major tactic in increasing reliability* of a case study research and is intended to guide the researcher in the carrying out of the case study (Yin, 2003). The protocol comprised of instrument (i.e. the *interview questions in line with the research objectives*), as well as procedures and general rules that are followed. This ensured the consistency in the covered areas. Secondly, to reduce the likelihood of misunderstanding or forgetting the data and to allow independent analysis of data by other investigators, the interviews have been *taped, transcribed and all original evidences are archived (refer Appendix A)*. Thirdly, the *use of Atlas.ti qualitative analysis software* allowed systematic and consistent analysis of qualitative data (Weitzman, 2000) that increased the reliability of research because the procedures can be repeated (Yin, 2003). Fourthly, the field notes that are taken by the research scholar have also been transcribed for future reference.

This Section 4.1.3 depicts the design for ensuring high quality of the study; further details of how these design measures have been employed are described in pertinent Sections 5.1.4 & 5.1.5 of the next Chapter.

4.1.4 Purview of this Research Work

This specific research is limited to addressing the identified Research Gap (Section 3.4) and the Research Problems (Section 3.5); as such, this research is bound to answering the earlier defined Research Questions (Section 3.6) in line with the set out Research Objectives (Section 3.7). Hence, the purview of this research work is bound only to find how piping engineering design management is being managed in the Indian oil & gas sector, what are the areas of improvements or challenges (including whether the challenges match with those of other sectors or are there some additional issues) and how those challenges can be improved upon through a model for PEDM. As discussed earlier it is echoed here that this present case (the Descriptive Qualitative Case Study with a

Grounded Theory Approach) is for reaching the basic causal relations (Table 4.1 point-e: Case Study) leading to theory formulation only and is neither the verification/testing of generated theory/concepts to ascertain applicability (Table 4.1 point-d: Exploratory or point-h: Experimental) nor 'Testing of hypothesis' (Table 4.2 Research Questions) / 'sample to population' (Table 4.2 Purpose) / 'External generalizability' (Table 4.2 External Validity). Limitations of this research work and findings through this research that are beyond this defined purview have been included as limitations and further research scope at the concluding section.

A study of the design process employing a *qualitative and inductive approach* enables the collection of a vast amount of primary data without any predetermined judgements as to what factors are most pertinent (Charnley, Lemon, & Evans, 2011). Researchers have found that the qualitative case study method is a favoured method to study & analyze practices of design management (Svengren, 1993).

Earlier researches have proved that a research, wherein the researcher gains access to companies and works as designers or with designers, gives the researcher an inside view of their activities; these inside-viewed activities have been found to be more useful in helping to understand how & why design happens, and teamwork in design teams (Wallace & Hales, 1989; Kennedy, 1997; Baird, Moore, & Jagodzinski, 2000; Green, Kennedy, & McGown, 2002). Yin (2003) advocated use of qualitative Case Study for investigating contemporary phenomena in real-life context, especially when the boundaries between phenomenon & context are not clearly evident. In this research case, since the existing practices are unknown, the boundaries are not evident & hence, it has been decided to use a **descriptive qualitative Case Study** approach in a large oil & gas company in India. This led to the case selection discussed hereinafter.

4.1.5 Case Selection & Rationale

Sample selection has been done in three stages: this Section 4.1.5 consists of the first stage where the company has been selected and the following Section 4.1.6 consists of two more stages - the sample pertinent to the cause of this research has been selected and lastly, the selection has been narrowed down to a focus group identified as being the key people in developing the model. Theory of Elimination has been used in each stage by relating to its relevance in this specific research.

This research is bound to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that *company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India* (the company is the oldest Indian oil & gas company, however the company's name is not mentioned here in order to protect that company from possible ignominious effects). It is the largest oil & gas company involved in petroleum refining, marketing, distribution and R&D in India. Therefore, the practices of piping engineering design management in that company is a perfect case for this study.

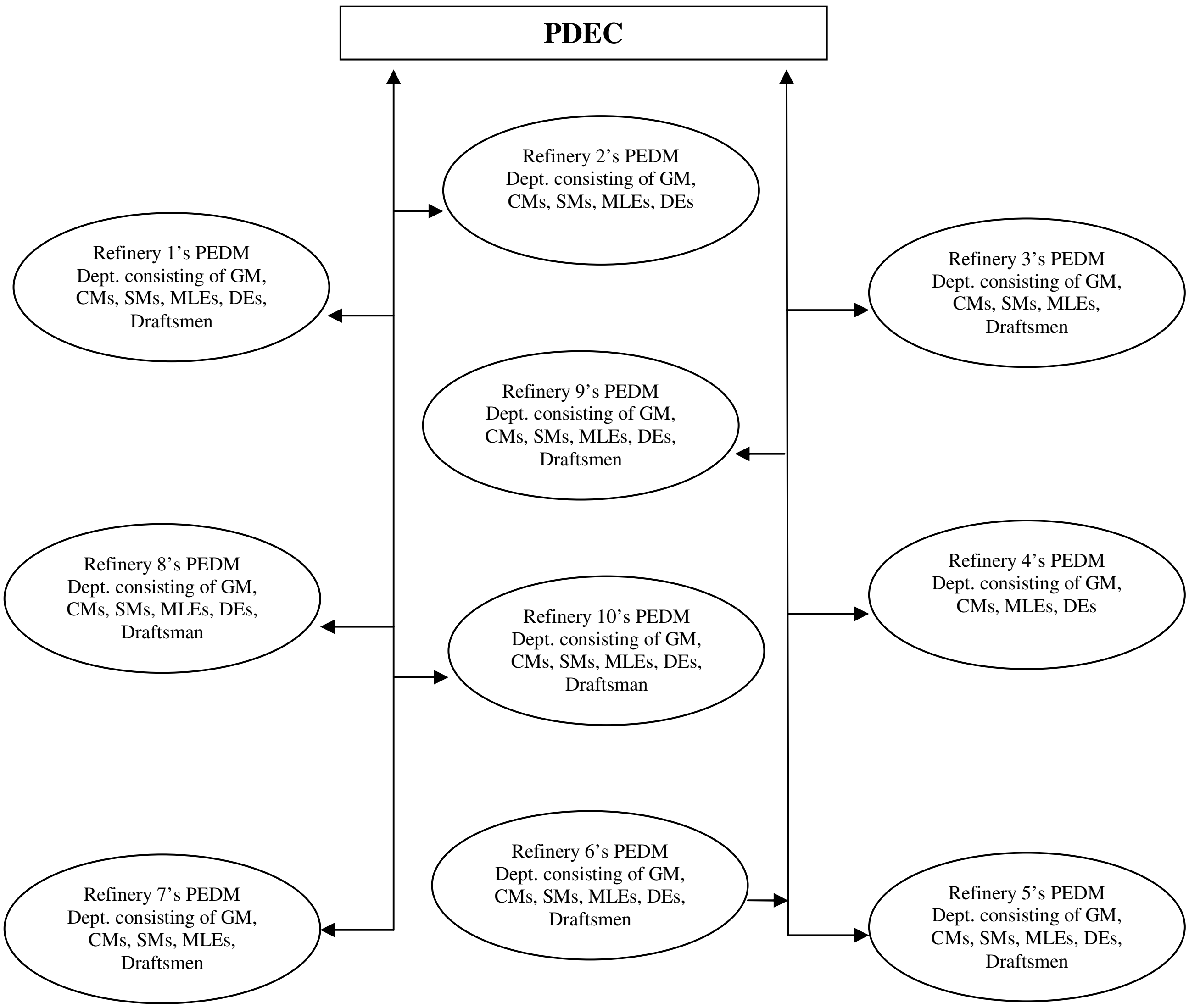
This has been the first stage of sample selection. The second and third stages, although further detailed in the following paragraph, are briefed here as follows. In the second stage, the researcher identified all employees who, by virtue of their knowledge, skills and experience, are being directly/indirectly involved or associated with piping engineering design management (PEDM). These people have been then examined through general screening questions (Appendix B) in order to identify their potential usefulness in finding the answers to the research objectives & questions discussed earlier. The employees ranged from many fresh engineers to many general managers in charge of PEDM in that particular location of that company, throughout the whole company. In the third stage, the sample has been narrowed down to a unit of employees who are the most relevant people in answering the research questions and in providing the key inputs to develop the model. Then the qualitative case study (in line with the overall approach discussed in Section 4.1.1 earlier) has been done in that piping engineering design department of the company. The data has been collected from the team members through a pre-defined instrument (i.e. case study questions derived from research questions). Then the data collected (all evidences referenced in Appendix A) has been analysed as per pre-designed data analysis strategy & rationale subsequently discussed (Section 4.3). After that the researcher proposed a new model based on the findings in order to answer the research questions.

4.1.6 Unit of Analysis & Rationale

The chosen particular company (the largest oil & gas company in India in terms of revenue, size & market share) has ten refineries all around India wherein each refinery has a piping engineering design management (PEDM) department. As initially the researcher has not known who all the pertinent people (sample) can be so he has started with all the PEDM departments throughout the whole company; it has been found that collectively, there are eighty two people working in different levels (from General Managers to Design Engineers to Draftsmen level) of PEDM including all the ten refineries throughout that company. Each of these people have been then examined through general screening questions (refer Appendix B) in order to identify their roles & potential usefulness in finding the answers to the research objectives & questions discussed earlier. Based on their answers, only if they qualified to be a useful or potential useful source in proving information for answering the research questions and in developing the model, they have been considered in the core study, while the remaining have been eliminated using the Theory of Elimination since their roles have been found to be non-pertinent to this particular study's requirements. It has been found that, each of the refinery's PEDM department is only involved in some recuperative/retrofit designs that are needed in the maintenance activities of that refinery and sometimes indirectly in the constructions of final design outputs that they receive from a common governing department named PDEC (elucidated subsequently). The individual refineries' PEDM departments have been found to be involved in only a very limited role in just carrying out the execution of the PEDM product (design output received from PDEC) in that refinery, some maintenance driven recuperative/retrofit design constructions and do not govern or have any pertinent role in the actual piping engineering design management cycle. Out of these eighty two people (refer Figure 4.2) who are in directly/indirectly associated with PEDM activities, six best of the experts, by virtue of their pertinent roles, super-skills, in-depth knowledge and experience superior to the other seventy six people, have been found be having the authority to govern all piping engineering design management activities throughout all locations of the company (all evidences referenced in Appendix A). These people are working in a specialized department named PDEC (Process Design Engineering Cell), which is a unique special cell with the Vision "To become world class Process Design Engineering group to carry out Front End Design & Engineering in Petroleum Sector" (for data source details see Appendix Ref. No. 1). These six people are authoritative and are empowered to act as the head authority for all PEDM activities throughout the company. As such, these six people of PDEC, comprising one General Manager (GM), one Chief Manager (CM), one Senior Manager (SM), one Lead Design Engineer (MLE) and two Design Engineers (DE1 & DE2) are the governing authority for all PEDM activities in all refineries across whole India. *These six people are designing improvement projects, developing the front end engineering design (FEED), basic engineering design, detailed engineering design as well as verifying, modifying and approving design change or minor projects requested from the different refineries (refer Figure 4.2); all these activities are not being done by the other seventy six PEDM related people at the* *different refineries; those seventy six people are only doing some construction related detailed engineering or some recuperative/retrofit designs as and when they needed in the maintenance or project activities of that refinery but are sending their designs to PDEC for review and approval prior to starting any job*. Therefore these six employees have been found to be the most relevant & key people in answering the research questions and in providing the key inputs to develop the model since their roles are the governing levels controlling the PEDM cycle; thus they comprised the core study focus. This head body PDEC's philosophy has been to use its team members' existing knowledge in projects and also gain world class expertise in their respective fields. As a governing body for PEDM, PDEC has delivered quite a number of PEDM projects across many refineries of this company as well as for external Clients outside the company. All of these information have been obtained through the collected data and sources of evidences have been substantiated in Appendix A.

(Figure 4.2 follows in next page)

Figure 4.2: PEDM Stakeholders in the Company *(source: Appendix A)*



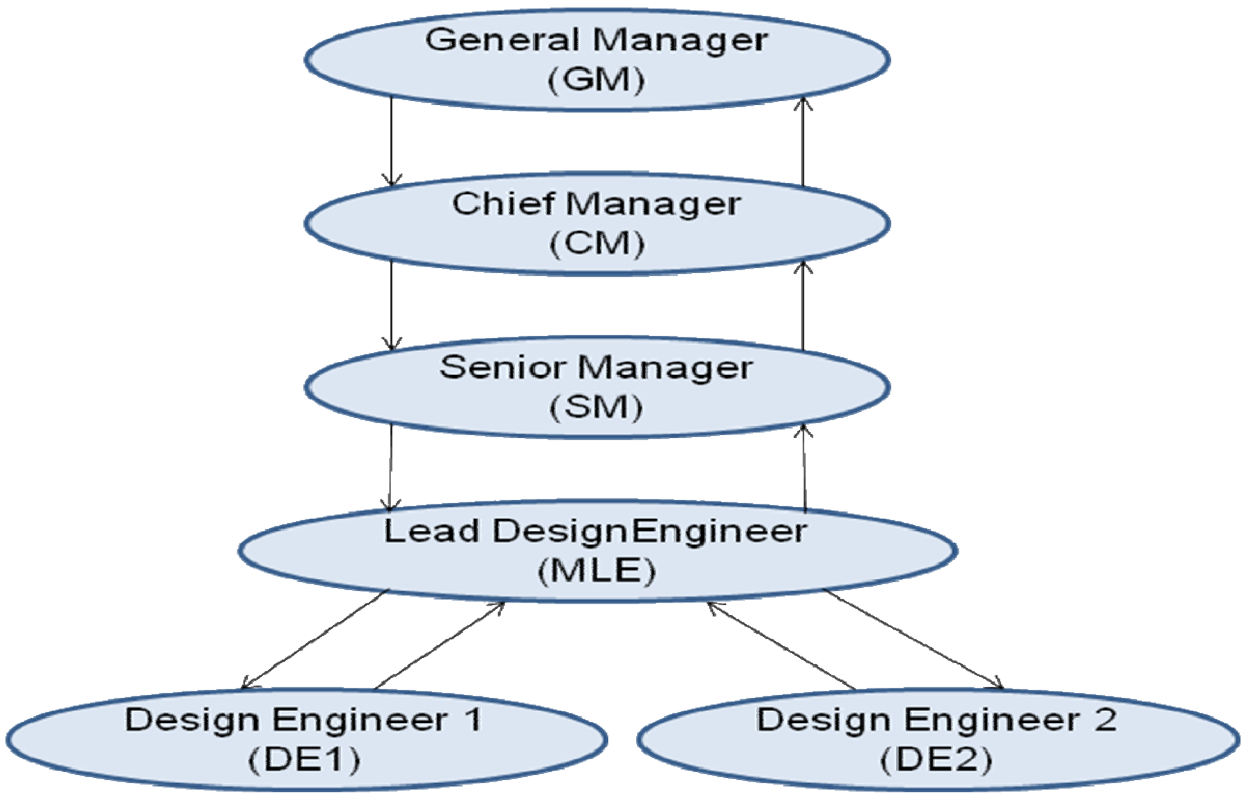
As discussed in the preceding paragraph, there are eighty two people (Appendix A) directly or indirectly involved in PEDM, six people in PDEC and seventy six in the different refineries. The Figure 4.2 shows how these seventy six people in the different refineries, across all levels, are depending upon the governance of the specialized cell PDEC for any piping engineering design management activity. Although these seventy six people across the refineries are directly/indirectly doing some PEDM work, however, these six experts of PDEC, acting as the main governors of PEDM across all refineries, have been found to be the key PEDM people for meeting this research's objectives & developing this research model since their roles are the governing levels controlling the entire PEDM cycle in all locations throughout the whole company; thus they comprised the core study focus and hence it has been decided to take these six experts only as the core unit of analysis; this sample selection is also in line with the philosophy discussed earlier in Section 4.1.3 as it enables the researcher to examine the case in more detail and to thoroughly understand the interrelationships of isolated data; this is more relevant because it focusses on depth of insightful knowledge instead of generality promoted by others (Yin, 2003) [1] .

Thus, the overall unit of analysis is the governing **Piping Engineering Design Management Team PDEC in the largest oil & gas company in India.**

1: The following has been comprehensively detailed in the forthcoming sections & pertinent chapters of this thesis, however an abridgement is noted here for maintaining an overall ligature: This approach may be criticized as developing localized theory; however, this is still a useful contribution to existing knowledge (Hughes & Jones, 2003), as discussed in subsequent sections. Further, the relevance of this specific research in the Indian oil & gas context, as already argued earlier (refer to Section 2.1) is bona fide (Sun, Williams, & Evans, 2011). The subject study has elicited (depicted in the next Chapters) the in-vogue scenario of piping engineering design management, directly from the people governing it through all refineries of that company in all locations across the whole of India. This has helped the researcher to get a direct feel of the existing scenario, in identifying & analysing the challenges for improving present system of managing piping engineering design in the Indian oil & gas industry. With reference to the earlier discussed research gaps (Section 3.4) this selected sample comprised a perfect core case for research in PEDM for the oil & gas industry in India. Further, the developed model, if put into use, has the potential to overcome the existing identified flaws in the system & thus accelerate the competitive advantage of the company, that in turn can substantially contribute to the country's economic growth.

The subject piping engineering design management (PEDM) team's structure is represented in following Figure 4.3 (refer Appendix A for source of this organogram).

Figure 4.3: PEDM Team Structure at PDEC *(Appendix A)*



With the growing recent recognition of engineering as essentially a human activity, an approach wherein the researcher gains access to companies and working as designers or with designers the researcher gets an inside view of their activities, prove to be more useful in helping to understand how and why design happens (Wallace & Hales, 1989; Kennedy, 1997; Green, Kennedy, & McGown, 2002). The inside view of the designers' activities are researched upon by being with the team during the case study. This helped the researcher understand the existing practices & the issues corresponding to the areas of improvements in depths that cannot be uncovered through other means.

4.2 Data Collection Plan

Data, as it is commonly known, is a collection of facts & information that is recorded for reference or analysis. Standard methods have been employed to collect data in this study as follows. Any research process calls for two types of data collection –

a. Primary Data: Primary data is the data that is directly collected by the researcher during the core research or case study; this is data that is analysed by the researcher for addressing the research questions & objectives; examples include records of interviews, transcriptions, etc. (Kothari, 2004); thus all data collected & analysed by the researcher during the case study is primary data.

b. Secondary Data: Secondary data is data that is first collected by someone else apart from the researcher; this is data that may have been used by the other person for some other reason but the researcher uses some of those findings/knowledge in his/her present study as per relevance; examples are published research papers, pertinent journals, published books, official records/documents, etc. (Kothari, 2004); thus, the existing literature on the subject as well as official records collected by the researcher is secondary data.

Most of the secondary data collection has been done from published books, published research papers, journals, etc. as discussed earlier in Section 3.1. Secondary data was collected with the help of online or internet-based as well as physical libraries, athenaeums, etc. Further secondary data like official records, documents, etc. have also been collected by the researcher from the company's databases. In order to maintain clear distinctions, primary data in this present study is classified as *explicit primary data* (data collected during the case study through interviews, interactions, observations) and official records & documents collected are classified as *ancillary secondary data* (data collected during the case study through from company's documents). The data collection methods designed for this research are discussed in the subsequent sections. The term *data* is hereinafter is designated to mean both explicit primary and ancillary secondary data collected during the case study only. It may be noted here that this sub-section enlists the data collection plan at a high level only. Further details have been discussed in the Case Study Protocol employed in the research, given in the next Chapter.

4.2.1 Explicit Primary Data Collection Design Methods

The researcher has done *in-depth Personal Interviews, Observations and Interactions with the team members* to collect & document Explicit Primary Data (refer Appendix A for details) for each stage of the design process, in order to understand the activities of the holistic piping engineering design management cycle.

4.2.2 Ancillary Secondary Data Collection Design Methods

As & when required, the researcher has collected Ancillary Secondary Data (refer Appendix A for details) from the *Company's Design Standards/Philosophies, Reports, Policies, etc*.

4.3 Data Analysis Strategy & Rationale

The researcher has done Textual Data Analysis [1] using Grounded Theory approach (Charmaz, 2006) to find what are being done, what are the areas of improvements & how to improve those. Why the grounded theory approach (Charmaz, 2006) has been chosen has been detailed in earlier Section 4.1. Data analyses through grounded theory approach involves process iterations connecting movements between existing theory and the interview data, observation data & interaction data (Charmaz, 2006). It may be noted that grounded theory approach is a systematic generation of theory from data that contains both inductive and deductive thinking (Strauss & Corbin, 1990, 1998; Charmaz, 2006). It is most applicable when the researcher wants to - ***formulate hypotheses based on conceptual ideas, to discover the main issues and how to resolve them***; the questions the researcher repeatedly asks in grounded theory are – ***what is going on, what are the main problems & how these can be resolved***; these questions get answered by the core issues & their properties in due course of the research (Charmaz, 2006). Since in this research, the researcher has wanted to know, what are the existing practices going on, what are the issues & how these can be improved, ***hence, this grounded theory approach is best suited in this case***. Accordingly and inline with the reasearch questions discussed earlier, the ***case study questions have been derived*** *on* ***what*** *is going on,* ***how*** *that is going on,* ***how*** *the activities are connected,* ***what*** *are the problem areas,* ***why*** *do the respondents consider that as a problem area,* ***how*** *these can be improved, etc. (the basic main questions and the further probing questions that are given in Section 5.1.3).*

1: Textual data analysis refers to profoundly investigating each word, line or segment of data in tune with the research objectives; coding of data using textual data analysis is an integral part of grounded theory approach that has been employed throughout the entire process of this study; the data analyses executions & outcomes have been extensively described in Section 5.1.4 of Chapter 5 (Case Study: Actions & Findings).

Through this grounded theory approach, structured interviews have been carried out and each subsequent interview has been adjusted based on the findings and interpretations from each previous interview, with the purpose to develop general concepts or theories through data analyses. The researcher has analysed how the different PEDM activities start, flow and end, the types, why and when of the activities, the interaction subjects, pathways & causes, the quality management practices, issues/challenges, etc. (all findings detailed in Section 5.2); then it has been analysed whether the identified issues or areas of improvements are matching with the issues that have emerged from literature review or there are any other issues plaguing the management of oil & gas piping design in India. Based on the findings, the researcher has developed theory through induction from data in order to propose the model. The researcher has also cited limitations & further scope of research. The collected data has been analysed (open coding, focussed coding, networks, families, links, dependencies, in-depth analyses, etc.) with the help of Atlas.ti software as one of the means for improving reliability (Section 4.1.3) as subsequently detailed.

Keeping in mind the scope of this research (Section 4.1.4), let us discuss a bit more here on why the grounded theory method (GTM) approach has been adopted in this case analysis. There are quite a lot of reasons for that. The grounded theory method of analysis has been already established as very effective in qualitative analysis by previous researches (Charmaz, 2006; Urquhart, 2013). GTM encourages the researcher to take a closer look at the data, the micro-phenomena; coding line by line or at the paragraph level encourages this close relationship with the data and this is what leads to new concepts as it encourages more analytical thought and all the constructs in a grounded theory are well grounded in the observations (Charmaz, 2006; Urquhart, 2013). The GTM facilitates slices of relevant data to be directly collected from the lowest level in order to build a substantive theory. The philosophical base, as discussed in earlier Section 4.1.2, uses constructivist grounded theory (Charmaz, 2006). Its two processes, discovering and emerging, are understood as covering a meticulous interpretative process in which the resulting concepts, and eventually theory, are constructed. This approach does not seek the truth as universal and lasting, but the research product is seen as a rendering or one interpretation among multiple interpretations of a shared or individual reality (Charmaz, 2006). Further details on how the grounded theory approach has been employed during the case study can be found in Section 5.1.4, Chapter 5 that is the pertinent chapter for the case study research actions & findings.

4.4 Conceptual Lens & Constructs

From the review of existing literatures (discussed earlier in Sections 3.1 & 3.2) the basic theoretical framework (Figure 3.1) has been derived by the researcher as chronicled earlier in Section 3.2. The Figure 3.1 framework can be treated as a built-up *conceptual lens which has been deployed in the research process.* The conceptual lens has been used in the study through the steps discussed in preceding Section 4.1.1 & Figure 4.1. The challenges/issues that have been identified through the reviews of existing literatures formed the constructs (Table 3.1) for the second objective (Section 3.7) alongwith the search for any new finding. The Table 3.1 constructs of seven issues, consisting of three on product side and four on process side, have been already described earlier in Section 3.2. Further details on employment of the conceptual lens & the constructs in the present research process has been appositely described in Sections 5.1 & 5.2 of Chapter 5 that is the pertinent chapter for the case study research actions & findings.

Researches in many countries, none of which has focused on India, so far have identified that *an Effective Model for integrated Design Management can be built if these three issues on product side & four issues on process side are taken* *care of*. However, previous research has proven that engineering design thinking & corresponding *design activities in different industries in differing situations have crucial differences* (Visser, Design: one, but in different forms, 2009) as discussed with examples in earlier Chapters and therefore, the earlier discussed design management studies, undertaken in other industries, are uncertain in terms of their applicability to the oil & gas industries and no research has been done on their applicability to the oil & gas industries. Furthur, previous research has proven that *design management roles & practices vary from country to country* (Sun et al., 2011) as exemplified in earlier Chapters. From the existing literature review, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. Moreover, design management practices vary from industry to industry and from country to country. Therefore, the *applicability of those identified issues to the Indian oil & gas context is uncertain*. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for a *comprehensive design management model* and in India no research has focussed on engineering design management.

This is the median point of the chapters in this thesis and hence, in order to maintain ligature continuum, a brief peek into the ensuing chapters is digested in this paragraph as follows: After the issues in Table 3.1 have been derived, the research has been designed (as detailed in the preceding sections) and the case study including data collection & analysis have been executed; the case study actions and results are discussed in the following chapters. The researcher has analysed if the areas of improvements are matching with the issues that emerged from literature review or there are any other issues plaguing the management of oil & gas piping design in India. Based on the findings, the researcher has developed theory through induction from data in order to propose the model. The researcher has also cited limitations & further scope of research. The collected data has been analysed (open coding, focussed coding, networks, families, links, dependencies, in-depth analyses, etc.) with the help of Atlas.ti software as one of the means for improving reliability (Section 4.1.3) as chronicled successively.

In this Chapter the plan for doing this research study has been designed. The proceeding Chapter 5 describes the specific actions taken in this study on the selected sample as well as the findings and as such, is the constructive employment of the Chapter 4 research design into the particular study.

Chapter 5: Case Study: Actions & Findings

Chapter 5: Case Study: Actions & Findings

This Chapter explains the whole case study research procedures & the *case study protocol* employed in this research on the selected sample, the actions including the *modes* of collected data, three levels of *case study questions* as well as the *findings* from the study.

5.1 Case Study Protocol

The case study protocol employed in this research has been detailed in the following paragraphs. It is to be noted here that this *Section 5.1 describes the case study protocol that has been employed in doing the case study research* and not the research design strategies & rationale that have been designed (in line with the research objectives) as chronicled in the anteceding chapters.

5.1.1 Introduction to Case Study and Purpose of Protocol

As per the earlier chronicles, an extensive review of existing literatures has shown that there has been no research on engineering design management in India. The objectives of this research project have been:

(Continues in next page)

(i) *To Study the Existing Practices/Models* of Piping Engineering Design Management that are being used in oil & gas industry in India, and

(ii) *To Identify the Areas of Improvements* in order to develop a Model of Piping Engineering Design Management for the oil & gas industry in India.

This has been achieved through a qualitative descriptive case study by mapping the existing piping design management practices in the design cell of India's largest oil & gas company (name of the Company has been kept confidential in order to guard against possible ignominious effects).

The Case Study Protocol is detailed in this document with the objective of providing guidelines to ensure that the data has been be *collected, presented and analyzed in a repeatable & reliable manner* by the researcher while minimizing interviewer bias.

5.1.2 Data Collection

The researcher has collected Explicit Primary & Ancillary Secondary Data from the company's unique & specialized design cell as antecedently discussed (case selection & unit of analysis have been chronicled in earlier Sections 4.1.5 & 4.16). In order to ensure validity & reliability of questions and answers (refer full Case-Study-Questionnaire, henceforth called C-S-Q), all data & findings have been verified through a number of tactics discussed in earlier Section 4.1.3. The substantiations are referenced in Appendix A. It may be noted here that Interviews & Interactions with team members have been done at individual members' convenient time, so as to ensure no disturbance to their official work. Also, the researcher has not divulged the names of the persons observed/interviewed/interacted with, without their written permission, in the case study report. Further the researcher has not used the data collected from this case study for any purpose other than the requirements of this research.

5.1.2.1 Explicit Primary Data Collection

The researcher, has *Interviewed, Observed & Interacted with the Team Members* to collect & document Primary Data (refer Appendix A for substantiation details) as answers to the research questions, in order to understand the activities of the holistic piping engineering design management cycle that are being practiced in the Indian oil & gas industry.

5.1.2.1.1 Interview Protocol

The researcher has interviewed the team members & recorded the interview audio/video for members who have consented to the live recording. For members who did not wish to be directly recorded, the relevant data has been written in the researcher's notebook.

5.1.2.1.2 Observation Protocol

The researcher has duly observed the activities in the team and sought answers to the research questions, while being with the piping engineering design management team. The researcher has documented the observations in his notebook.

5.1.2.1.3 Interaction Protocol

The researcher has interacted with the team members, collected relevant data as & when required and recorded the findings in his notebook.

5.1.2.2 Ancillary Secondary Data Collection

During data collection phase, as & when required, the researcher has collected Ancillary Secondary Data (Department Organogram, Direct Reporting Relationships, Job Descriptions, etc.) from the *Company's published Design Standards/Philosophies, Designs, Drawings, Reports, Policies, etc*. and has been used in this study with appropriate references. Ancillary Secondary data (refer Appendix A for substantiation details) also has been used for understanding a brief history of the department, its philosophies and functions at the start of the case study.

5.1.3 Case Study Interview/Interaction/Observation

Case Study Questions have been asked in order to collect Explicit Primary Data (discussed earlier) through Interview/Interaction/Observation. The rationale that drove the framing of the case study questions came from the objectives of this research; the research questions and the descriptive qualitative case study with grounded theory approach has been found to be an apt fit to this research (refer discussions in Sections 2.1, 3.6, 3.7, 4.1, 4.1.3 & 4.3).

The present research objectives (refer Section 3.7) have been to find facts about the present state of affairs in Piping Engineering Design Management (PEDM), the research objectives & research questions require to find the existing challenges and how to overcome those. Since the objectives of this research have been to find ***what are being done, what are the areas of improvements & how to improve those***, the researcher has done textual data analysis using Grounded Theory approach (Charmaz, 2006) through the descriptive qualitative case study as discussed in earlier sections. Data analyses through grounded theory approach involves process iterations connecting movements between existing theory and the interview data, observation data & interaction data (Charmaz, 2006). Grounded theory approach is a systematic generation of theory from data that contains both inductive and deductive thinking & is most applicable when the researcher wants to - ***formulate hypotheses based on conceptual ideas, to discover the main issues and how to resolve them***. The questions the researcher repeatedly asks in grounded theory are **–** ***what is going on, what are the main problems & how these can be resolved***. These questions get answered by the core issues & their properties in due course of the research (Charmaz, 2006). Since in this research, the researcher has wanted to know, what are the existing practices that are going on, what are the issues & how these can be improved, ***hence, this grounded theory approach is best suited in this case***. Accordingly and inline with the reasearch questions discussed earlier, the ***case study questions have been derived*** *on* **what** *is going on,* **how** *that is going on &* **when**, **how** *the activities are connected,* **what** *are the problem areas,* **why** *do the respondents consider that as a problem area,* **how** *these can be improved, etc.* In line with this discussion the ***case study questionnaire (refer C-S-Q) has been arrived at through a 3 step philosophy – first***, the information required from the team members (Design Engineers/Managers) of the company's piping engineering design management team have been first grouped under the following *9 basic head-inquests* (refer **Table 5.1**): these are the preliminary/basic information-to-be-taken that the researcher kept in his mind during data collection); then in the ***second*** step, ***each of these 9 head-inquests had further multiple basic as well as further in-depth probing-inquests*** (refer **Table 5.2**); finally in the ***third*** step, ***multiple case study questions*** (refer ***C-S-Q*)**, the individual conversations led to ask more questions) have been used till the objective information (*minimum limit*: answers to the research questions & *maximum limit*: as much as practically possible to get), could be obtained from each of the sources. It may be noted here that due to the natural human tendency to differ from each other, the details of the required information that emanated from the responses, are varied and as such the multiple case study questions (refer full Case-Study-Questionnaire, named C-S-Q) have been suitably modified (while maintaining relevancy) corresponding to the individual responses; the answers to the questionnaire satisfied the present research questions given in Section 3.5 and thus helped to fulfill the research objectives.

(Table 5.1 follows in next page)

Table 5.1: Basic Information Required / Head-Inquests (Step 1)

H-I No.	Basic Information Required / Head-Inquests (H-I) [i to v]
1	The complete range of piping engineering design management activities typically done by the individual
2	The activities irregularly done by the individual & their linkups with the regular activities
3	Bottom-up managerial control
4	Top-down managerial control
5	Other input & output communications
6	Quality management approach & its associated activities
7	Areas of improvements
8	Inhibitors to improvements
9	Ways to improve

---

i. *The H-Is in Table 5.1 have been the basic queries that needed answers. In many cases where the required information did emerge, but not fully from these basic Head-Inquests, additional Probing-Inquests (as depicted in Table 5.2) have been employed through even further Case Study Questions (refer C-S-Q).*

ii. *In order to ensure validity & reliability of questions and answers (refer C-S-Q), all data & findings have been verified through a number of tactics discussed in earlier Section 4.1.3. The substantiations are referenced in Appendix A.*

iii. *Interviews & Interactions with team members have been done at individual members' convenient time, so as to ensure no disturbance to their official work.*

iv. *The researcher has not divulged the names of the persons observed/interviewed/interacted with, without their written permission in the case study.*

v. *The researcher has not used the data collected from this case study for any purpose other than the requirements of this research.*

Table 5.2: Probing-Inquests (Step 2)

H-I No.	***H-I to Further Multiple-Basic-Inquests (M-B-I)***	***M-B-I to Further In-depth Probing-Inquests (P-I)*** [i, ii]
1	What are all the different activities that you do on typical working days & why?	How & when do those activities start, flow through the links between the activities, and then end?, etc.
2	What are all the different activities that you do less frequently or are not typical & how?	Why & when are these less frequent activities required?, etc.
3	How frequently do you interact with your Boss & why?	How many Bosses you report to?, etc.
		What leads you to interact with your Boss & when?, etc.
4	What does your Subordinate report to you & why?	How many Subordinates report to you?, etc.
		What do you do with your Subordinate's report?, etc.
5	Apart from your Boss & Subordinate, who are the other people you communicate to & why?	How & when do you need to talk to them?, etc.
6	What do you do to check the quality of your output & when?	Do you do check it yourself or through some other person/agency & how?, etc.
		How frequently do you check the quality?, etc.
7	What are the challenges that you face in your work & how?	Why do you regard these as challenges?, etc.
		What do you do to counter these?, etc.
8	What leads to these challenges & how?	Why are the causes of these challenges not avoided/removed?, etc.
9	What do you think will help you to overcome these challenges & why?	How will those things help you overcome the challenges?, etc.

---

i. These further probing-inquests have been suitably increased/customized depending on the responses till all required information, in line with this study's objectives, could be obtained as a minimum & in many cases exceeding the objectives, from each of the respondents (Appendix B); see C-S-Q (Section 5.1.3.1) for details on Case Study Questionnaire.

ii. In order to ensure validity & reliability of questions & answers (refer C-S-Q), all data and findings have been verified through a number of tactics discussed in earlier Section 4.1.3. All substantiations are referenced in Appendix A.

5.1.3.1 Case-Study-Questionnaire (C-S-Q, Step 3)

The *full set of questions* that have been asked to each of the team members, are referenced in this sub-section 5.1.3.1. As per the earlier discussed grounded theory approach, structured interviews have been carried out and each subsequent interview has been adjusted based on the findings and interpretations from each previous interview, with the purpose to develop general concepts or theories through data analyses. The answers to the present research questions (Section 3.5) emanated from these data collected and helped to *fulfill the research objectives* as detailed in subsequent Section 5.2. The case research has been printed in public domain (titled "Piping Engineering Design Management Scenario in a Top Oil & Gas Company") as one of the three research papers (refer Appendices E, F, G & H) of the researcher that have been published & presented to the world during the course of this research. All the case study questions that have been employed to obtain the explicit primary & ancillary secondary data are referenced in Appendix B. The case research including responses is referenced in Appendices E & G and the findings from the analysed data are detailed in Section 5.2. It may be noted that this particular company is named as "C" & the specific department as "D" here in order to guard against undesirable possible ignominious effects. All collected data including the questions and answers have been *recorded, transcribed and substantiated* (Appendix A). For ensuring the *validity & reliability* of questions & answers, all data and findings have been verified through a number of tactics discussed in earlier Section 4.1.3.

5.1.4 Data Analyses & Inference

This sub-section summarises the data analysis and inference process followed in this present case study.

The researcher has done Textual Data Analysis [1] using Grounded Theory approach on the answers to the research questions, as per the rationale earlier discussed in Section 4.1. Based on the findings, the researcher developed theory through induction from data in order to propose the model. The researcher has also cited limitations & further scope of research, if any. The collected data has been analysed (open coding, focussed coding, networks, families, links, dependencies, in-depth analyses, etc.) with the help of Atlas.ti software [2] as one of the means for improving reliability (Section 4.1.3) as detailed in the subsequent Sections. Constructivist grounded theory methodology, as discussed in earlier Sections 4.1 & 4.3, have been employed. Let us take a little further look into the analysing process.

The data analyses in Atlas.ti has been done using Codes. "Coding means categorizing segments of data with a short name that simultaneously summarizes and accounts for each piece of data" (Charmaz, 2006). Grounded theory coding involves "two main phases: 1) an initial phase involving naming each word, line, or segment of data followed by 2) a focused, selective phase that uses the most significant or frequent initial codes to sort, synthesize, integrate, and organize large amounts of data" (Charmaz, 2006). During "initial coding, the goal is to remain open to all possible theoretical directions indicated by" (Charmaz, 2006) the researcher's understanding of the data. Then later, focused coding is used "to pinpoint and develop the most salient categories in large batches of data" (Charmaz, 2006). A common terminology of coding may be define here as *In Vivo Codes*; these are codes of participants' terms, codified in the participants' used words that may convey a meaning/dimension in terms of the research objectives and as such, in vivo coding can be employed in both open as well as focussed coding (Charmaz, 2006).

1: Textual data analysis refers to profoundly investigating each word, line or segment of data in tune with the research objectives; coding of data using textual data analysis is an integral part of grounded theory approach that has been employed throughout the entire process of this study.
2: Atlas.ti is a renowned data analysis software tool that is mostly used in qualitative researches around the world; it may be noted that this software only acts as a tool to segregate, categorise and link data, thus helping to managing data effectively but does not give the inductive solutions which can only emanate from the researcher.

The first phase is the *Open Coding that has been done by coding parts of text, sentences & paragraphs of the collected data, in Atlas.ti*. In the second phase *Focussed Coding has been done from the perspectives of the theoretical framework/lens, the existing constructs and search for any new finding* (Section 4.4). *Code Families* and *Code Networks* have been developed from the codes and their inter/intra/contra/cross-relationships [1]. It may be noted here that a few glimpses from the in-action coding are given in Appendix C for reference and the full Atlas.ti work record has been archived as substantiation.

There is a variety of schools of thought on the phases of grounded theory coding technique, however, Open Coding & Focussed Coding are generally accepted worldwide and therefore the present research followed Open Coding & Focussed Coding. Some other school of researchers call *Focussed Coding* as *Selective Coding* and some also sub-categorise *Focussed Coding* into *Axial Coding which is further sub-categorised into specialised Theoretical Coding* (Strauss, 1987; Strauss & Corbin, 1990, 1998). *Axial Coding* is for assigning categories/concepts to subcategories, with properties & dimensions (Charmaz, 2006). A "dense texture of relationships around the axis of a category" can also be called axial coding (Strauss, 1987; Charmaz, 2006). *Theoretical Coding* is a sophisticated/specialised focussed coding to specify relationships between categories (Charmaz, 2006).

Data analyses through grounded theory approach involves process iterations connecting movements between existing theory and the interview data, observation data & interaction data (Charmaz, 2006) collected as described earlier. The present case data analysis can be represented in three steps or levels. The first step has been the open coding, followed by the second & third steps.

1: Refer to footnotes in Page 122 of 298.

Both the second and third steps are focussed/selective coding and used axial focussed as well as theoretical focussed coding techniques. In vivo coding has been used in all three steps to eliminate misinterpretations. While the first & second steps helped the researcher in exploring & understanding the existing practices of piping engineering design management and the challenges/issues by developing the codes, categories & concepts, the third step helped the researcher understand the relationships of the codes to the challenges/issues that affect the design management output in the existing practices. In the first step, open coding has been done in parts of text/words, sentences & paragraphs of the collected data illustrating evidence of any kind of relevance to the questions; the coded data has been assigned labels for easy retrieval and categorisation (Miles and Huberman, 1994) by using open coding technique (Strauss and Corbin, 1990; Charmaz, 2006).

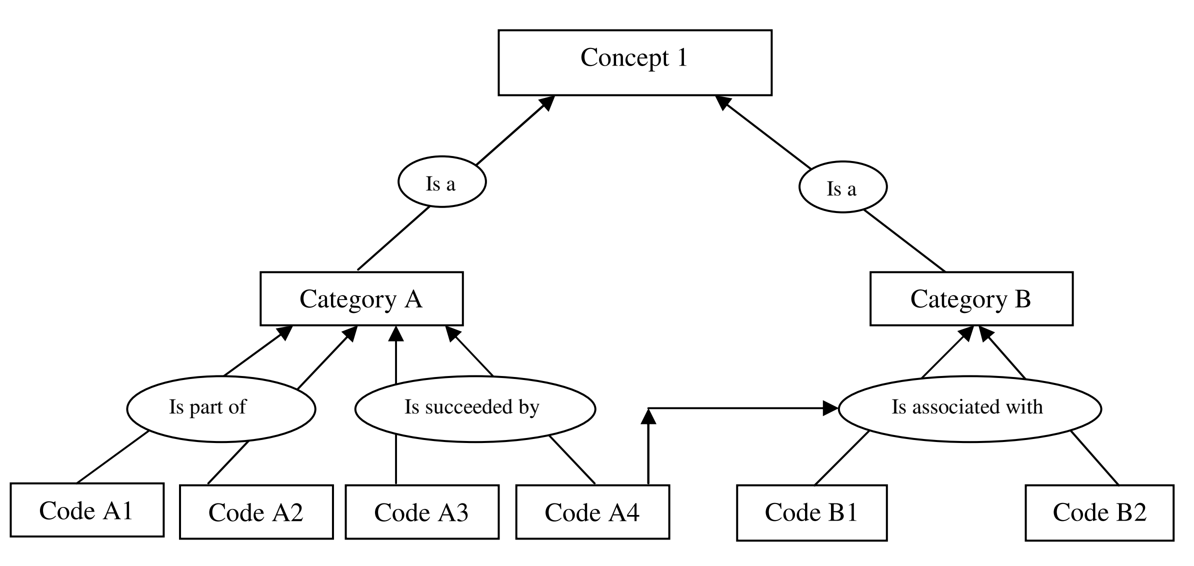
Data analyses has been done through grounded theory approach involving process iterations for movements between existing theory and the interview data, observation data & interaction data collected. The coding approach has involved perspectives of the theoretical framework/lens, the existing constructs and search for any new finding, in tune with the research objectives. The present case data analysis can be represented in three steps or levels. The first step has been open coding, followed by the second & third steps. Both the second and third steps have been focussed/selective coding and used axial focussed as well as theoretical focussed coding techniques. The third step differed from the second step by focussing deeper into the underlying relationships among the codes, categories & concepts; the identified inter-relationships, intra-relationships, contra-relationships and cross-relationships are linked as a pertinent root causal function. It may be noted that in vivo coding has been used in all three steps. While the first & second steps helped the researcher in exploring & understanding the existing practices of piping engineering design management and the challenges/issues by developing the codes, categories & concepts, the third step helped the researcher understand the relationships of the codes to the challenges/issues that affect the design management output in the existing practices.

Focussed/selective coding followed from the second step onwards. The focussed coding proceeded from perspectives of the theoretical framework/lens, the existing constructs and search for any new finding (Sections 3.2 & 4.4), in line with the research objectives. In this second step, similar codes having common attributes have been merged together to form conceptual categories & abstractions from the collected data (Strauss & Corbin, 1990). The codes have been categorised and linked as a 'belongs to' or definitional function of: *is a* [1] */ is part of* [2] */ is associated with* [3] */ is preceded by* [4] */ is succeeded by* [5] */ is property of* [6] */ etc.*; these case consolidations into code families enabled the reduction in the number of units working with (Strauss and Corbin, 1990) and thereby clarified the main themes emerging from the data. The codes have been grouped into categories using a bottom up approach as exemplified in Figure 5.1. It may be noted that the detailed discussions on what is coding, types of coding, etc. in the preceding paragraphs of this Section 5.1.4 are harbingers to the proceeding discussions.

The following retinues are the linking relations of codes as in software Atlas.ti; linking has been done in different dimensions as per suitability: inter-relation between objects, intra-relation within object, divergent cross-relation, antagonistic contra/clashing-relation, etc.; a specific relation can be of three formal properties/attributes–> transitive: able to take or be a direct object/code, symmetric: similar [sharing similar interest or comes/happens with] or asymmetric: non-similar [are different but may come/happen before or after or is integrated with the other object]:-

1. *is a = a transitive attribute link to signify: is itself a*
2. *is part of = a transitive attribute link to signify: is an element of a bigger object*
3. *is associated with = a symmetric attribute link to signify: is a concurrent companion of the other object*
4. *is preceded by = an asymmetric attribute link to signify: comes just after the other object*
5. *is succeeded by = an asymmetric attribute link to signify: comes just before the other object*
6. *is property of = an asymmetric attribute link to signify: is intrinsic to the other object*
7. *is cause of = a transitive attribute link to signify: is root causal producer of the other object*
8. *contradicts = a transitive attribute link to signify: opposes the other object*
9. *explains = a transitive attribute link to signify: analytically substantiates the other object's correctness*
10. *criticizes = an asymmetric attribute link to signify: analytically substantiates the other object's incorrectness*
11. *leads to = a transitive attribute link to signify: is intrinsic to & directs to the other object*

Figure 5.1: Code Categorisations

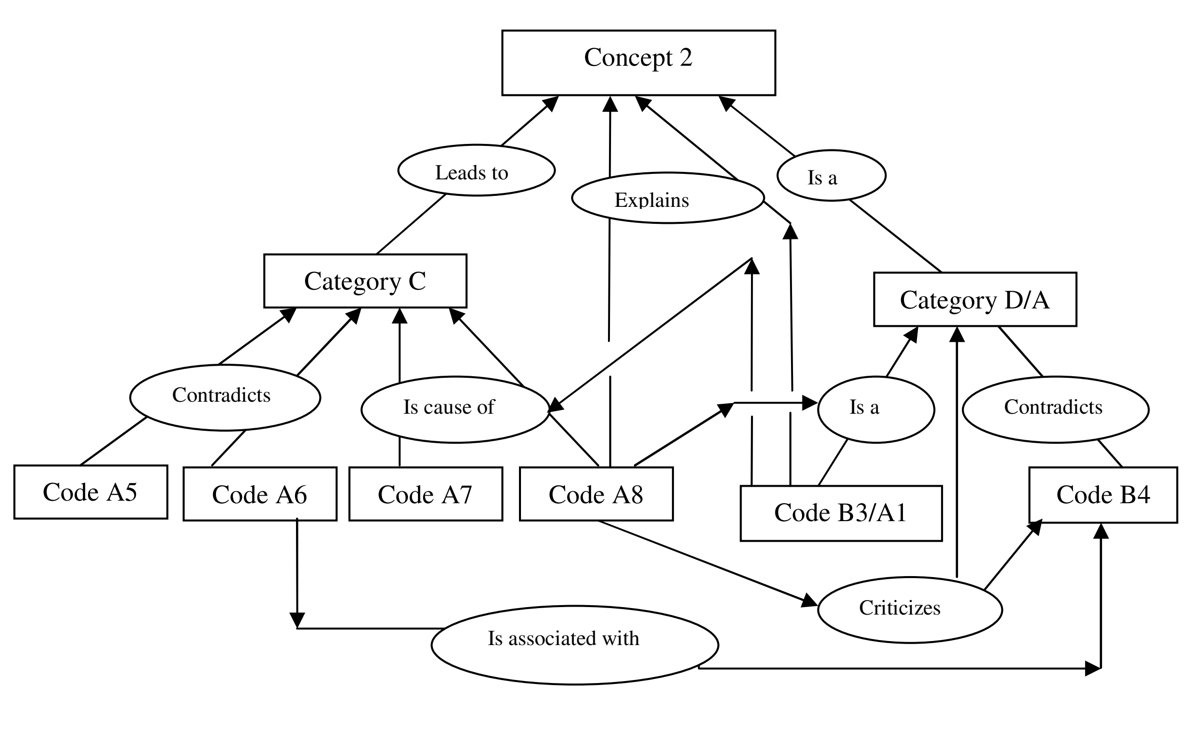


Terminologically, the categories as well as concepts are also codes and when a category is assigned, the reporting codes to that category become its sub-codes and this is same as when a concept code is created from two category codes, then the category codes become sub-codes or vice versa. For clarity of representation, codes / sub-codes / categories / concepts shall be henceforth called codes.

In the third step, efforts have been focussed in finding the underlying relationships among the codes, categories & concepts. Identified inter-relationships, intra-relationships, cross-relationships and contra/clashing-relationships are linked as a pertinent root causal function of *is a* [1] */ is part of* [2] */ is associated with* [3] */ is cause of* [7] */ contradicts* [8] */ explains* [9] */ criticizes* [10] */ leads to* [11] */ etc.* Comparing patterns and prospecting on other possible or rival explanations have been an intrinsic part of the analysing process. Code families have been linked and c*ode networks* have been developed based on the interrelationships as exemplified in Figure 5.2.

1 to 11: Refer to footnotes in Page 122 of 298.

Figure 5.2: Code Cognations



In the second and third steps, each category has been linked to the pertinent concept/s. If a category could not be associated with any of existing concepts or existing lens or existing constructs, then a new factor (new/additional concept) has been identified or thus emerged.

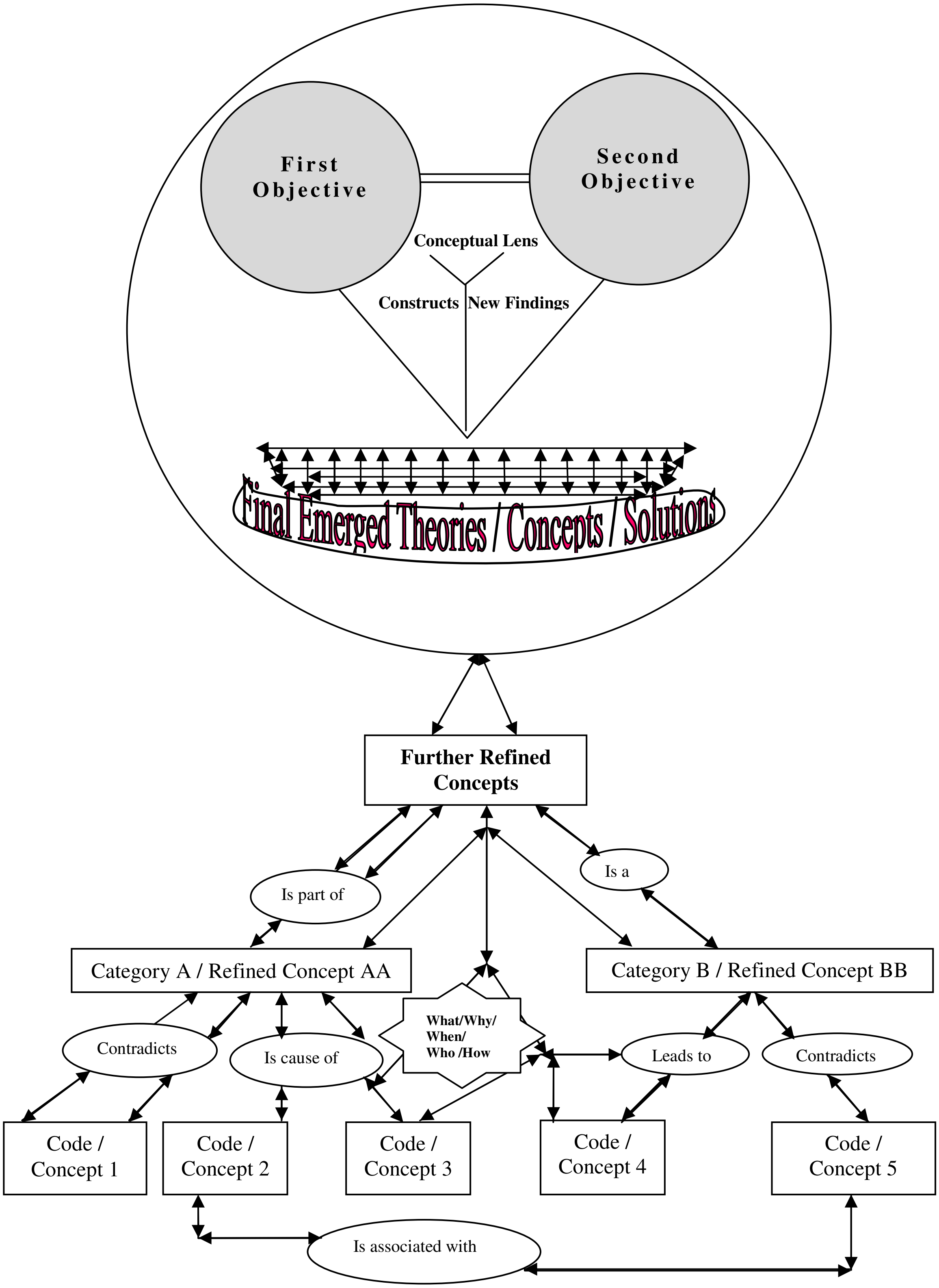
It may be noted here that while the second and third steps both involve focussed coding using axial as well as theoretical coding, the basic differences between them are in the different dimensional relationships (definitional function of: *is a / is part of / is associated with / is preceded by / etc.* in the second step versus root causal function of: *is a / is part of / is associated with / is cause of / contradicts / explains / criticizes / leads to / etc.* in the third step), depth of the relationships and the focus level (concepts in second step versus concepts as well as root causal relationships in the third step). For example: a particular statement "Gives non-technical non-piping related personal work to DE1 & DE2 in midst of their official work and then blames the SM due to delays in the work completion of DE1 & DE2" is open coded in the first step and is categorised as non-typical work and also a challenge in second step; in the third step, this code is found to be contradicting official work and is also found be a cause or an element causing a challenge to the overall time efficiency, thus affecting the desired output of the design management cycle, etc. As a result of the third step being so much more extensive, deep & root focussed than the other steps, any pertinent code or link that might have been missed in the earlier steps, is caught and integrated, thus rendering the iterative analyses cycles as fool-proof.

Further references on the coding part including operational definitions and a few glimpses of coding in-action can be glanced in Appendix C.

"Theoretical integration begins with focused coding and proceeds through all subsequent analytic steps" (Charmaz, 2006) & as such the concepts have naturally emerged and that is how the gradual theoretical build-up has been accomplished through those steps. The concepts themselves are the theory built-ups from the analysis. For example: many concepts emerged like the Concept 1 through the built-up approach in Figure 5.1 that are pertinent to the existing practices of piping engineering design management and the challenges/issues; further, in the third step many concepts emerged like the Concept 2 through the built-up approach in Figure 5.2 that are also pertinent to the existing practices of piping engineering design management and the existing/new/additional challenges/issues at the same or differing depths or relationships. These refined concepts/solutions are then again iteratively integrated to synthesise the final refined concepts/theory/solutions. Further, within case analysis has been performed for each step in two phases: conceptual & detailed, as one of the methods employed to improve quality (refer Chapter 4) by triangulation of perspectives on the same set of data (Patton, 1990) as discussed earlier. The conceptual analysis findings are intrinsically descriptive whereas the detailed analysis findings are naturally prescriptive (Tsang, 1997) through the multidimensional causal relations, from which the results/theory/solutions naturally emerged. The theory triangulation approach of two phases employed in each step is represented along with the gradual & iterative theory built-up process in exemplified Figure 5.3. Based on all of these preceding discussions, further detailed results of the case research are presented in the pertinent Sections 5.2, 6.1 & 7.1.

(Figure 5.3 follows in next page)

Figure 5.3: Phases & Emerging Concepts / Solutions



As discussed earlier, this interpretive study (basis clarified in Section 4.1.2) tries to understand phenomenon through the meanings that the people assign to that and the interpretive research methods are “aimed at producing an understanding of the context of the problem, and the process whereby the problem influences and is influenced by the context" (Walsham, 1995). Furthermore, the research study adopts a social constructivist point of view for reality, which implies that reality is socially constructed by the observer (Berger and Luckmann, 1967). Specifically, the research study employs an adapted version of the grounded theory (Glaser and Strauss, 1967), also referred to as the constructivist grounded theory (Charmaz, 2006). Its two processes, discovering and emerging, are understood as covering a meticulous interpretative process in which the resulting concepts eventually theory is constructed. This approach does not seek the truth as universal and lasting, but the research product is seen as a rendering or one interpretation among multiple interpretations of a shared or individual reality (Charmaz, 2006).

5.1.5 Quality Ensurance

The quality ensurance of this study in terms of construct validity, internal validity and reliability has been done as per the quality ensurance approach designed in earlier Section 4.1.3 of the Research Design Chapter. Further, in the preceding Section 5.1.4 it has been seen how the different levels of coding, within case analysis (conceptual & detailed – Section 5.1.4), theory triangulation (Section 5.1.4), employment of case study protocol (Section 5.1), use of software Atlas.ti (Sections 4.1, 5.1 & Appendix-C), archival of all evidences (Sections 4.1, 5.1 & Appendix-A), etc. have been carried out to ensure high quality (construct validity, internal validity & reliability) of the study. However, a brief on the quality measures are summarized in this section for ligature continuum.

Construct Validity:

Construct validity refers to establishing the correct or apt measures for concepts that are being studied (Yin, 2003). The constructs as well as all data & new findings have been analysed through the conceptual lens (discussed earlier in literature review Section 3.8). To ensure construct validity, two tactics are employed. First, two levels of analyses are undertaken during data analysis – conceptual and detailed, by triangulation of perspectives (also called theory triangulation) on the same set of data (Patton, 1990). The conceptual analysis findings are intrinsically descriptive whereas the detailed analysis findings are naturally prescriptive leading to solutions (Tsang, 1997) through the multidimensional causal relations, from which the results/theory/solutions naturally emerged. Secondly, the case study reports are reviewed by key informants as advocated by Yin (2003) and their feedbacks have been incorporated in the final research.

Internal Validity:

Internal validity is obtained by "establishing a causal relationship, wherein certain conditions are found to lead to other conditions, as distinguished from spurious relationships" (Yin, 2003). Internal validity includes interpretive and causal validity apart from the validity of other aspects (methods, data transcription, etc.). The problem associated with internal validity is that of spurious effects when there may be other determinative factors apart from those identified in this particular research design. In order to overcome this problem & improve internal validity, a number of tactics have been employed as discussed in the preceding Section 5.1.4. First, during case analysis the same data set has been analysed from different perspectives/phases – on conceptual as well as detailed levels. This is done as one of the methods to improve quality by triangulation of perspectives (also called theory triangulation) on the same set of data (Patton, 1990) through the multidimensional causal relations, from which the results/theory/solutions naturally emerged. The conceptual analysis findings are intrinsically descriptive whereas the detailed analysis findings are naturally prescriptive leading to solutions (Tsang, 1997). Secondly, the key participants have been requested to appraise, review & comment on the case reports and their comments are incorporated in the final research. All these steps ensured the identification & assessment of alternative explanations in order to ensure the causal validity. To ensure internal validity the researcher has been focused on the understanding as well as the interpretation of the processes that can be represented as causal relationships between concepts: one concept (or a cause) leads to another concept (or an effect). Moreover, review by the respondents and incorporation of their comments ensure elimination of any flaws in the detection & analysis, thus upkeeping the interpretive validity.

External Validity:

External validity is the ability to extend the research findings to a more general Case (Yin, 2003). This present research is intended to provide an insight into the probable relationships suggested. As discussed in Section 4.1, a case study methodology is expected to provide depth and not external generalizability. This research should then lead to additional valid research to confirm the relationships using measures that provide the necessary confidence in the results for generalizing. As discussed in Section 4.1, a case study methodology is expected to provide depth and not external generalizability. Therefore to generalize beyond this particular research area would require additional confirmation of results that is beyond the scope of this particular research and has been included as a further research scope in the concluding chapter. As such, external validity is beyond the scope of this particular research and is a future research arena.

Reliability:

Reliability test in a case study research implies that if any other research scholar does the same procedures, as employed by the previous researcher for conducting the same case study, he/she shall arrive at the same findings & conclusions (Yin, 2003). In this particular research a number of tactics have been employed to ensure consistency while applying the data collection & analyses procedures. First, the case study protocol has been used to guide the research process. The protocol is a major tactic in increasing reliability of a case study research and is intended to guide the researcher in the carrying out of the case study (Yin, 2003). The protocol comprised of instrument (i.e. the interview questions in line with the research objectives), as well as procedures and general rules that are followed. This ensured the consistency in the covered areas. Secondly, to reduce the likelihood of misunderstanding or forgetting the data and to allow independent analysis of data by other investigators, the interviews have been taped, transcribed and all original evidences are archived (refer Appendix A). Thirdly, the use of Atlas.ti qualitative analysis software allowed systematic and consistent analysis of qualitative data (Weitzman, 2000) that increased the reliability of research because the procedures can be repeated (Yin, 2003). Fourthly, the field notes that are taken by the research scholar have also been transcribed for future reference.

As discussed in earlier Section 4.1, it may be reiterated for clarity here that this present case (the employed Descriptive Qualitative Case Study with a Grounded Theory Approach) is for reaching the basic causal relations (Table 4.1 point-e: Case Study) leading to theory formulation only and is –

Neither: the verification or testing of generated theory/concepts to ascertain applicability (Table 4.1 point-d: Exploratory or point-h: Experimental),

Nor: ‘sample to population’ (Table 4.2 Purpose) or ‘Testing of hypothesis’ (Table 4.2 Research Questions) or ‘External generalizability’ (Table 4.2 External Validity).

The present study has involved identification of issues or challenges to engineering design management in the Indian oil & gas context and building of a new model catering to those issues (since previous researches have established that engineering design can be effectively managed if a model is built to cater to the identified issues); this study has verified that those seven issues (Table 3.1), that have been identified in other industries, are applicable to the Indian oil & gas context plus there are five additional challenges; the researcher has then built an integrated model to cater to all those identified twelve issues (Table 5.4), as described in the proceeding sections.

5.1.6 Data Archival

The evidential references to all collected original & raw data/records (in soft & hard forms), collected as part of this Case Study, have been archived as per date, time & source of collection, to serve as evidential references their original soft as well as hard forms – see Appendix A for details.

5.2 Data Analyses Findings

The preceding subsection 5.1.4 has explicitly detailed how the data has been analysed. This Section 5.2 summarises answers to the specific Case Study Questions (Section 5.1.3) in order to answer the Research Questions (Section 3.5) and as such, the research objective-wise findings are presented in sub-sections 5.2.1 & 5.2.4. As chronicled earlier, the analysis has been done in data analysis software Atlas.ti, initially with a grounded open coding approach followed by a focused thematic (research question specific) viewpoint. Referring discussions in Section 4.3, initially all collected data have been coded (lines as well as paragraphs have been coded) and then the codes have been categorised (sub-coded) as depicted in following Table 5.3. Apart from the detailed discussions on the analyses, codes, sub-codes, etc. in preceding Section 5.1.4, the operational definitions of all these codes and sub-codes alongwith a few glimpses of the in-action (Grounded as well as Focused) software Atlas.ti Codes, Sub-Codes, Networks & Families are given in Appendix C for reference. A few codes & sub-codes are shown here in Table 5.3 and a code with one sub-code in-action is presented in Figure 5.4 (it is noted that this Figure 5.4 has been taken from the Appendix C Figure C-17 where all other in-action analysis snapshots are given) as an example. *All details of codes, sub-codes, networks, families, dependencies, links, etc. have been referenced in Appendix C for further detailed insight into the analysis process through Atlas.ti software*.

(Table 5.3 follows in next page)

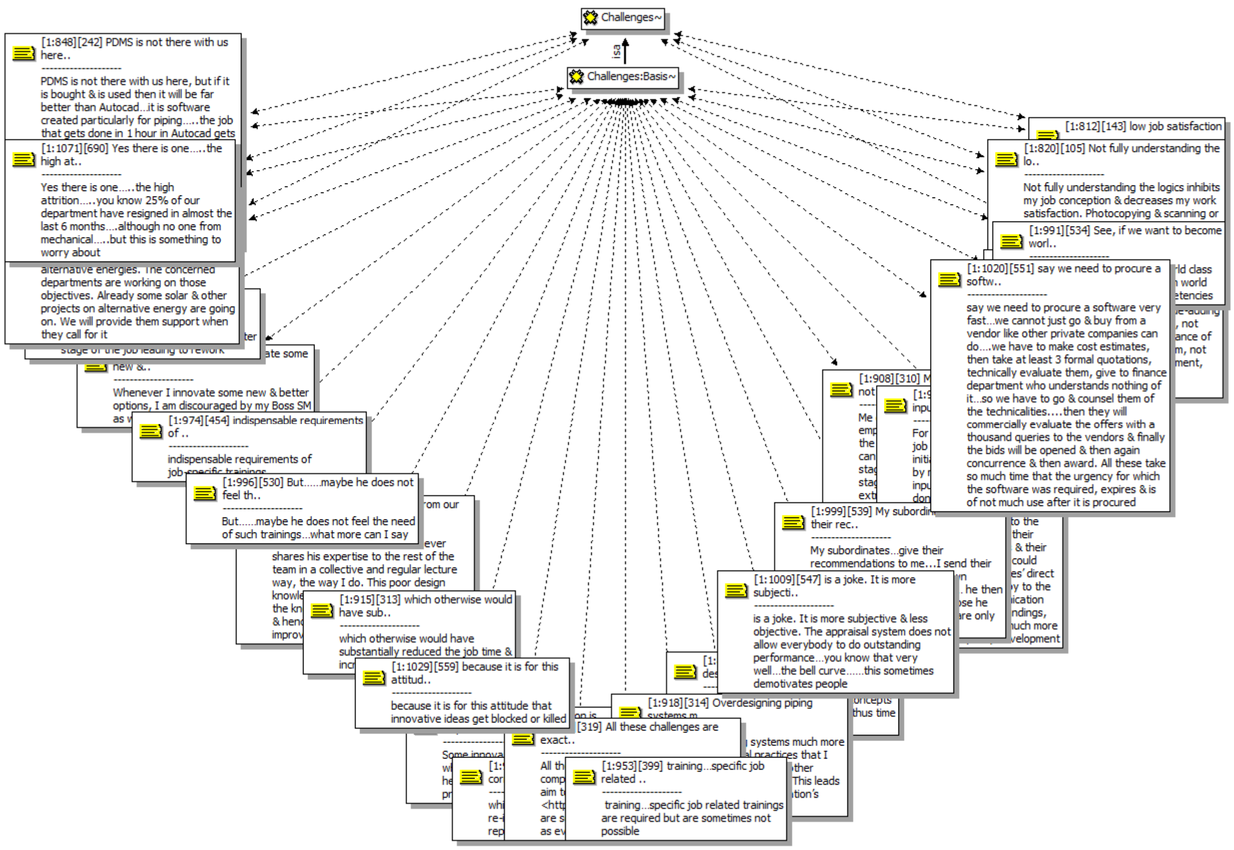
Table 5.3: Few Codes & Sub-Codes employed through Atlas.ti Software

(Appendix C)

Code	Sub-Code
Work	Work:Typical
	Work:Non-Typical
Interaction	Interaction:Boss
	Interaction:Subordinate
	Interaction:Others
Quality	Quality:Process
	Quality:Depth
	Quality:Breadth
Challenges	Challenges:Elements
	Challenges:Basis
	Challenges:Countering
	Challenges:Barriers
	Challenges:Elimination

The focused approach of analysis elicited the existing practices specific to the piping engineering design management cycle being practiced in the company and also the areas of improvements in details. The existing challenges found, mostly matched with the seven issues of Table 3.1 that have been intriguing the PEDM cycle worldwide; additionally the focused approach yielded a few more (five) areas of improvements or challenges hindering the development through the PEDM business cycle and these additional challenges may be attributed to the unique Indian context of the subject. First the found existing practices of piping engineering design management are described. Secondly, the found areas of improvements are discussed alongwith inductive solutions. The interpreted *results are presented here, in a simplistic, condensed and easy to understand format*.

Figure 5.4 (Figure C-17 from Appendix C): One of the Codes: Challenges and its one Sub-Code Challenges:Elimination with its Relevant Neighbours



5.2.1 The Practices of Piping Engineering Design Management

This subsection addresses the first research objective by answering the first research question, i.e. how piping engineering design is being managed at present (refer Sections 3.6 & 3.7), through the built-up conceptual lens (refer Section 4.4). How the answers have been arrived at, has already been explicitly chronicled in the earlier sections.

The case selection rationale given in Sections 4.1.5 & 4.1.6 has confirmed three governing levels of PEDM – Strategic Management, Tactical Management and Operational Management (refer Section 3.2 for details). From the analysis of the collected data it has been found that the General Manager (GM) is responsible for Strategic Management, the Chief Manager (CM) for Tactical Management and the Senior Manager (SM) & his subordinates for Operational Management, consistent with the theoretical framework/lens (refer Section 4.4).

The GM, as a strategic manager to ensure that the company's vision and mission are implemented, takes a stroll in the department at 9:45 am every day to identify his subordinates who are late by more than 10 minutes in any two consecutive days and orders those latecomers to take half-day leave. The GM personally interacts with the CM on a regular basis (every two days on an average) to take feedbacks on ongoing jobs and discuss execution action plans & time schedules for new jobs. With his other subordinates and other people he interacts as & when he feels necessary, mostly through telephone and emails. Apart from these work that he does regularly, he also checks and approves cost estimates for projects, performance appraisals, training proposals, software/Code/standard procurement and maintenance contracts, contributes in company standard design philosophies, attends business meetings with prospective Clients, interacts with his Boss the Executive Director for budget approvals beyond his authorized limits and his foreign trips, provides telephonic advice to refineries when called for and reviews designs with his team for any particular project that his engineering judgement makes him feel like reviewing. The GM also approves the yearly performance appraisal ratings of each member under him, after discussions with the SM & the CM.

The CM receives jobs (projects) from Chief Managers of the company's various refineries mostly and rarely from other companies, through emails. He then reads the documents and studies the requirements. He then forwards those to the SM with instructions on carrying out the job highlighting any critical/special engineering requirement and the time schedule. In case the SM and his team requires any additional resources like additional software, Codes/Standards, refinery data or clarifications then he arranges that from the relevant vendor/refineries' Chief Managers. He personally interacts with the GM regularly every two days on an average) to take the GM's directions in executing strategies and with his subordinates on a daily basis through emails/phone/physically to seek feedbacks on work progress and discuss further action plans. He also reviews the design output of the design team (drawings/documents) together with the SM & the MLE for every job, gives his comments based on the applicable Codes/Standards/project specifications, re-verifies that the comments are incorporated and then sends those final outputs to the respective Clients (Chief Managers of refineries or other departments/disciplines). Apart from all these typical work, he also drafts training proposals, software/code/standard procurement and maintenance contracts. The CM's work also involves reviewing yearly performance appraisal ratings of his subordinates given by the SM, before forwarding that to the GM.

The SM, being responsible for operational management of PEDM, receives the design engineering jobs from the CM and delegates that to the MLE with the special technical instructions, if any and the priority (time schedule). The SM acts as a link between the design engineers and the Client (refineries/other departments) through the CM on matters of input clarifications & output delivery. In case a clarification is needed from a Client, the SM first consults the CM and as per CM's directive, he sometimes seeks the clarifications directly from the Client through phone/email and sometimes through the CM. The SM acts as a guide to the design team members on technical issues and also facilitates the design process by raising new Code/standard/training/tour requirements of his team members by liaising with the CM on his team's behalf. The SM mainly interacts personally with his subordinates on a daily basis and with the CM when some clarifications are needed or when a product is ready to be final reviewed. To ensure product quality, the SM reviews the design outputs together with his lead the Lead Design Engineer (MLE), with respect to the code/standard/project specification requirements and ensures that any corrections, if necessary, are done before taking the output to the CM. The SM also judges and rates the yearly performance of his team members, before forwarding those to the CM and then revising the ratings as per the CM's recommendations. Besides these, the SM also takes quotes from vendors for Code/standard/software purchases, software annual maintenance contracts (AMC) before handing over to the CM for further action.

The MLE is the "SM's key to the operational management level of each phase in the cycle of piping engineering design management; he leads two design engineers on the jobs he gets from the SM. His daily activities are - going through his current work list to see what is pending, following up with Design Engineer 1 (DE1) & Design Engineer 2 (DE2) on the work delegated to them, resuming or starting to work on piping analyses jobs in Caesar II, updating SM & CM the status of the jobs as & when asked for, seeking clarifications from SM & CM or from Clients/Other Disciplines (Civil/Electrical/Instrumentation) through SM & CM as per need, reviewing & commenting on DE1 & DE2's outputs, providing clarifications to them, reviewing his work (DE1's output + DE2's work + MLE's output), reviewing his own work (stress analyses) & technical discussions alongwith SM, incorporating modifications, then emailing that output to CM, jointly reviewing that work finally with CM & SM, incorporating modifications (if any) & then finally emailing the output to CM. After that he seeks new assignment from SM. The MLE's non-typical or irregular work activities are giving short lectures on design subjects of his expertise to others in the team, performance plans & reviews, monitoring issues of latest applicable Codes & Standards and coordinating Code/standard purchase activities, from enquiries to getting the latest Codes, controlled by the SM, recommended by the CM and approved by the GM. Performance plans & reviews of himself and his subordinates are also coordinated by him. The MLE interacts with his Boss SM many a times regularly for seeking clarifications, status reporting, output reviews & further assignments. Although his official Boss is SM, he also sometimes interacts with CM as & when called for clarifications, reviews and status reporting, through personal contacts, phones & emails. He communicates with vendors for enquiries of latest Codes/Standards" through emails/phone as per need" (Dutta, 2013c).

Both the DE1 and DE2 have been found to be doing the similar Operational Management activities that are as follows. They start their day from any unfinished drawings of their last day in office. "They develop the piping plan, elevation, isometric drawings, bill of materials or technical notes from the sketches/documents given to them by the MLE. They seek clarifications from the MLE as per need. On completion, they show & get the drawing/document reviewed by the MLE. Then they incorporate the modifications/corrections directed by the MLE before finally emailing the drawing to him. After this, they await further direction & input for their next job. The different activities that they do less frequently are - Scanning (digitization) of engineering books & standards given to them by their seniors MLE/SM/CM/GM & giving them the soft copies, photocopying non-work related bills given to them by CM/GM & giving them back and sometimes the CM/GM send them to post their things, self-knowledge improvement like studying the different piping codes & standards, specifications, etc. as & when they get time between two job assignments. They interact personally with their immediate boss the MLE many times daily for job inputs, clarifications, output reviews & handing over of outputs. They also interact with the MLE's other seniors SM/CM/GM as & when they are called to help for those irregular works. The check the contents of their outputs as per the technical information & the hand sketches/documents given to them by MLE, before handing it over to the MLE for review. They also do their performance planning and self-appraisals yearly as per the directives of the MLE/SM" *(*Dutta, 2013c).

5.2.2 The Areas of Improvements and Inductive Solutions

This subsection addresses the second research objective by answering the second research question, i.e. what are the areas of improvements in order to develop a Model of Piping Engineering Design Management (refer Sections 3.6 & 3.7) through the viewpoints of theoretical framework/lens, the existing constructs and search for any new finding (as depicted in anteceding sections). How the answers have been arrived at, has already been discussed extensively in the earlier sections.

Plenty of improvement areas have been identified through the grounded open and focused coding approaches; some areas have scopes of improvements and some absolutely need immediate improvements which otherwise have tremendous potential to erode the competitive advantage of the company. All of these improvement areas have been inquired in details from the participants on the root causes, the existing countering measures, if any, the barriers to overcome and the best possible elimination methods; the biggest challenge identified by the majority is the lack of a well-defined & systematic design management system and they think it is only an integrated model that can counter/cater to those challenges, they also explained how they think the issues can be catered to through that integrated model, also consistent with the theoretical framework/lens (Section 4.4). Further, the case study has been validated through the respondents (as chronicled earlier). Most of the challenges are observed to be exactly similar to the issues found by other PEDM researchers through their independent researches worldwide as discussed earlier (Table 3.1) but a few (five) additional challenges are also found that may be unique to the Indian context. Table 5.4 presents these challenges and the best feasible solutions that are obtained from an in-depth inductive analyses of all challenges and their probable practical solutions, as extensively described earlier. The challenges and the solutions entail some key terms (the ***bold & italicised*** letters in the Solutions column of Table 5.4), named Owners and Operators respectively, that are depicted in Table 5.4 & further detailed in Sections 6.1 & 7.1 wherein the integrated model is described.

Table 5.4: Challenges & Solutions

Sl. No.	**Challenges/Issues**		**Solutions**
1	Design Product Engineering Side	Higher management (CM/GM) severely lack ***Objectivity*** in matters of technical decisions as well managerial decisions owing to their lack of managerial competence and absence of a well-defined PEDM system, thus affecting the **Aesthetics, Functionality, Buildability and Economics** of the PEDM product outputs as well the employees' efficiency and job-satisfaction.	A ***PEDM system*** with an ***Objectivity-Ensurer***
2	Design Product Engineering Side	Exploitation of the ***Positive Side of Uncertainty*** is seldom practiced, thus losing potential competitive advantage.	A ***PEDM system*** with an ***Uncertainty-Positiviser***

<table>
<tr><th>Sl. No.</th><th colspan="2">Challenges/Issues</th><th>Solutions</th></tr>
<tr><td>3</td><td rowspan="2"></td><td>Interdiscipline-Dependancy based Design Optimization is never done and hence combination of more than one analysis type like Hazard Identification & Operability (HAZOP) Studies and Mechanical Audits are out of question; this is affecting the economics of the design outputs and the profitability of the company.</td><td rowspan="2">A PEDM system with an Interdisciplinary-Optimizer</td></tr>
<tr><td>4 (new)</td><td>Sometimes issuing Design Outputs without Checking at least once, owing to pressure from Client (other departments/refineries).</td></tr>
<tr><td>5</td><td>Design Process Side</td><td>Management of Design Knowledge is not at all Transparent , thus there is no Balance between Top-Down & Bottom-Up management grooming methods in each of the Six Phases of the design cycle, that could have easily being done through Sequencing-Controlling-Monitoring; this is resulting in poor succession planning that in turn is dooming the company's as well as the country's future.</td><td>A PEDM system with a Transknowledge-Balancer</td></tr>
</table>

Sl. No.	Challenges/Issues		Solutions
6		There is no focused *or **Effective Communication*** for – Conflict Resolution by **Shared Understanding & treating Assertions as Facts** or **Dynamic Bi-Directional Feedback Integration**, or efforts for **Team Integration**; this is ensuring time loss, opportunity loss and revenue loss.	A ***PEDM system*** with a ***Multi-Integrative-Communicator***
7 (new)		**Very low *Accountability* in high level** of management, resulting in the strategic manager not formulating any development strategies and discouraging growth efforts.	
8		***Systematic Innovation Integration*** in the Three Governing Levels existing in each of the Six Phases **through Three Management Layers** – i. Enabling Technology Layer, ii. Solution Layer & iii. Interface Layer **by analysing Explicitness, Novelty, Importance & Usability** of each innovative suggestion/practice, is seldom encouraged, thus ensuring the erosion of the company's competitive design edge.	A ***PEDM system*** with an ***Innovation-Integrator***

Sl. No.	**Challenges/Issues**		**Solutions**
9		There is no effort towards Rework Minimization by ***Identification & Elimination of Non-value adding activities***, thus reducing the overall efficiency of the PEDM Cycle.	A ***PEDM system*** with a ***Rework-Minimizer***
10 (new)		There is no ***empowerment*** of junior employees, initially under supervision to move on the unsupervised authorities; this is affecting mutual trust & employee confidence besides eroding job satisfaction.	
11 (new)		***Lack of required Technical Competencies*** of the Engineers and ***Managerial Competencies*** of the Managers, affecting the Output Qualities, Reputation and misalignment of the department from the Company's vision and mission.	A ***PEDM system*** with a ***Professional-Developer***
12 (new)		***Subjective performance appraisal system*** that ensures that someone has to be axed in order for others to be benefitted.	

In tune with the philosophy, rationale & methodologies chronicled in earlier Section 4.1, this research is limited to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India; however, a point to be noted here is - this research establishes that the challenges of design management outside India (seven) are applicable to the oil & gas industry in India plus there are some additional (five) challenges specific to the Indian oil & gas context and therefore, theoretically it can be inducted that most/all of the found out issues and their solution model proposed through this research shall be applicable to the other oil & gas companies as well (the researcher, through his previous work experiences, has also experientally observed these issues to be plaguing design management in some other oil & gas companies in India as well as abroad); further, as discussed in Sections 4.1.3 & 5.1.5, external validity is beyond the scope of this particular research and is a future research arena.

In this Chapter the actions and findings from the particular study have been discussed. The proceeding Chapter describes the modelling mechanism for gradually building up a new model from the findings and also depicts the fulfillment of the research objectives.

Chapter 6: Modelling

Chapter 6: Modelling

This Chapter discusses the modelling mechanism and the gradual buildup of the model as per the philosophies discussed in the anteceding chapters. This Chapter also describes the fulfillment of the research objectives.

6.1 Building the Integrated Model

In ligation to the anteceding discussions, this modelling chapter is dedicated to addressing the elicited areas of improvements challenging the efficiency and development of the of the design product through the PEDM cycle. As such, the model needs to address the critical issues presented in Table 5.4 in order to answer the research question. These critical issues are the particular issue owners & so they are termed Owners and the solutions from the inductive analyses are proposed to be the actual solution operators in the system & hence are termed Operators (refer the ***bold+italicised*** terms in Table 5.4).

6.1.1 Owners & Operators

The Owner of a particular challenge is defined as the property of any particular activity, the lack of which has been identified to negatively (disdainfully) impact the PEDM Cycle that in turn directly/indirectly erodes the competitive advantage of the company.

The Operator of a particular solution is defined as a managerial tool that administers a particular solution to a particular Owner in order to overcome a specific challenge, thus making a positive (coveted) impact on the PEDM Cycle that in turn directly/indirectly sharpens the competitive advantage of the company.

In Table 5.4 of the preceding Chapter 5 all the identified Owners & the proposed Operators have been seen; it has been noted in Table 5.4 that there are eight or octo-operators (of solutions) to the twelve owners (of issues); a closer look at the operational meanings of each these Owners & Operators and the working constituents of the new model are as follows:

1: Objectivity in Technical Decisions

Technical decision making needs to be based on facts, technical experience & company's benefit, rather than on any pre-conceived notions or personal interests; these decisions need to be verified to be Aesthetic: compliant to sound engineering/management practices, Functional: able to achieve the desired result/s, Buildable: is practically feasible, Economic: is potent to give the best quality result among all the other decision options within the budget yet is the cheapest among the similar other options. The Operator named Objectivity-Ensurer (O-E) shall ensure that these activities are automatically done before the decision can reach to the next level in the PEDM cycle.

2: Positivity of Uncertainty

Every uncertain decision has a negative as well as a positive side; any uncertain decision needs to be taken after careful analysis of both the sides; just like some measures are put to prevent or limit the negative side effects to ALARP, the decision needs to ensure that AHARP exploitations of the positive side effects have also been analysed, before accepting or rejecting any uncertain option in any decision. The Operator named Uncertainty-Positiviser (U-P) shall ensure that these activities are automatically done before the decision can reach to the next level in the PEDM cycle.

3: Interdisciplinary Design Optimization

In jobs requiring multiple design disciplines (for e.g. Mechanical & Piping Engineering, Chemical/Process Engineering, Electrical & Instrumentation Engineering, etc.), after each discipline is ready with their preliminary output, they should jointly review their designs to know each other’s specific design concerns and address that in their own designs as applicable; further they should periodically audit their own designs (at least once even in extremely urgent schedules) as well as each other’s designs before issuing to Client, in order to ensure that the agreed objectives have been met; examples are HAZOP Studies, Mechanical Audits of Electrical designs (only on the Mechanical Engineering aspects), etc. The Operator named Interdisciplinary-Optimizer (I-O) shall ensure that these activities are automatically done before the design output can reach to the next level in the PEDM cycle.

4: Design Knowledge Management

It is as vital for the company’s designers to have the required design knowledge for the present design job as it is for the experiental design knowledge of the seniors to flow into the juniors and vice-versa for the company’s future. The Operator named Transknowledge-Balancer (T-B) shall ensure that these processes are automatically complied with in each of six phases, through transparent (well documented) Sequencing-Controlling-Monitoring before the design output can move on to the next phase in the PEDM cycle.

5: Effective Communication

Keeping all stakeholders in the PEDM cycle well informed is a key to achieving the best design in the shortest time; technical disagreements shall be encouraged as that brings out diverse views to the same problem, however, conflicts shall have to be positively resolved by Shared Understanding & Treating Assertions as Facts; this has to be bi-directionally practiced in each phase of the PEDM cycle both internally (among the Design Engineers & the Design Managers) as well as externally (with the Clients) in order to ensure that the whole team is Integrated towards achieving the best possible design goal in the shortest possible time; also the higher management need to ensure that their all subordinates understand the company's vision, mission and the Company's strategies to achieve the goals. The Operator named Multi-integrative-Communicator (M-C) shall ensure that these processes are automatically complied with in each of six phases before the design output can move on to the next phase in the PEDM cycle.

6: Innovation

Innovation is a key to business success and hence, neglecting or discouraging innovation, in whatever little way, can go a long way to sabotage the Company's future. Every innovative idea needs to be analysed closely and objectively by the immediate superior before being verified by another person; further, all the team members need to think of innovative ways on the design and the whole process, right from the innovative idea popping in a member's head to the verifier, has to be recorded to enable future audits. The Operator named Innovation-Integrator (I-I) shall rigorously ensure that AHAPR innovation is being systematically practiced on each side (process side & product side) in each phase of the PEDM cycle.

7: Non-Value Adding Activities

The timely identification and elimination of non-value adding activities to ALARP level is another important factor to achieve the highest returns from any process. Hence, Design Managers & Design Engineers shall need to identify & systematically remove valueless activities that waste time, money and energy. The term rework is defined here as any non-value adding activity that wastes time without giving any positive desired result, hence directly/indirectly causes some rework or some delayed other important work in the PEDM cycle. The Operator named Rework-Minimizer (R-M) shall ensure that the identification and removal is systematically done in each phase before a design product can reach to the next phase in the PEDM cycle.

8: Competencies

The other meaning of competency is the right people with the right knowledge at the right place in the right time. It is vital to develop competencies of engineers as well as managers because only then the engineers shall have the right knowledge to apply at the right place at the right time and only then the managers shall be able to ensure that all the right resources i.e. engineers, design trainings, design software, etc. have been synchronized properly to achieve continuously developing competency levels. For example, if a manager does not have the managerial competency to understand the company's future goal requirements, then he/she may not approve any costly but indispensable training of his/her subordinate in order to show more profit in the current financial year of the company. Further, the development shall have to be periodically monitored through a transparent & clearly defined performance appraisal system for each design project in order to reap the maximum benefits (competency alignment to technical requirements, specific learnings from specific mistakes/trainings on the project, positive identification & proportional reward for performers, positive identification & proportional penalties for non-performers, etc.) The Operator named Professional-Developer (P-D) shall ensure that these processes are automatically complied with in each of six phases before the design output can move on to the next phase in the PEDM cycle.

All the preceding eight operators act on both product & process sides in each phase of the PEDM cycle. The preceding discussions have clarified the working of the individual constituents that make up the model; following from there, the details on the integrated functioning of the whole model with all its constituents are described in the proceeding chapter.

(Section 6.1.2 follows in next page)

6.1.2 Naming the New Model

The anteceding discussions have described the ingredients that make up the Integrated Piping Engineering Design Management Model. Before forging ahead further on the topic, the name of this New Model is meaningfully derived; '***D***' [1] is selected as the first constituent of the name, as it is the researcher's consecrated Deb's [1] model; the second constituent is '***Octo***' [2] , as the model is operated by eight/octo operators so it is octo-operated; the third constituent is '***Naut***' [3] as the octo-operated model navigates/nauticates throughout the entire piping engineering design management cycle or orbit; therefore, integrating these three constituents, the new model's name is derived as D's (Deb's) plus Octo (Octo-operated) plus Naut (Nauticator) equals to ***Doctonaut***.

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1 = the study has been dedicated to God and Deb means God in the researcher's innate language or Mother-tongue Bengali, thereby, the first letter of Deb's, i.e. ***D*** *is selected*

2 = there are eight Operators or Octo-operators solving the challenges/issue-owners to catalyse the PEDM cycle towards business excellence as earlier described, thereby short form of Octo-operated, i.e. ***Octo*** *is selected*

3 = anything navigational is metonymious with Nautical and this new model with its octo-operators navigates throughout the entire PEDM cycle/orbit, thereby short form of Nauticator, i.e. ***Naut*** *is selected*

1 + 2 + 3 = Deb's Octo-operated Nauticator = ***Doctonaut***

6.2 Checking Fulfillment of Research Questions & Research Objectives

The research objectives & questions have been always borne in the mind of the researcher throughout the entire research process, with special emphasis during the data collection and analyses stages of the research; as a result, each step has been deeply thought upon, profoundly analysed, rigorously verified and then used in the research (as discussed in the preceding sections). The following discussion corroborates whether the findings do indeed answer the research questions discussed in Section 3.5.

1st Question: HOW Piping Engineering Design is being managed in oil & gas industry in India?

Answer: As described in sub-section 5.2.1, it has been seen how the different PEDM activities start, flow and end, the types, why and when of the activities, the interaction subjects, pathways & causes, the quality management practices, etc.; thus the first objective has been gratified.

2nd Question: WHAT are the areas of improvements in the existing practices/models and HOW those areas can be catered to through a Model of Piping Engineering Design Management?

Answer: In sub-section 5.2.2, the identified areas of improvements challenging the development of the PEDM cycle have been seen and in sub-section 6.1.1 it has been discussed how those areas can be improved upon through the use of specially designed Operators. Further, it has also been seen in sub-section 5.2.2 that most of the challenges are observed to be similar to the issues found by other PEDM researchers through their independent researches worldwide as discussed earlier (Table 3.1) but a few (five) additional challenges (the ones identified as 'new' in Table 5.4) are found that are unique to the Indian context. The second research question has required to identify the issues/challenges and also ingredients to make a model for catering to those issues. The issues have been identified and the modelling ingredients for catering to those issues have been developed (refer Table 5.4, Sections, 5.2.2 & 6.1.1); with the preceding described tools (Operators of Owners) and tackles (augmented knowledge) the ingredients/constituents of the new Model Doctonaut have been developed in accordance with the earlier discussed philosophies & rationales of research design; thus the second objective has bountifully gratified. For ligature continuum it may be marked here that while the ingredients have been workably described in the anteceding sections, the integrated working of Doctonaut has been described in the following chapter. In this context it is noted that one particular approach on the product side, that has been identified to be a sub-component of one issue/challenge in PEDM cycle (Design & Drawing Reviews in Multiple Stages: refer Table 3.1 point-3) in other industries, is not a sub-component of any challenge in this present research case since design & drawing reviews are observed to be reviewed in multiple stages in this particular company; as such this has not been included in the design definition of the Operator Interdisciplinary-Optimizer in sub-section 6.1.1.

In consideration of these facts, this present research has provided detailed answers to the research questions and has thus rhapsodically fulfilled/achieved the research objectives.

In this Chapter the workable ingredients for catering to all those identified issues, modelling tools & mechanism for gradually building up the new model and the fulfillment of the research objectives have been depicted. The proceeding Chapter describes the new model Doctonaut & its integrated working, and epitomizes the neoteric knowledge advancement through this research.

Chapter 7: The New Integrated Model Doctonaut

Chapter 7: The New Integrated Model Doctonaut

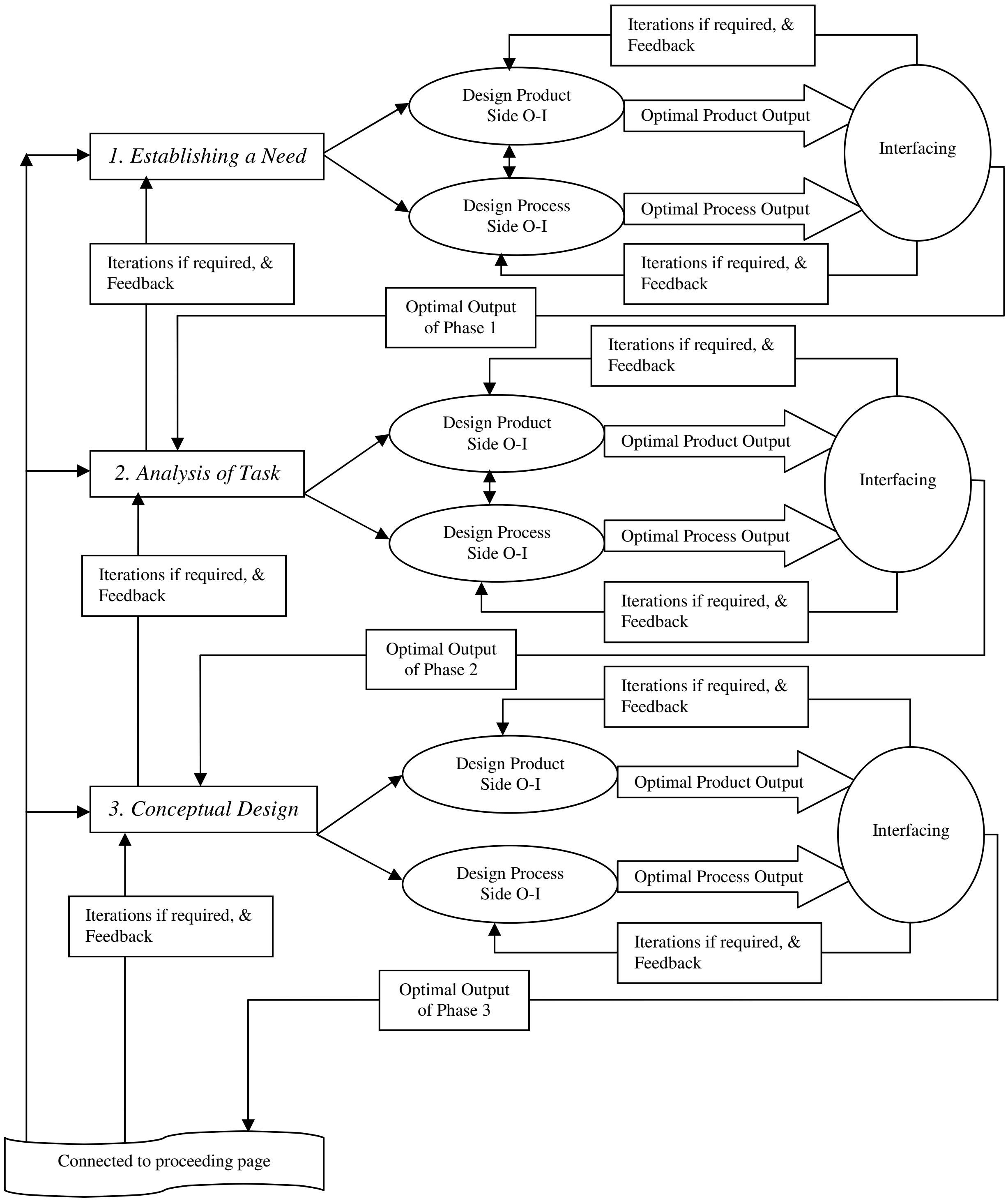
This Chapter describes the radically New & Integrated Model of Piping Engineering Design Management named Deb's Octo-Operated Nauticator or Doctonaut & its working, and features the neoteric knowledge advancement by this research.

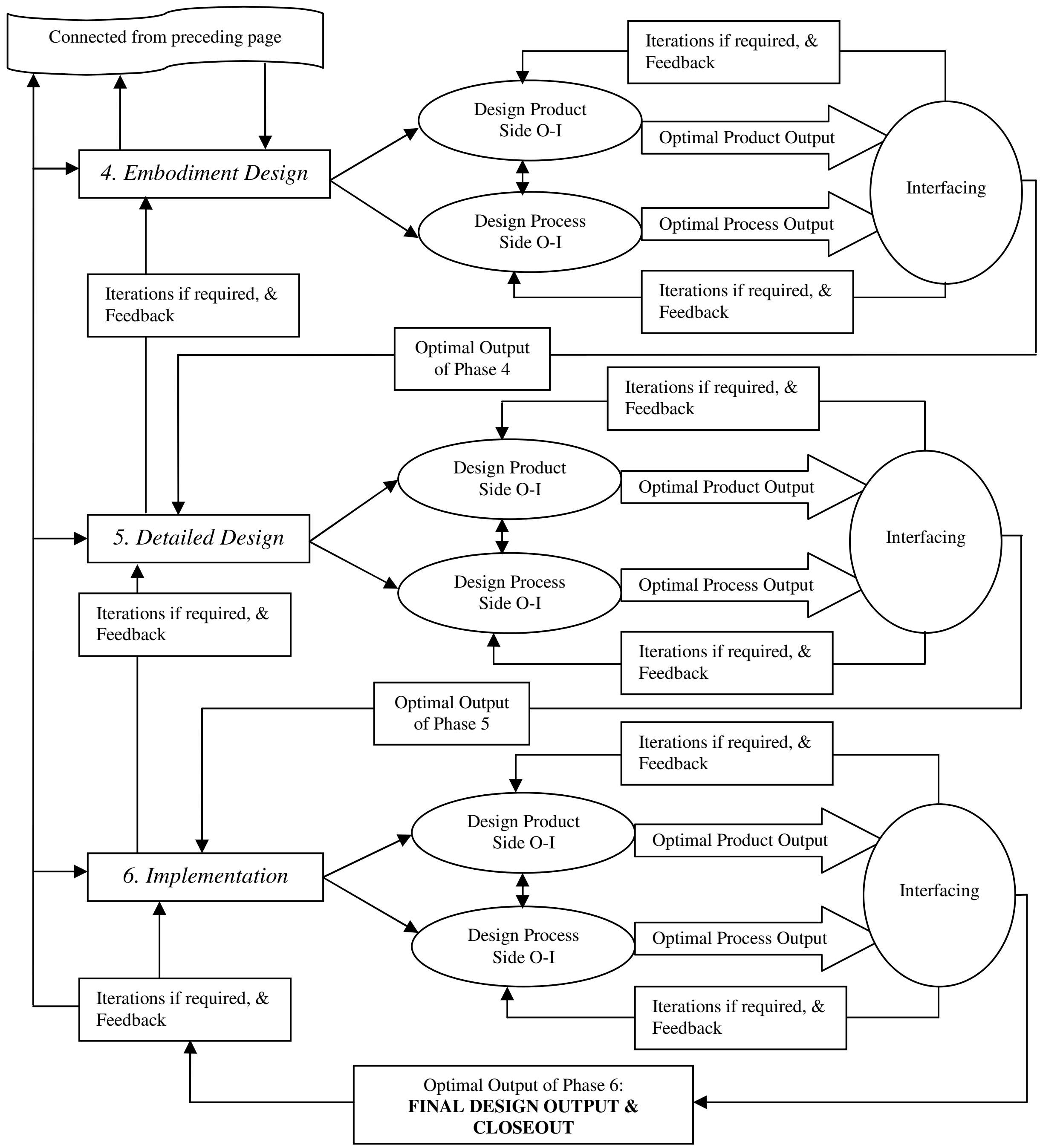
7.1 The Integrated Piping Engineering Design Management Model Doctonaut

As discussed in the preceding Chapters, it has been described that the Operators need to act on the Owners in specific positive ways in order to ensure the desired outcomes from the PEDM cycle. The following illustrative Figure 7.1 & Figure 7.2 demonstrate the working processes of the model that is proposed from this research work.

(Figure 7.1 follows in next page)

Figure 7.1: The Operator Integrated Comprehensive PEDM Model, Doctonaut



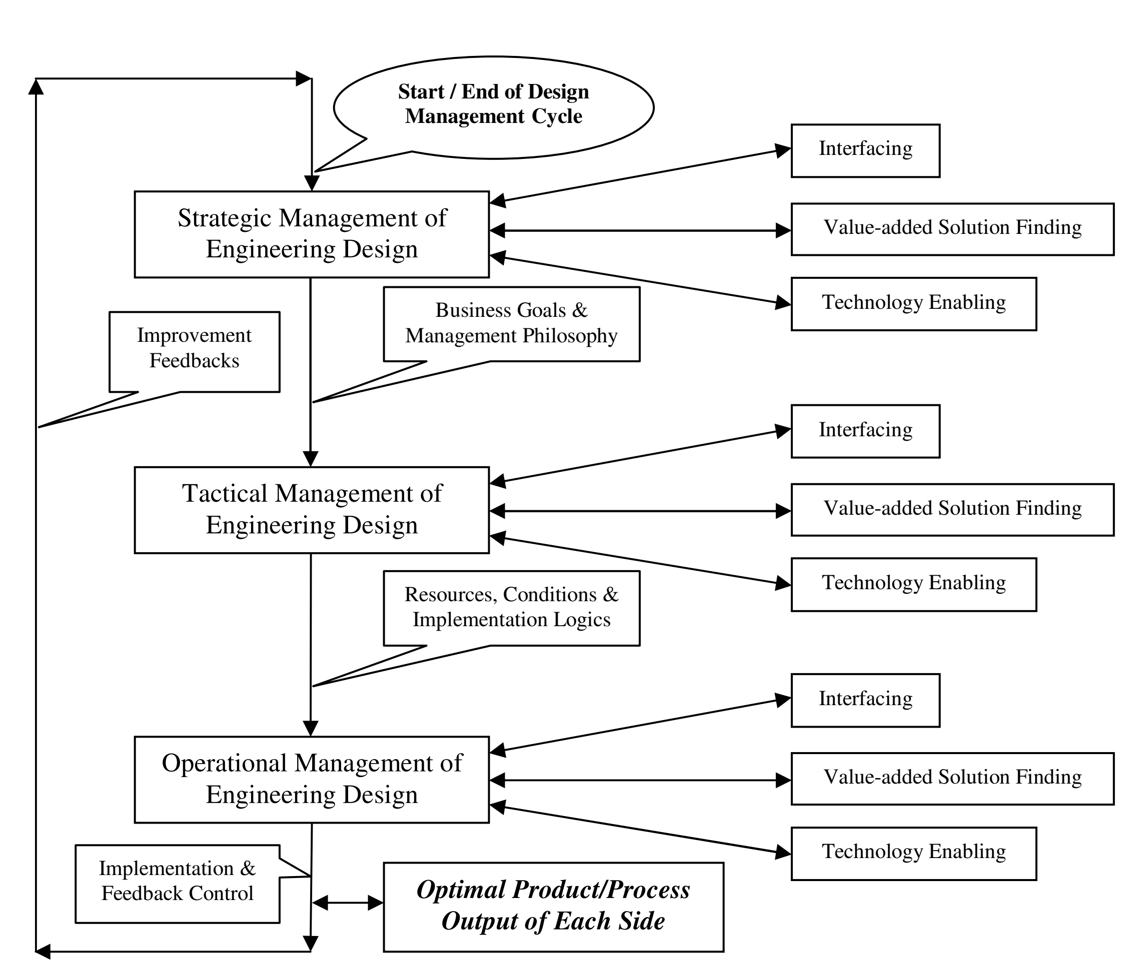

Connected from preceding page
Iterations if required, & Feedback
Design Product Side O-I
Optimal Product Output
4. Embodiment Design
Interfacing
Design Process Side O-I
Optimal Process Output
Iterations if required, & Feedback
Iterations if required, & Feedback
Optimal Output of Phase 4
Iterations if required, & Feedback
Design Product Side O-I
Optimal Product Output
5. Detailed Design
Interfacing
Design Process Side O-I
Optimal Process Output
Iterations if required, & Feedback
Iterations if required, & Feedback
Optimal Output of Phase 5
Iterations if required, & Feedback
Design Product Side O-I
Optimal Product Output
6. Implementation
Interfacing
Design Process Side O-I
Optimal Process Output
Iterations if required, & Feedback
Iterations if required, & Feedback
Optimal Output of Phase 6: FINAL DESIGN OUTPUT & CLOSEOUT

In the Figure 7.1, the 'O-I' or Operator-Integrator integrates each of the eight Operators for catering to all the issue/challenge Owners (the owners, operators and the individual working details of these Operators have been discussed heretofore in Section 6.1.1 and the integrative workings are described in the following paragraphs). The Operator integrated optimal design output is thus produced inside both the Product Side & the Process Side inside each of the Six Phases of the entire design management cycle, as shown in Figure 7.1, to produce the Final Design Output & Closeout of the particular project's Piping Engineering Design Management Cycle. It can be noted in Figure 7.1 that even though feedbacks are exigently incorporated on each side in each phase throughout the cycle, on top of that, the learnings from errors/mistakes or feedbacks from the current project are ensconced in the closeout stage to be fed back to all relevant steps; then whenever the next project begins, the steps start only from those concerted fed back learnings (the starting keys of any phase/side are those links to the step-specific earlier learnings); this systematically ensures that the same mistakes are never repeated as well as all the past learnings are intrinsically applied for continuous improvement - directly in the competitive edge of the final output product, the employees as well as the company, and, indirectly in its contributions to the country & the world.

Inside the New Model Doctonaut, each O-I shall work through a sub-cycle as depicted in the following Figure 7.2. Therefore, each Side (Product/Process) in each PEDM Phase of Doctonaut, shall have eight sub-cycles as per Figure 7.2. It can be noted that each governing level in Figure 7.2 shall also ensure continuous improvement through learnings from mistakes/errors/feedbacks in the same process described in the preceding paragraph; thus, the past cognitions are consistently ensured throughout each phase, each side and each governing level of the New Model Doctonaut.

(Figure 7.2 follows in next page)

Figure 7.2: Each Operator-Integrator (O-I)



The Figure 7.2: Operator-Integrator (O-I) cycle is similar to the Figure 3.1 basic conceptual framework with suitable modification in the final product output, i.e. Figure 7.2 O-I process produces 'Optimal Product/Process Output of Each Side' of PEDM inside each of the Six Phases whereas the Figure 3.1 is a basic & generic process. The principles and description of this integrator cycle has already been discussed in Section 3.2 and hence are not repeated here. On the other hand, the functioning of each of the eight Operator-Integrators, which shall need to follow some mandatory activities specific to the particular O-I, are described in the following paragraphs.

In the Operator **Objectivity-Ensurer** (O-E), there has to be documented (soft/hard) checks, with only Yes/No check-mark options, for each technical decision in terms of Aesthetics: whether is compliant to sound engineering/management practices, Functionality: whether is able to achieve the desired result/s, Buildability: whether is practically feasible, Economics: whether is potent to give the best quality result among all the other decision options within the budget yet is the cheapest among the similar other options.

In the Operator **Uncertainty-Positiviser** (U-P), there has to be documented (soft/hard) checks, with only Yes/No check-mark options, for each technical decision in terms of Negative Uncertainty: whether negative uncertainty has been analyzed and proper measures put into place to reduce chances to ALARP and in terms of Positive Uncertainty: whether positive uncertainty has been analyzed and proper measures put into place to increase chances to AHARP.

In the Operator **Interdisciplinary-Optimizer** (I-O), there has to be documented (soft/hard) checks, with only Yes/No/NA* check-mark options, for completing each Design Side (Product/Process) in terms of – whether joint reviews of their designs have been done, whether periodical audits of their own designs (at least once even in extremely urgent schedules) as well as each other's designs (before issuing to Client) been scheduled and being adhered to.

In the Operator **Transknowledge-Balancer** (T-B), there has to be documented (soft/hard) checks, with only Yes/No/NA* check-mark options, for completing each Side (Product/Process) in terms of – whether the project specific knowledge (engineering/management related & pertinent to that specific Side) sharing session has been sequenced/scheduled by a senior (GM/CM/SM) for a junior (MLE/DE1/DE2) on an area identified by the senior as weak in that junior, whether the project specific knowledge sharing session has been scheduled by a junior (MLE/DE1/DE2) for a particular senior (GM/CM/SM) on areas identified by the junior as weak in that senior (for e.g. the junior due to his previous experience, may be in a different company, might possess expertise knowledge on any specific small area like say reinforcement calculations or say design software assessment or say management of change in as-built design, etc. on which the senior may not have had any experience) and whether the sessions' schedules are being complied with.

In the Operator **Multi-integrative-Communicator (M-C)**, there has to be documented (soft/hard) checks, with only Yes/No/NA* check-mark options, for completing each Design Side (Product/Process) in terms of – whether any interdisciplinary/inter-engineering/external conflict has been potentially identified or already reported, whether the stakeholders are sharing their understandings & treating assertions as facts in conflict-resolution meetings, whether technical disagreements are being expressed & being treated objectively in conflict-resolution meetings, whether there are bi-directional communications both internally (among the Design Engineers & the Design Managers) as well as externally (with the Clients) and whether the Company's vision, mission and strategies to achieve the goals been made understood by the seniors to the juniors in terms of that particular Side activities.

In the Operator **Innovation-Integrator (I-I)** there has to be documented (soft/hard) checks, with only Yes/No check-mark options, for each Side in terms of – whether every innovative idea has been analysed closely and objectively by the immediate superior AHARP (As High As Reasonably Practicable) & then been verified by another person, whether he/she (the team members) is thinking of innovative ways on the design and the whole process AHARP and whether periodic audits are being carried out on the documented appraisal of my already given innovative ideas.

In the Operator **Rework-Minimizer (R-M)** there has to be documented (soft/hard) checks, with only Yes/No/NA* check-mark options, for each Side in terms of – whether non-value adding activities are being searched for & reported in every Side and whether those activities have been eliminated from the entire PEDM cycle.

In the Operator **Professional-Developer (P-D)** there has to be documented (soft/hard) checks, with only Yes/No/NA [1] check-mark options, for each Side in terms of – whether all required resources i.e. engineers, design trainings, design software, etc. have been made available to each other, whether the past learnings from completed projects being checked upon the applicable Side, whether the development of each member is being periodically monitored & fed-backed upon through clearly defined performance appraisal system for each design project, whether performance is being positively identified & proportionately rewarded and whether non-performance is being positively identified & proportionately fined.

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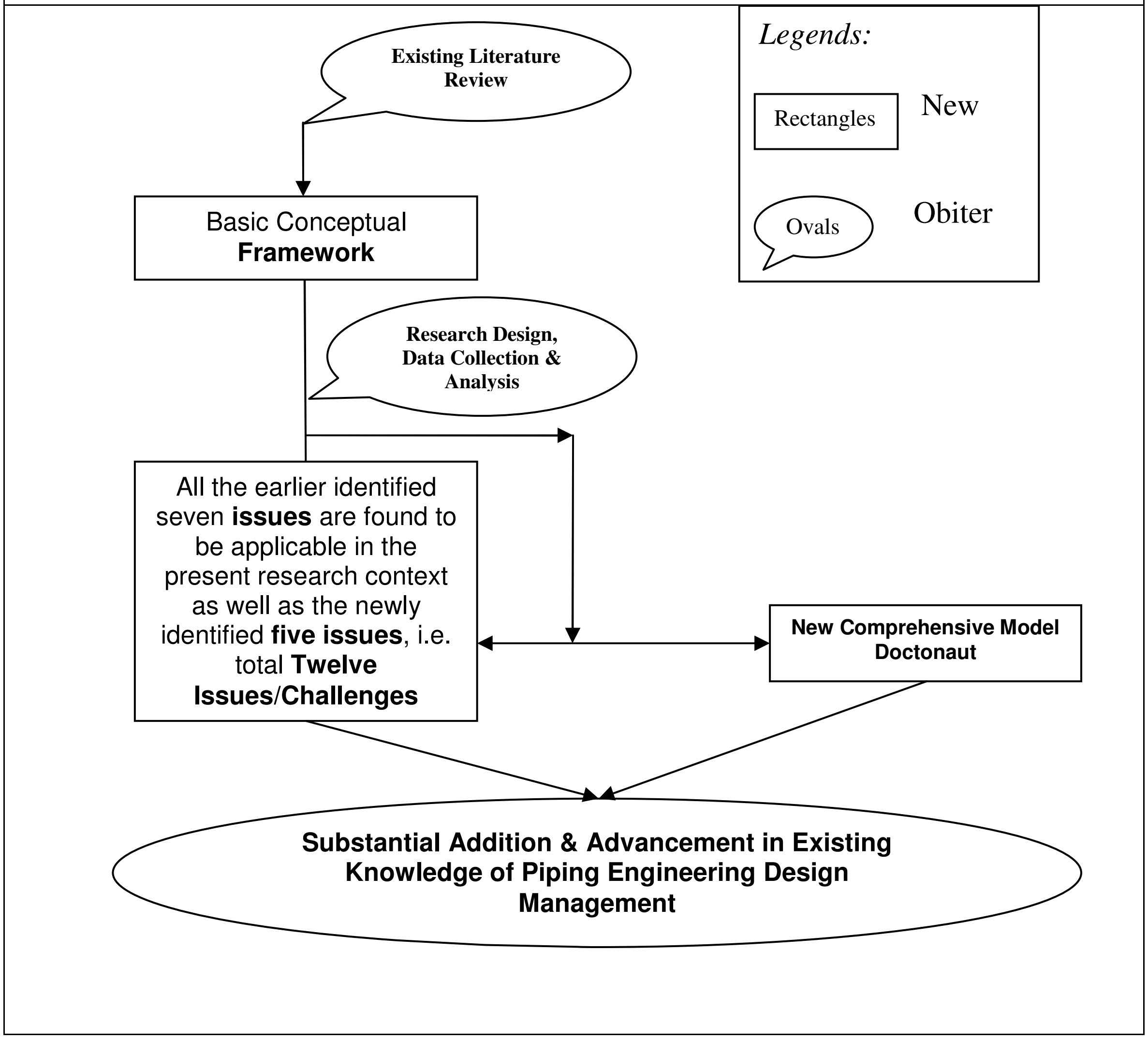
1 = While Yes or No are the mostly chosen options in all Operator-Integrators (O-Is), Not Applicable or NA may also be required in some special cases; sometimes, one/more operator integrating activity may not be applicable to some specific small design project, for e.g. for a project requiring only a pipe's thickness design, it is not pertinent to have an Interdisciplinary-Optimizer (I-O) activity with Electrical discipline; on the other hand, for a project requiring full piping engineering design shall require the I-O to ensure that the Electrical Wiring/Connections are consistent with those specified in the P&ID by Piping/ Process, to agree on time schedules for both inter-discipline and Client deliveries, etc. The option NA (Not Applicable) can be applied in only the special case of a O-I having a potential to be not applicable, as illustrated in the example. In order to tick an NA, there shall be a mandatory text box to be filled with the justification for rendering latency to that particular O-I for the specific discipline.

7.2 Neoteric Knowledge Advancement

This study has reviewed pertinent existing research knowledge and has built a new basic conceptual framework; after that data has been collected and analysed as per a critically chosen research design and the previous research knowledge has been compared to the findings; it has been found that all the earlier identified seven issues are applicable to the Indian oil & gas context and additionally five more issues are found to be plaguing the effective management of piping engineering design. Finally, in line with the research objectives and questions, from the analysed data a brand new model of piping engineering design management, appositely named Doctonaut, has been built encompassing the entire PEDM cycle throughout each of the bi-sided six phases; the initially built basic conceptual framework has been suitably modified, augmented and aptly included as a part of this new model Doctonaut through an Operator-Integrator sub-model; this integrated model Doctonaut has been built extensively catering to all the previous seven issues (from previous researches) that are found to be applicable in the present context as well as the newly identified five issues (from this particular research), catering to a total of all the twelve issues/challenges; thus, this present study substantially adds & advances the existing knowledge in this field of Piping Engineering Design Management. The details are pictorially represented in Figure 7.3.

(Figure 7.3 follows in next page)

Figure 7.3: Neoteric Knowledge



Further, this research work's ***consistency*** *with the research objectives and questions* have been successfully verified as described in earlier Section 6.2. The ***advantages*** of the study's findings, especially the new model Doctonaut, and the elicited potential areas of ***future research*** have been highlighted in the following Chapter.

This Chapter has discussed the integrated operation of the brand new model Doctonaut and has gravitated the neoteric knowledge advancement by this research. The proceeding Chapter wraps up the thesis by providing a glimpse of the key eruditions enlightened through this research study, salient features of Doctonaut, limitations of the study and indicative areas of further research.

Chapter 8: Conclusion

Chapter 8: Conclusion

This concluding section epitomizes a brief sylloge of the main points in this research, salient features of Doctonaut, limitations of the study and indicative areas of further research.

8.1 Conclusion

Previous researches have established that an integrated management model for managing engineering design is indispensably needed to aid design engineers in their design management decisions and to sustain the competitive edge of the company because efficient management of piping engineering design management cycle is indispensable to sustain any company's competitive advantage, thereby preventing time loss, opportunity loss & revenue loss. The companies who do not have effective design management practices/models are much less successful in business than the ones having it.

Previous researchers have established that design management cycle comprises of Three Governing Levels:

Strategic Design Management,

Tactical Design Management,

Operational Design Management

and some other researchers have established that at Each Level, design expertise can be effectively managed to produce an innovative solution through Three Layers:

Enabling Technology Layer,
Solution Layer,
Interface Layer.

The holistic Piping Engineering Design Management Cycle has Six Phases namely:

Establishing a Need Phase,
Analysis of Task Phase,
Conceptual Design Phase,
Embodiment Design Phase,
Detailed Design Phase,
Implementation Phase.

The management of Piping Engineering Design has two interfering Sides:
Design Product Engineering Side,
Design Process Side.

The three governing levels of design management run on both sides (Product Side and Process Side) through each of the six phases of the design management cycle. Multiple issues have been found to be plaguing the design management cycle in each phase, on each side and through each governing level.

From the comprehensive reviews of over three hundred available relevant existing literatures, it has been found that there have been some researches in the broader field of Multidisciplinary Engineering Design Management. There have also been some researches in the Management of specifically Piping Engineering Design. It has been found that these studies have been done for Architecture, Civil, Construction, Electronics, Transportation industries; they are different among themselves and do not throw any light on the state of design management affairs in the oil & gas industry. Previous studies have also established that, engineering design thinking & corresponding design activities in different industries in differing situations have crucial differences.

Previous studies have established that an integrated management model for managing engineering design is indispensably needed. The previous studies have their respective limitations. Some researchers have focused only on the Product Side of Engineering Design Management and have so far found out three issues challenging the efficient management on engineering design on the Product Side. Whereas some other researchers have focused only on the Process Side of Engineering Design Management and have so far found out four issues challenging the efficient management on engineering design on the Process Side. Existing literature review has evidenced that engineering design management can be effectively managed if the identified issues are catered to. Previous studies for specifically piping engineering design management have focused only from a pure engineering point of view, ensuing a colossal dearth of focus on the management aspects in the product as well as the process sides of design management; the existing studies did neither focus on the piping enginering design management aspects present in both the product sides and the process sides nor into any integrated model for the complete cycle that caters to the management issues of the product as well as the process sides. Further, it has been found that no research has focused on whether there are any issues plaguing the management of engineering design in India. An extensive literature review covering over three hundred relevant available literatures yielded no references of any design approaches & models for oil & gas piping engineering design management in India. The previous studies neither throw any light on the design management in the global oil & gas industry nor on the design management issues of any industry in India. There has been no research to know how design is being managed in India. The existing studies have identified issues plaguing engineering design management worldwide in other industries & outside India. However, previous studies have established that design management roles, practices and activities significantly & crucially vary from industry to industry and from country to country. Therefore, the applicability of those identified issues to the Indian oil & gas context is uncertain. No study has focussed on their applicability to either the oil & gas industry or on their applicability to India. Moreover, previous researchers have stressed the growing & indispensable need for an integrated design management model and in India no research has focussed on engineering design management. The identified research gaps have not been addressed by any of the previous studies. This present research tries to answer these questions and thus address these dodged research gaps in a bid to improve engineering design management in India.

The business problem has been:

An integrated model for managing engineering design is indispensably needed to aid design engineers/managers in their management decisions and to sustain the competitive advantage of the company.

The research gaps, that this study has addressed, have been:

Extensive literature review yielded no references of any design approaches & models for oil & gas piping engineering design management in India. There has been no research to know how design is being managed in India.

The identified research gaps have not been addressed by any of the previous studies.

The research problems have been:

The Existing Practices/Models of Piping Engineering Design Management that are being used in Oil & Gas Industry in India are unknown, although are indispensably needed to be known in order to sustain the competitive advantage of the company.

The Areas of Improvements or Issues, that are needed to be identified in order to develop a Model of Piping Engineering Design Management, are also unknown.

The research questions have been:

HOW Piping Engineering Design is being managed in oil & gas industry in India?

WHAT are the areas of improvements in the existing practices/models and HOW those areas can be catered to through a Model of Piping Engineering Design Management?

The present research objectives have been:

To Study the Existing Practices/Models of Piping Engineering Design Management that are being used in oil & gas industry in India.

To Identify the areas of improvements in order to develop a Model of Piping Engineering Design Management.

To solve this business problem, address the research gaps, answer the research questions and fulfill the research objectives, the existing practices of piping engineering design management that are being used in the piping engineering design department of India's largest oil & gas company have been studied, issues identified, compared with other researchers' finding, each research step has been deeply thought upon, profoundly analyzed, rigorously verified and an integrated model of piping engineering design management has been proposed as seriated through the following paragraphs.

After careful consideration of established methods & approaches, a descriptive qualitative case study with a grounded theory approach has been chosen as the philosophy of this research owing to the approach being the best suitable research mode for this particular study of the problem through the objectives. This is because the present research purpose has been descriptive (fact finding about a state of affairs), research process has been qualitative (for a phenomenon related to quality) and research approach has been a grounded outlook (to systematically generate theory from data through inductive thinking about a phenomenon of interest). Sample selection has been done in three stages, while decreasing sample size by using the Theory of Elimination and unit of analysis has been critically chosen in line with the research objectives. Detailed case study questionnaire has been developed in three steps so as to enable an appropriate research into the answers to the research questions. Data have been collected and analysed in line with the research philosophy and rationale. All evidences substantiating the case study have been archived and are being maintained with the researcher. The validity of the case study has been verified by employing a number of tactics. To ensure construct validity & internal validity, two tactics have been employed. First, two levels of analyses are undertaken during data analysis – conceptual and detailed. Secondly, the case study reports are reviewed by key informants and then their feedbacks have been incorporated in the final research. This present research study is expected to provide depth and so the study intended to provide an insight into the probable relationships suggested and therefore to generalize beyond this particular research area would require additional confirmation of results that is beyond the scope of this particular research and has been included as a further research scope. Although the research is limited to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India, however, a point to be noted here is - this research establishes that the seven challenges of design management identified outside India are applicable to the oil & gas industry in India plus there are some additional five challenges specific to the Indian oil & gas context and therefore, theoretically it can be inducted that most/all of the found out issues and their solution model proposed through this research shall be applicable to the other oil & gas companies as well (the researcher, through his previous work experiences, has also experientally observed these issues to be plaguing design management in some other oil & gas companies in India as well as abroad); further, external validity is beyond the scope of this particular research and is a future research arena. Reliability has been highly ensured through apt instruments, archival of all evidences and use of data analysis software Atlas.ti. This research employed a number of approaches to ensure high reliability while applying procedures for data collection and analysis. First, the case study protocol has been used to guide the research process as the protocol is a major tactic in increasing the reliability of a case study research and is intended to guide the researcher / investigator in carrying out the case study. The protocol has comprised of instruments as well as procedures and general rules that have been followed. This ensured consistency in the areas covered. Secondly, to reduce the likelihood of forgetting or misunderstanding the data and to allow independent data analysis by other researchers, interviews have been taped, transcribed and all original evidences are archived. Thirdly, the use of Atlas.ti qualitative analysis software allowed systematic & consistent analysis of the qualitative data and further increased the reliability of this research because procedures can be repeated. Fourthly, the field notes taken by the researcher have been also transcribed for future reference. Different levels of coding, within case analysis (conceptual & detailed), theory triangulation, employment of case study protocol, use of software Atlas.ti, archival of all evidences, etc. have been carried out to ensure high quality (construct validity, internal validity & reliability) of the study.

Data analyses has been done through grounded theory approach involving process iterations for movements between existing theory and the collected interview data, observation data & interaction data. The coding approach has involved perspectives of the theoretical framework/lens, the existing constructs and search for any new finding, in tune with the research objectives. The present case data analysis can be represented in three steps or levels. The first step has been open coding, followed by the second & third steps. Both the second and third steps have been focussed/selective coding and used axial focussed as well as theoretical focussed coding techniques. The third step differed from the second step by focussing deeper into the underlying relationships among the codes, categories & concepts; the identified inter-relationships, intra-relationships, cross-relationships and contra/clashing-relationships are linked as a pertinent root causal function. It may be noted that in vivo coding has been used in all three steps. While the first & second steps helped the researcher in exploring & understanding the existing practices of piping engineering design management and the challenges/issues by developing the codes, categories & concepts, the third step helped the researcher understand the relationships of the codes to the challenges/issues that affect the design management output in the existing practices.

The case study has been done through various data collection methods including interviews, observations and interactions with the team members. This study focusses on reality as perceived by the researcher himself, in line with the ideology that reality is what & how we perceive any particular issue and as such, this study is one of the several probable theories of the business management problem. By limiting the study to a single organization, the researcher is able to examine the case in more detail and to thoroughly understand the interrelationships of isolated data; this is more relevant because it focusses on depth of insightful knowledge instead of generality promoted by others. This approach may be criticized as developing localized theory; however, this is still a useful contribution to existing knowledge since it establishes that the issues plaguing the management of piping engineering design in other industries in other countries, are also applicable to India and there are some additional issues in the Indian oil & gas scenario. Further, the relevance of this specific research in the Indian oil & gas context is bona fide.

The concepts/theories/solutions have been refined in a number of iterative stages leading to natural theory built-ups from the analysis. These refined concepts/solutions have been then again iteratively integrated to synthesise the final refined concepts/theory/solutions.

The existing practices have been described and challenges existing in the present practices have been identified and compared to the issues found by other researchers in other industries; it has been observed that all the seven issues from previous researches are existing and five additional issues are identified to be plaguing the efficient management of piping engineering design in the oil & gas Industry in India. Catering to all the identified issues, a conceptual new model (appositely named Doctonaut) has been proposed to systematically and judiciously manage piping engineering design management.

The research objectives & questions have always been borne in the mind of the researcher throughout the entire research process, with special emphasis during the data collection and analyses stages of the research. As a result, each step has been deeply thought upon, profoundly analysed, rigorously verified and then used in the research. At the later stages, it has been verified whether the findings do indeed answer the research questions and meet the objectives.

Neoteric Knowledge Advancement by this study is gravitated in this paragraph. This study has reviewed pertinent existing research knowledge and has built a new basic conceptual framework; after that data has been collected and analysed as per a critically chosen research design and the previous research knowledge has been compared to the findings; it has been found that all the earlier identified seven issues are applicable to the Indian oil & gas context and additionally five more issues are found to be plaguing the effective management of piping engineering design. Finally, in line with the research objectives and questions, from the analysed data a brand new model of piping engineering design management, appositely named Doctonaut, has been built encompassing the entire cycle throughout each of the bi-sided six phases; the initially built basic conceptual framework has been suitably modified, augmented and aptly included as a part of this new model Doctonaut through an Operator-Integrator sub-model; this integrated model Doctonaut has been built extensively catering to all the previous seven issues (from previous researches) that are found to be applicable in the present research context as well as the newly identified five issues (from this particular research), catering to a total of all the twelve issues/challenges; thus, this present study substantially adds & advances the existing knowledge in this field of Piping Engineering Design Management.

This research work's consistency with the research objectives and questions has been successfully verified. Further, a few salient advantages of the study's findings, especially the new model Doctonaut, have been highlighted in the following paragraphs; for e.g., sustaining & developing the competitive edge of a company, improving the safety of personnel, equipment, environment & other stake holders of the design group, etc. The limitations of the study & the elicited potential areas of future research have also been documented; for e.g. applicability of the new model in other industries, etc.

In short, the previous researches as well as existing practices of piping engineering design management have been analysed and a conceptual new model named Doctonaut has been built that takes the existing knowledge a step further by validating the presence of issues identified elsewhere plus additional issues to be applicable to the Indian oil & gas sector as well as by integrating inductive solutions systematically into each stage of the entire design management cycle; this has been an indispensable step that the previous researchers have not ventured into and a step that ensures that the full benefits of the research knowledge of this field permeate each step of the entire design management cycle, thus guaranteeing continuous improvement as well as safety of the company's competitive edge, that in turn shall positively contribute directly to the development of the company and indirectly to the country & the world.

8.2 Salient Features of the New Model Doctonaut

A few salient features of the New Model Doctonaut, that edges it over contemporary/in-vogue practices, are enlisted as follows –

- First of its kind product & process sides integrated comprehensive model for the oil & gas industry

- Offers full systematization of the PEDM cycle that so far is being used to be managed by people as per their own experience & thoughts, and thus being prone to subjective managerial decisions affecting the profitability as well as the future of the company

- Real time issues established to be affecting the cycle efficiency, that are mostly ignored, can now be managed easily & effectively through this model

- The New Model can be administered through any custom designed software

- Doctonaut is expected to improve the quality of the design product because the identified challenges are recognized and taken care of; this automatically improves the safety of personnel, equipment, environment and all other direct as well indirect stake holders of engineering design

- The New Model ensures continuous & consistent development, thereby intrinsically & invariably safeguarding and sharpening the company's competitive advantage

- The New Model's features are definitely going to reduce, if not completely eliminate, time loss, revenue loss and opportunity loss of any company practicing it resolutely; success is theoretically guaranteed through the New Model Doctonaut, however, the extent of success may vary from company to company, from people to people owing to human being's inherent unique differences from each other affecting their competencies in administering, operating & controlling the Model

- Many other advantages of the New Model Doctonaut may eventually emanate in terms of improving time, energy & money utilizations, that in turn shall make positive differences in the success of the PEDM cycle and the company

8.3 Limitations of this Research

Albeit this research adds substantially to the existing knowledge in the field of piping engineering design management for the oil & gas industry in India and also envisages quite some critical benefits for sustaining & improving the competitive advantage of the company, the study has the following limitations –

- The research is limited to only one organization that has been selected as a representative of the oil and gas industry in India based on the fact of that company being the largest (in terms of revenue, size as well as market share) among all oil & gas companies in India; however, a point to be noted here is - this research establishes that the challenges of design management outside India are applicable to the oil & gas industry in India; plus there are some additional challenges specific to the Indian oil & gas context and therefore, theoretically it can be inducted that most/all of the found out issues and their solution model proposed through this research shall be applicable to the other oil & gas companies as well (the researcher, through his previous work experiences, has also experientially observed these issues to be plaguing design management in some other oil & gas companies in India as well as abroad); further, as discussed in Section 4.1.3, external validity is beyond the scope of this particular research and is a future research arena

- The New Model Doctonaut that has although been developed through practical findings, has not yet been practically administered in any company and hence is not verified

8.4 Further Research Arenas

This discussed research elicits the following further research arenas in Piping Engineering Design Management -

- To Design a Software for the New Model Doctonaut

- The extent of practical success through Doctonaut-in-use at Oil & Gas Companies in India

- Applicability of the New Model Doctonaut to industries other than Oil & Gas in India

- Applicability of the New Model Doctonaut to other Indian Oil & Gas companies

- Applicability of the New Model Doctonaut to Oil & Gas companies outside India

- Applicability of the New Model Doctonaut to industries other than Oil & Gas outside India

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References

This part enlists the references made: Bibliography & Appendices (A, B, C, D, E, F, G & H), that have been cited in different sections of this thesis.

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Appendices

Appendices

This sub-section enlists the references made as Appendices A, B, C, D, E, F, G & H in different sections of this thesis.

Appendix A notes the details of the data collection sources for reference.

Appendix B references all the case study questions that have been employed to obtain the explicit primary & ancillary secondary data.

Appendix C contains the operational definitions of the software Atlas.ti (data analysis software) codes and sub-codes as well as a few glimpses of the in-action (Grounded as well as Focused) Codes, Sub-Codes, Networks and Families for reference.

Appendix D contains the researcher's Curriculum Vitae.

Appendix E enlists the substantiation details of the three publications authored by the researcher during the course of this research.

Appendix F presents an exhibit of the researcher's published paper titled Findings from a Review of Existing Approaches & Models of Engineering Design Management.

Appendix G presents an exhibit of the published case research including the elicited responses to the case study questionnaire titled Piping Engineering Design Management Scenario in a Top Oil & Gas Company.

Appendix H presents an exhibit of the researcher's published paper titled A Theoretical Model of Innovation Integrated Engineering Design Management.

Appendix A: Data Collection Details

Table A-1: Appendix of Collected Data

Ref. No.	Type of Primary Data	Content	Date	Time	Source	Substantiation Details
1	Ancillary	PDEC Presentation	Nov 20, 2012	5 pm	PDEC Intranet - \\10.20.64.118\pdec\pdec_engg_data on 07.07.2011\PDEC Work Experience	
2	Ancillary	PDEC Organogram	Nov 20, 2012	5 pm	PDEC Intranet - \\10.20.64.118\pdec\pdec_engg_data on 07.07.2011\Organogram_EPMS	
3	Explicit	Interview with DE1	Dec 13, 2012	6 pm	DE1, PDEC Office	Original interview has been given by respondent in Hindi & that has been audio-recorded. The Hindi & subsequent English transcriptions have been shown to the respondent & he has signed as a token of his approval that whatever he has said has been fully written in the transcription*.
4	Explicit	Interview with DE2	Dec 13, 2012	3:15 pm	DE2, PDEC Office	Original interview has been given by respondent in Hindi & that has been audio-recorded. The Hindi & subsequent English transcriptions have been shown to the respondent & he has signed as a token of his approval that whatever he has said has been fully written in the transcription*.

Ref. No.	Type of Primary Data	Content	Date	Time	Source	Substantiation Details
5	Explicit	Interaction with MLE	Dec 14, 2012	4 pm	MLE, PDEC Office	The respondent has spoken at length on the his detailed working experience and the challenging issues on condition of keeping it off the live audio recording & off any signed transcript and so the researcher has taken running notes*.
6	Explicit	Interview with SM	Dec 17, 2012	3:45 pm	SM, PDEC Office	Original interview has been audio-recorded. The transcriptions have been shown to the respondent & he has signed as a token of his approval that whatever he has said has been fully written in the transcription*.
7	Explicit	Interaction with SM	Dec 17, 2012	4 pm	SM, PDEC Office	The respondent has spoken at length on the issues on condition of keeping it off the live audio recording & off his signed transcript and so the researcher has taken running notes*.
8	Explicit	Interview with CM	Jan 23, 2013	5 pm	CM, PDEC Office	The respondent has consented to the interview only on conditions of no live audio recording & no signing in transcript and so the researcher has taken running notes* during the interview, showed

Ref. No.	Type of Primary Data	Content	Date	Time	Source	Substantiation Details
						the printout of the fair transcript to the respondent & taken his verbal approval of the transcript.
9	Explicit	Interview with GM	Jan 24, 2013	5 pm	GM, PDEC Office	The respondent has consented to the interview only on conditions of no live audio recording & no signing in transcript and so the researcher has taken running notes* during the interview, showed the printout of the fair transcript to the respondent & taken his verbal approval of the transcript.
10	Explicit	Screening Interview	Septem-ber to October, 2012	Day Office Hours	GMs, CMs, SMs, MLEs, Draftsmen at 10 Refineries' PEDM Departments	Original interview has been through personal visits as well through telephone calls.
NB: *Original signed Transcripts of Interviews, Recordings, Researcher's Notes of Interactions/Interviews, Company's Standards, Policies, etc. are being maintained by the Researcher.						

Appendix B: Case-Study-Questionnaire (C-S-Q) Employed to Collect Explicit Primary & Ancillary Secondary Data

Case-Study-Questionnaire (C-S-Q) Employed to Collect Explicit Primary & Ancillary Secondary Data

A. EXPLICIT PRIMARY DATA

A.A. From General Manager (GM)

A.A.A Through Interview (Appendix A, Ref. No. 9)

Q1. What are all the different activities that you do on typical working days?

Q2. What are the typical activities that you do?

Q3. This job comes from whom?

Q4. What are your other typical activities?

Q5. What are the company's vision, mission & objectives and how are you implementing them in the piping engineering design department?

Q6. How are you implementing the company's vision mission & objectives in our piping engineering design department?

Q7. What are all the different activities that you do less frequently or non-typically?

Q8. Why are these non-typical?

Q9. How frequently do you interact with your Boss?

Q10. Is it on a daily basis?

Q11. How many subordinates report to you?

Q12. What does your Subordinate report to you?

Q13. Who are the other people with whom you communicate to, apart from your Boss & immediate Subordinate?

Q14. You interact through which medium?

Q15. Why are you required to interact with them?

Q16. Do you interact with any other person apart from these?

Q17. What do you do to check the quality of your output?

Q18. What points you check for quality?

Q19. How frequently you do this, do you do this for every job?

Q20. Do you check it yourself?

Q21. What are the challenges that you face in your work?

Q22. Why are you not developing this?

Q23. But you told that these high-tech things are not even available on the internet or the manuals, only specific trainings can help.

Q24. So for this challenge of competency you are saying that improvement can be done by searching sincerely, do you see any other challenge apart from this?

Q25. Apart from these, is there any other area of concern?

Q26. What is causing this high attrition?

Q27. Although being a top Fortune 100 & world class company why can't "C" give unmatched world class opportunities to their engineers?

Q28. What do you feel can be done to mitigate this challenge of attrition?

Q29. Is there any other scope of improvement you see in our piping engineering design team?

A.A.B. Through Observation

Apart from what the GM has already talked about & explained during the interview, -

1. Is there anything else in addition/contradiction to what the GM said he does during his interview and if yes, then how/why?

2. What the GM does to work in the interest of the company & the country and how apart from what he already said?

3. What strategic plans & actions the GM takes for the development of his specific PEDM team at PDEC and how other than what he stated in the interview?

4. How does the GM actionate on the company's as well as the team's business goals and the management philosophy, when and why?

5. Does the GM approve pertinent resources & facilitate the engineers with the right exposure & learning opportunities and if yes, then how/when/why?

6. What does the GM typically express on the work quality and the performance of the team members?

7. What are the things that can improve the GM's job satisfaction and how?

8. Apart from what he already said, in what other ways and how does the GM lead/inspire the team members by example/words so as to boost present individual performance as well as future succession planning?

9. What are the areas or improvements that the GM observes in his team members and how can those be improved upon?

10. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

11. Can any objective areas of improvements be observed in GM's activities or his knowledge & skills and if yes what & how?

A.B. From Chief Manager (CM)

A.B.A Through Interview (Appendix A, Ref. No. 8)

Q1. What are all the different activities that you do on typical working days?

Q2. What are the typical activities that you do for this?

Q3. This job comes from whom?

Q4. What are all the different activities that you do less frequently or non-typically?

Q5. How frequently do you interact with your Boss?

Q6. Is it on a daily basis or any other?

Q7. How many Bosses you report to?

Q8. What does your Subordinate report to you & when?

Q9. Who are the other people with whom you communicate to, apart from your Boss?

Q10. You interact through which medium, through email, phone or any other?

Q11. Why are you required to interact with them, can you specify the exact activities?

Q12. Do you interact with any other person apart from these?

Q13. What do you do to check the quality of your output?

Q14. How frequently you do this, do you do this for every job?

Q15. Do you check it yourself or through some other person or any other?

Q16. What are the challenges or improvement areas that you see in your work?

Q17. Why are these trainings so indispensable?

Q18. This job-specific training challenge, what leads to this challenge?

Q19. How can this training challenge be improved?

Q20. What are the other areas of improvements you see? Can you please elaborate?

Q21. Can you please elaborate how this subjectivity & bureaucracy is challenging our development?

Q22. How can these challenges be overcome?

Q23. Apart from these, is there any other challenge or anything else that you would like to share?

A.B.B. Through Observation

Apart from what the CM has already talked about & explained during the interview, -

1. What other related PEDM activity does the CM do, how, when and why?

2. Does the CM do what he said he does during the interview and if yes/no, then how/why/when?

3. What, how & when does the CM do to facilitate resources, conditions and implementation logics?

4. Apart from what he already said, in what other ways and how does the GM lead/inspire the team members by example/words so as to boost present individual performance as well as future succession planning?

5. What are the things that can improve the CM’s job satisfaction and how?

6. What other PEDM related activities can be observed in the CM besides what he already said?

7. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

8. What does the CM typically express on the work quality and the performance of the team members?

9. What tactical plans & actions the CM takes for the development of his specific PEDM team at PDEC and how other than what he stated in the interview?

10. What are the areas or improvements that the CM observes in his peers/subordinates & senior and how can those be improved upon?

11. Can any objective areas of improvements be observed in CM's activities or his knowledge & skills and if yes what & how?

A.C. From Senior Manager (SM)

A.D.A Through Interview (Appendix A, Ref. No. 6)

Q1. What are all the different activities that you do on typical working days?

Q2. What are the activities that you do typically?

Q3. This job comes from whom?

Q4. What are all the different activities that you do less frequently or non-typically?

Q5. Why are these activities non-typical or less frequent?

Q6. How frequently do you interact with your Boss?

Q7. Is it on a daily basis or any other?

Q8. How many Bosses you report to?

Q9. What does your Subordinate report to you?

Q10. Who are the other people with whom you communicate to, apart from your Boss?

Q11. You interact through which medium, through email, phone or any other?

Q12. Do you interact with any other person apart from these?

Q13. You said you interact with the software vendors & other refineries, why are you required to interact with them…can you tell the exact activities?

Q14. What do you do to check the quality of your output?

Q15. You said you check the important things for checking the quality, how frequently you do this, do you do this for every job?

Q16. Do you check it yourself or through some other person or any other?

Q17. What are the challenges that you face in your work?

Q18. This job-specific training challenge, what leads to this challenge?

Q19. Why is it so?

Q20. What do you think, how can this challenge of job specific training, not all are given only some given by HR, how can this challenge be improved?

Q21. And this second challenge that you said that lack of refinery conceptions or ideas, how can that be improved?

Q22. Apart from this do you see anything else where there is a non-value adding activity or where we can improve upon?

Q23. Can you think of anything that is not adding value in our present job of piping design management in our team in “D”?

Q24. Do you think there is any other challenge where it can be improved upon in order to improve the design management in our team?

Q25. So that has already been started in “C”?

Q26. You mean online archival?

Q27. Apart from these, is there anything else that is challenging the improvement or any other?

A.C.B Through Interaction (Appendix A, Ref. No. 7)

Q1. Please elaborate on the challenges you feel or face in your work.

A.C.C Through Observation

Apart from what the SM has already talked about & explained during the interview and the interaction, -

1. What other related PEDM related actions do the SM take, how, when and why?

2. Does the SM do what he said he does during the interview and if yes/no, then how/why/when?

3. What does the SM typically express on the work quality and the performance of the team members?

4. What, how, when and why the SM does for implementation and feedback control of the PEDM instructions to and from his boss, Apart from what he already stated?

5. What operational plans & actions the SM takes for the development of his team members and how other than what he stated in the interview?

6. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

7. What are the things that can improve the SM's job satisfaction and how?

8. Can any objective areas of improvements be observed in SM's activities or his knowledge & skills and if yes what & how?

9. What are the areas or improvements that the SM observes in his peers/subordinates & seniors and how can those be improved upon?
10. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

A.D. From Lead Design Engineer (MLE)

A.D.A Through Interaction (Appendix A, Ref. No. 5)

1. What are all the different activities that you do on typical working days?

2. What are all the different activities that you do less frequently or are not typical?

3. Why & when are you required to do these less frequent activities?

4. Do you do any other relevant activity apart from what he said and if yes, then how/why?

5. How frequently do you interact with his Boss?

6. How many bosses do you report to?

7. What does your Subordinate report to you & when?

8. Who are the other people with whom you communicate to, apart from your Boss?

9. What, how, when and why do you do at your level for implementation and feedback control of the PEDM instructions to and from your boss?

10. What operational plans & actions do you take for the development of his team members and how?

11. What do you do to check the quality of his output?

12. How frequently do you do this?

13. Do you do this for all the designs/drawings/specifications he produces as well as for his reporting engineers' work?

14. How & to what breadth & depth do you check the quality?

15. What are the challenges that you face in his work?

16. Why do you regard these as challenges?

17. What do you do to counter these challenges & how?

18. What leads to these challenges?

19. Why are the causes of the challenges not removed or tackled?

20. What do you think needs to be done to overcome these challenges?

21. How do you think that those things will help overcome the challenges?

22. Apart from this, is there are any other challenges or ways to improve?

23. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

24. What does the peers & seniors typically express on your work quality and performance?

25. What are the areas or improvements that you observe or think in your peers/subordinates & seniors and how can those be improved upon?

26. What are the things that can improve your job satisfaction and how?

27. Do you observe any areas of improvements in your own activities or your knowledge & skills, like through self-appraisal and through the viewpoints of your peers/team members, and if yes what & how?

A.E. From Design Engineer 1 (DE1)

A.E.A Through Interview (Appendix A, Ref. No. 3)

Q1. What are all the different activities that you do on typical working days?

Q2. What are all the different activities that you do less frequently or are not typical?

Q3. Why & when are you required to do these less frequent activities?

Q4. How frequently do you interact with your Boss?

Q5. How many bosses you report to?

Q6. What does your Subordinate report to you & when?

Q7. Who are the other people with whom you communicate to, apart from your Boss?

Q8. What do you do to check the quality of your output?

Q9. How frequently you do this?

Q10. Do you do this for all the drawings you produce?

Q11. How do you decide which ones are complex?

Q12. What are the challenges that you face in your work?

Q13. Why do you regard these as challenges?

Q14. What do you do to counter these challenges?

Q15. Does it mean that you tell me & I turn it down?

Q16. What leads to these challenges?

Q17. Why are the causes of the challenges not removed or tackled?

Q18. What do you think will help you to overcome these challenges?

Q19. How do you think it will help?

Q20. Apart from this, do you feel there are any other challenges or ways to improve?

A.E.B Through Observation

1. Does DE1 carry out the activities as he said he does during his interview?

2. Does DE1 do any other relevant activity apart from what he said and if yes, then how/why?

3. Can any objective areas of improvements be observed in DE1's activities or his knowledge & skills and if yes what & how?

4. What are the areas or improvements that the DE1 observes in his peer & seniors and how can those be improved upon?

5. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

6. What are the things that can improve the DE1's job satisfaction and how?

A.F. From Design Engineer 2 (DE2)

A.F.A Through Interview (Appendix A, Ref. No. 4)

Q1. What are all the different activities that you do on typical working days?

Q2. What are all the different activities that you do less frequently or are not typical or irregular?

Q3. Why & when are you required to do these less frequent activities like you said scanning, photocopying etc.?

Q4. You do scanning of what documents?

Q5. Who gives you these non-regular work?

Q6. In your regular work which you said is making drawings from sketches, do these irregular work come in between your regular work?

Q7. How frequently do you interact with your Boss?

Q8. You said you prepare the drawings from the sketches, now do these sketches & regular work given to you by your immediate boss, do these come through him?

Q9. And remaining irregular work like you said medical bill, etc. copying, scanning, etc. works are given to you when you are free?

Q10. How many Bosses do you have & report to?

Q11. You interact with your bosses like MLE, why do you interact with him, for what for?

Q12. For anything other than this?

Q13. Do you have any Subordinate?

Q14. Who are the other people with whom you communicate to, apart from your Boss?

Q15. Do you interact with any other person?

Q16. What do you do to check the quality of your output?

Q17. Your Sir means whom, whom do you show?

Q18. In the 1st stage only you check it?

Q19. Do you check fully 100%?

Q20. What are the challenges that you face in your work?

Q21. In your work of design management, do you feel anything is lacking or there is any scope of improvement anywhere?

Q22. Why do you consider this as a challenge?

Q23. What do you do to counter these challenges & actualize it?

Q24. So this PDMS is an area of improvement?

Q25. Do you see any other challenge apart from this?

Q26. What do you think, why does the management not encourage innovation?

Q27. Management does not give any encouragement to any new idea or way which is an innovative one?

Q28. How do you feel this situation can be improved?

Q29. So, like what you are saying, if innovation is properly considered with proper feedback & after analysis if it is seen that something better can be achieved then it will be implemented, how will that benefit?

Q30. Apart from this, do you see any other non-value adding activity or something that does not add any value or hold any meaning or some area of improvement in the existing piping design practices, you have said PDMS & innovation management, apart from these you feel anything else?

Q31. So the main challenges that you said are one PDMS & second innovation management, is there any other?

A.F.B Through Observation

1. Does DE2 carry out the activities as he said he does during his interview?

2. Does DE2 do any other relevant activity apart from what he said and if yes, then how/why?

3. Can any objective areas of improvements be observed in DE1's activities or his knowledge & skills and if yes what & how?

4. What are the areas or improvements that the DE2 observes in his peer & seniors and how can those be improved upon?

5. What can be done to increase the design management process efficiency and ensure continuous improvement of the PEDM cycle?

6. What are the things that can improve the DE2's job satisfaction and how?

B. ANCILLARY SECONDARY DATA

The following Ancillary Secondary Data have been collected by the researcher during this data collection phase & used where appropriate in this study:

(i) "D" Presentation (Appendix A, Ref. No. 1): This has been pertinently used with due reference in this study (for e.g. Section 4.1.6, Figure 4.2, etc.)

(ii) "D" Organogram (Appendix A, Ref. No. 2): This has been pertinently used with due reference in this study (for e.g. Section 4.1.6, Figure 4.3, etc.).

A.G. General Screening Questions (2nd Stage of Sample Selection)

A.G.A Through Interview (Appendix A, Ref. No. 10)

Q1. We are doing a research on improving piping engineering design management, may I please have a few minutes of your precious time that will go a long way in improving our company & country's future?

Q2. If not now, then please give me appointment so that you can comfortably speak to me for a few minutes?

Q3. Are you in any direct/indirect way involved in piping engineering design and its management?

Q4. Can you please elaborate your associations with piping engineering design?

Q5. What activities you are required to do in piping engineering design management?

Q6. How do you execute those activities of piping engineering design management?

Q7. From your experience what all things do you think can be improved in the ways piping engineering design is managed as of now?

Q8. How or in what ways can your suggestions improve the present practices of piping engineering design management?

Q9. How do you think a model can be developed to effectively & efficiently manage piping engineering design?

Q10. In case your answers are negative, can you please think of something related to this subject or anything that you think shall improve the way piping engineering design is being managed today?

Appendix C: Analysis Codes, Sub-Codes, Networks and Families

Few Codes & Sub-Codes – Operational Definitions & In-Action Glimpses

Work: This is one of the Codes. This Code comprises of two Sub-Codes Work:Typical & Work:Non-Typical. This Code is used to codify descriptions of these 2 types of work.

Work:Typical:: This is one of the Sub-Codes of the Code Work. This Sub-Code is used to codify descriptions of typical work.

Work:Non-Typical:: This is one of the Sub-Codes of the Code Work. This Sub-Code is used to codify descriptions of non-typical work.

Interaction: This is one of the Codes. This Code comprises of three Sub-Codes Interaction:Boss, Interaction:Subordinate & Interaction:Other. This Code is used to codify descriptions of these three types of interactions.

Interaction:Boss:: This is one of the Sub-Codes of the Code Interaction. This Sub-Code is used to codify descriptions of interactions between the respondent & his boss.

Interaction:Subordinate:: This is one of the Sub-Codes of the Code Interaction. This Sub-Code is used to codify descriptions of interactions between the respondent & his subordinate.

Interaction:Others:: This is one of the Sub-Codes of the Code Interaction. This Sub-Code is used to codify descriptions of interactions between the respondent and people other than his boss & subordinate.

Quality: This is one of the Codes. This Code comprises of three Sub-Codes Quality:Process, Quality:Depth & Quality:Breadth. This Code is used to codify descriptions of these 3 aspects of quality.

Quality:Process:: This is one of the Sub-Codes of the Code Quality. This Sub-Code is used to codify descriptions of the quality check process practised by the individual respondents.

Quality:Depth:: This is one of the Sub-Codes of the Code Quality. This Sub-Code is used to codify descriptions of quality check in terms of the elements inside each work output (technical aspects in drawings/documents, etc.) checked in a particular lot of multiple outputs i.e. intra-output checking.

Quality:Breadth:: This is one of the Sub-Codes of the Code Quality. This Sub-Code is used to codify descriptions of quality check in terms of the numbers of work output (drawings/documents, etc.) checked in a particular lot of multiple outputs i.e. inter-output checking.

Challenges: This is one of the Codes. This Code comprises of five Sub-Codes Challenges:Elements, Challenges:Basis, Challenges:Countering, Challenges:Barriers & Challenges:Elimination. This Code is used to codify descriptions of these five aspects of challenges.

Challenges:Elements:: This is one of the Sub-Codes of the Code Challenges. This Sub-Code is used to codify the basic elements of the challenges identified by the respondent.

Challenges:Basis:: This is one of the Sub-Codes of the Code Challenges. This Sub-Code is used to codify the basis why the particular elements are regarded as challenges by the respondent.

Challenges:Countering:: This is one of the Sub-Codes of the Code Challenges. This Sub-Code is used to codify the description of any action that the respondent has taken/or is going to take in order to counter/mitigate the challenging elements.

Challenges:Barriers:: This is one of the three Sub-Codes of the Code Challenges. This Sub-Code is used to codify the description of the causes preventing the removal of the challenging elements.

Challenges:Elimination:: This is one of the three Sub-Codes of the Code Challenges. This Sub-Code is used to codify the description of the possible remedial measures of the challenging elements.

Codes, Sub-Codes, Networks & Families – In-Action Glimpses

Figure C-1: One of the Codes: Work and its two Sub-Codes Work:Typical & Work:Non-Typical

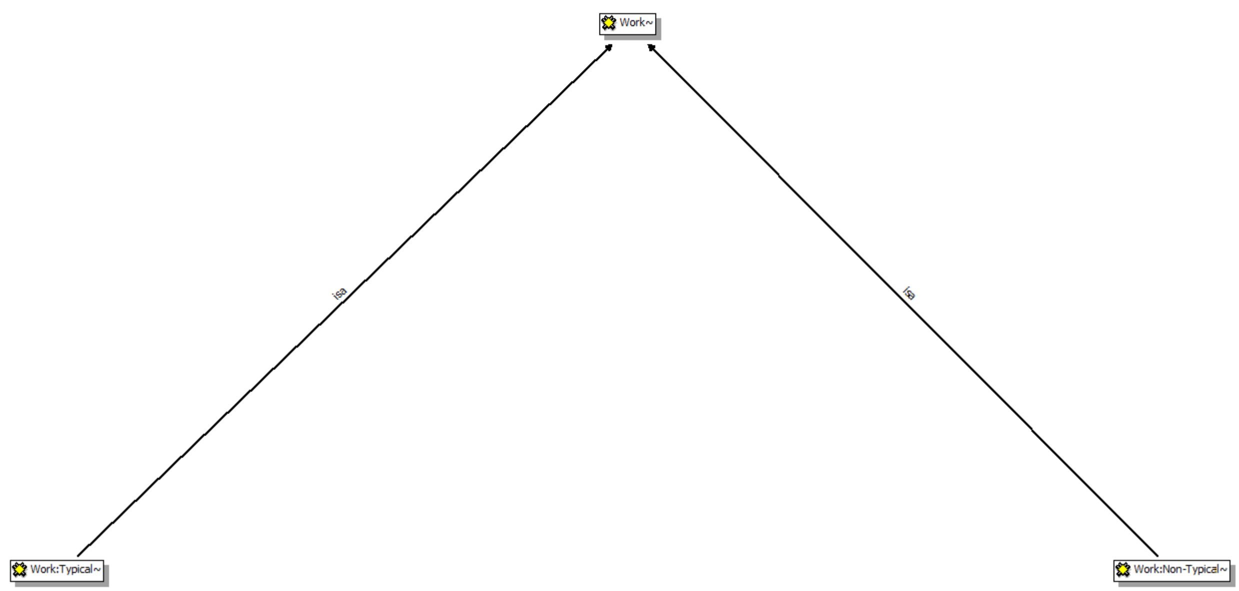


Figure C-2: One of the Codes: Work and its one Sub-Code Work:Typical with its Relevant Neighbours

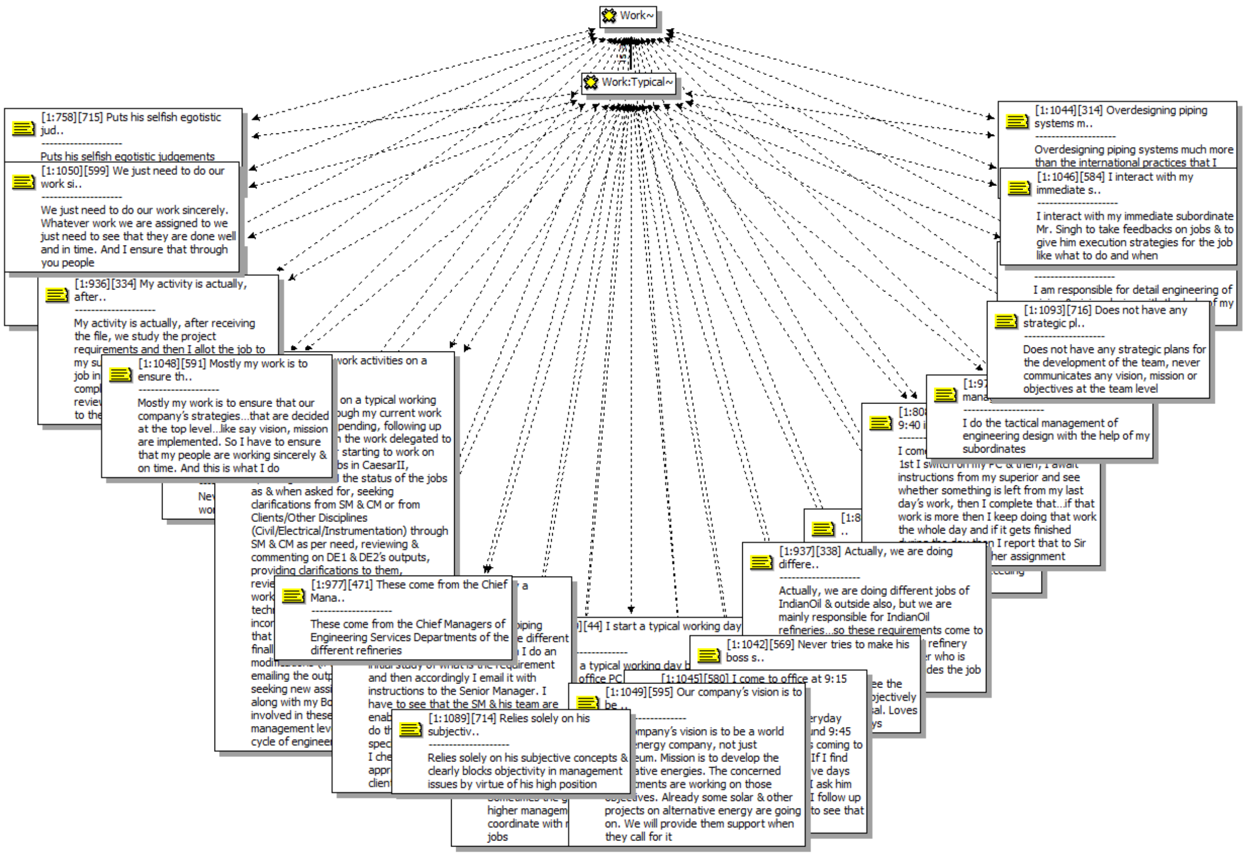


Figure C-3: One of the Codes: Work and its one Sub-Code Work:Non-Typical with its Relevant Neighbours

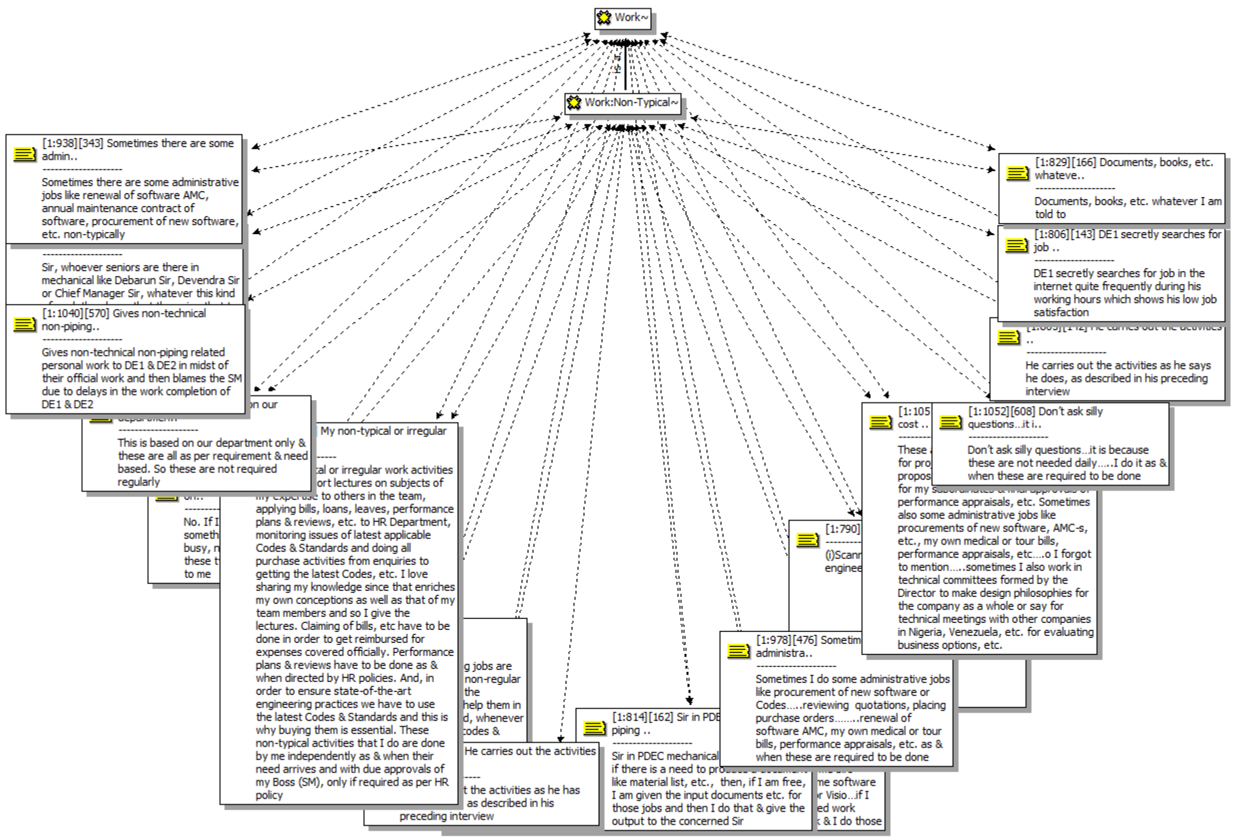


Figure C-4: One of the Codes: Interaction and its three Sub-Codes Interaction:Boss, Interaction:Subordinate & Interaction:Others

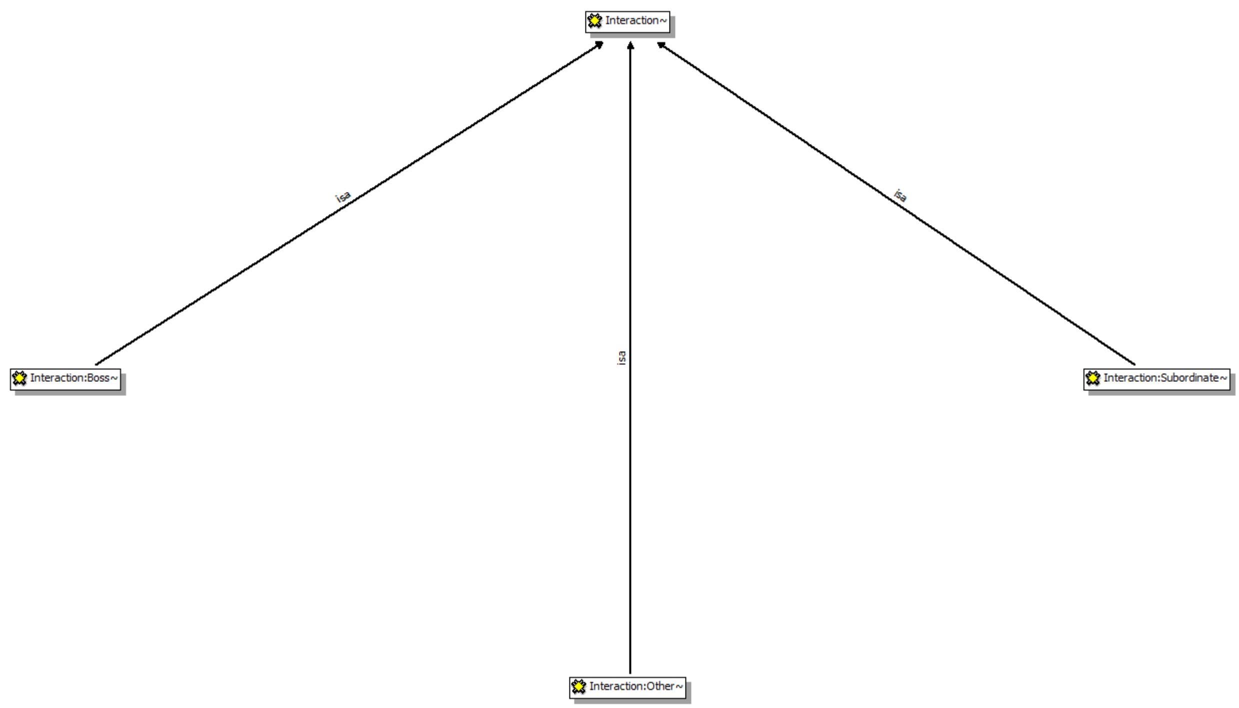


Figure C-5: One of the Codes: Interaction and its one Sub-Code Interaction:Boss with its Relevant Neighbours

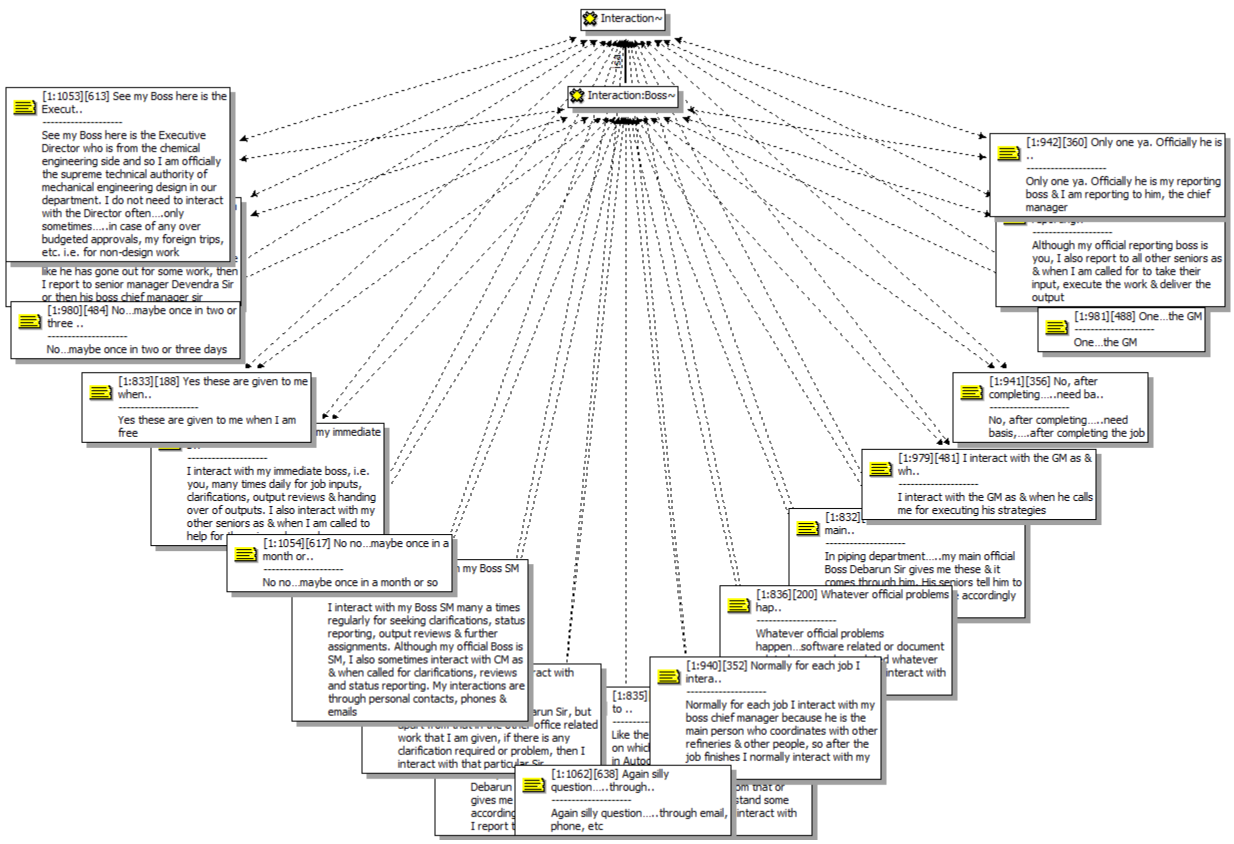


Figure C-6: One of the Codes: Interaction and its one Sub-Code Interaction:Subordinate with its Relevant Neighbours

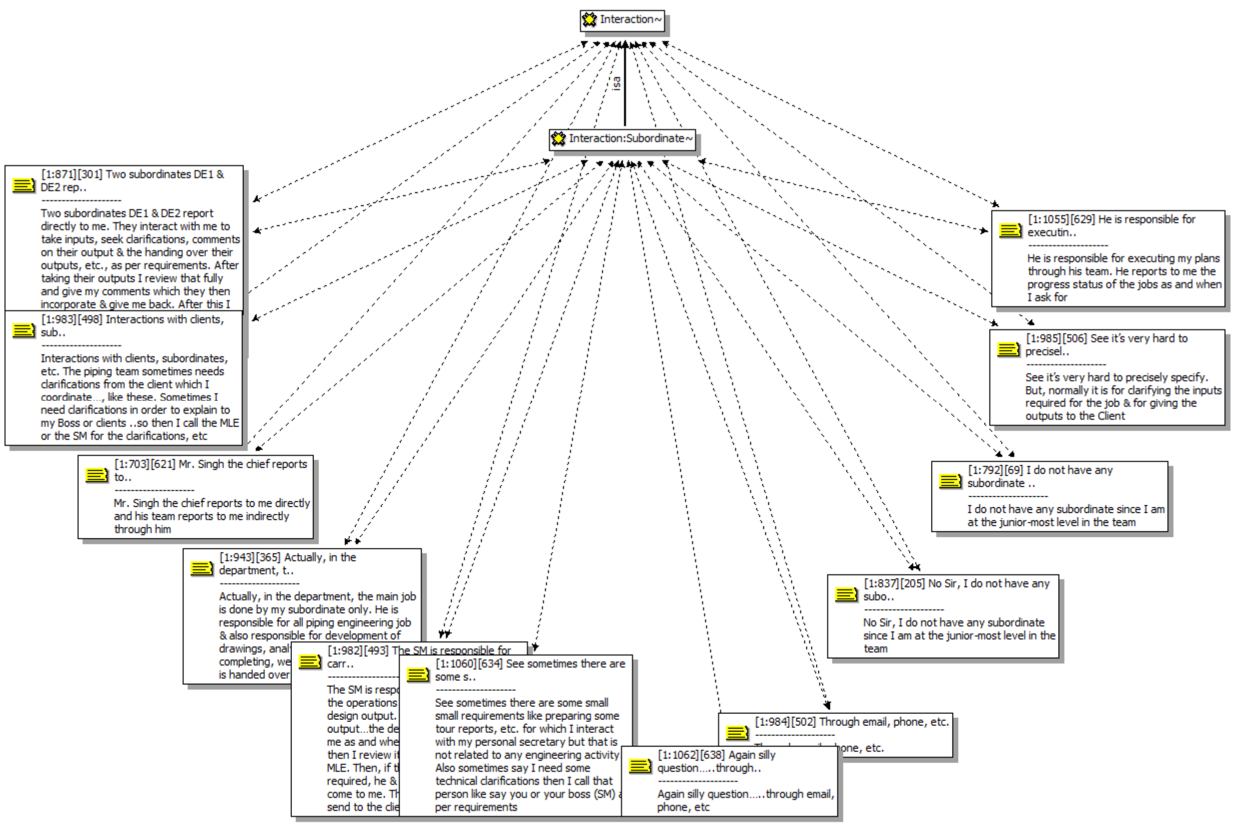


Figure C-7: One of the Codes: Interaction and its one Sub-Code Interaction:Others with its Relevant Neighbours

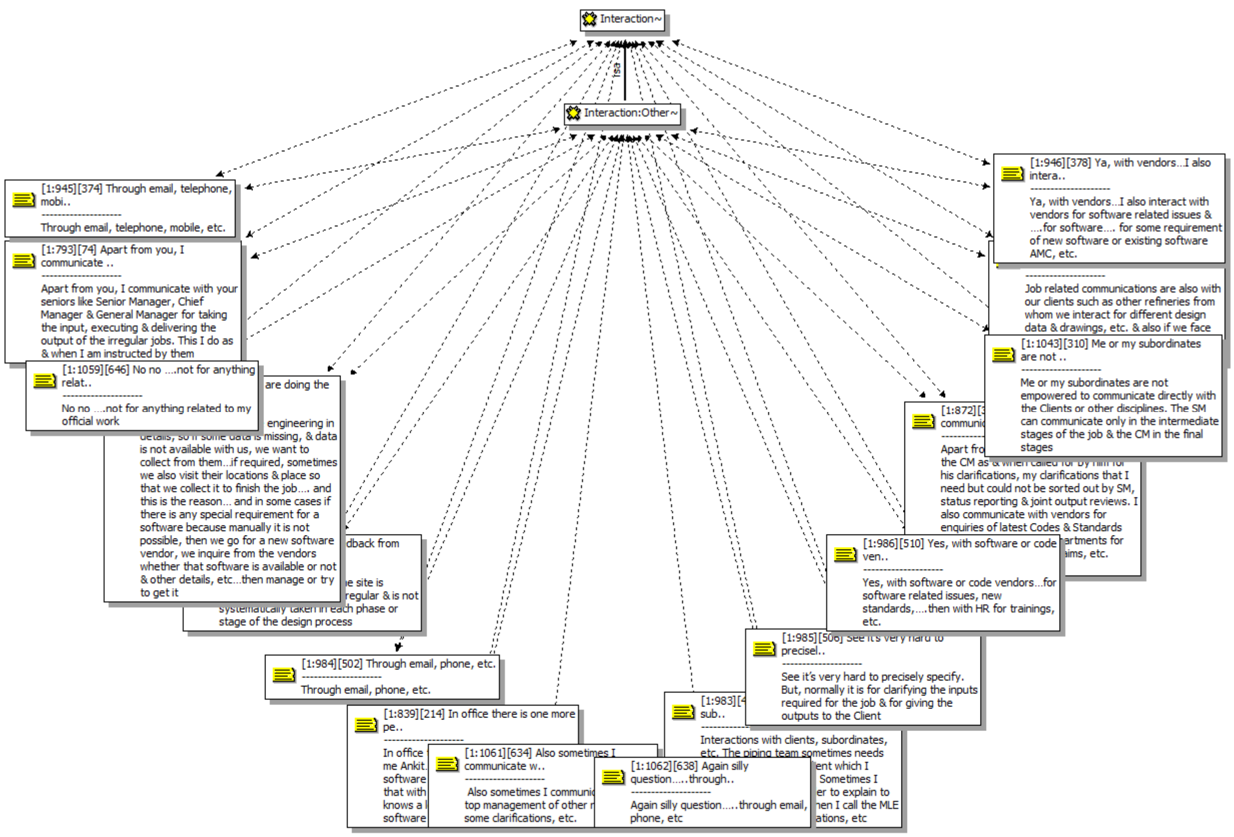


Figure C-8: One of the Codes: Quality and its three Sub-Codes Quality:Process, Quality:Depth & Quality:Breadth

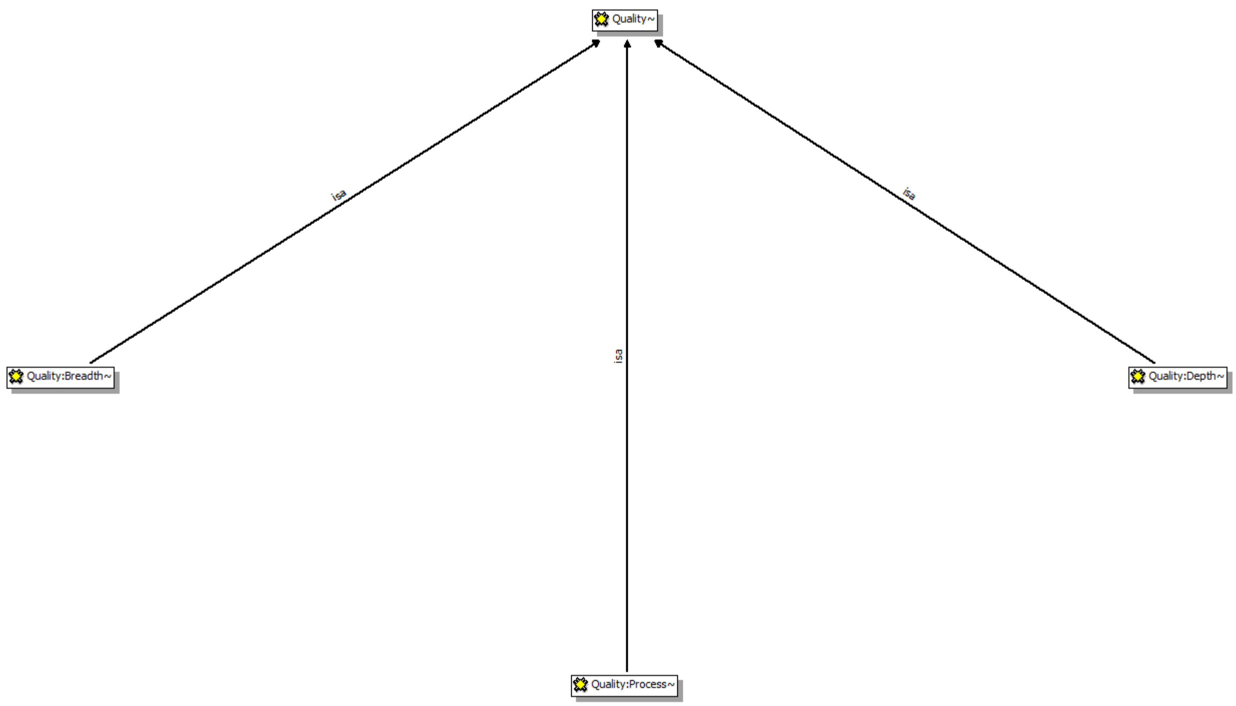


Figure C-9: One of the Codes: Quality and its one Sub-Code Quality:Process with its Relevant Neighbours

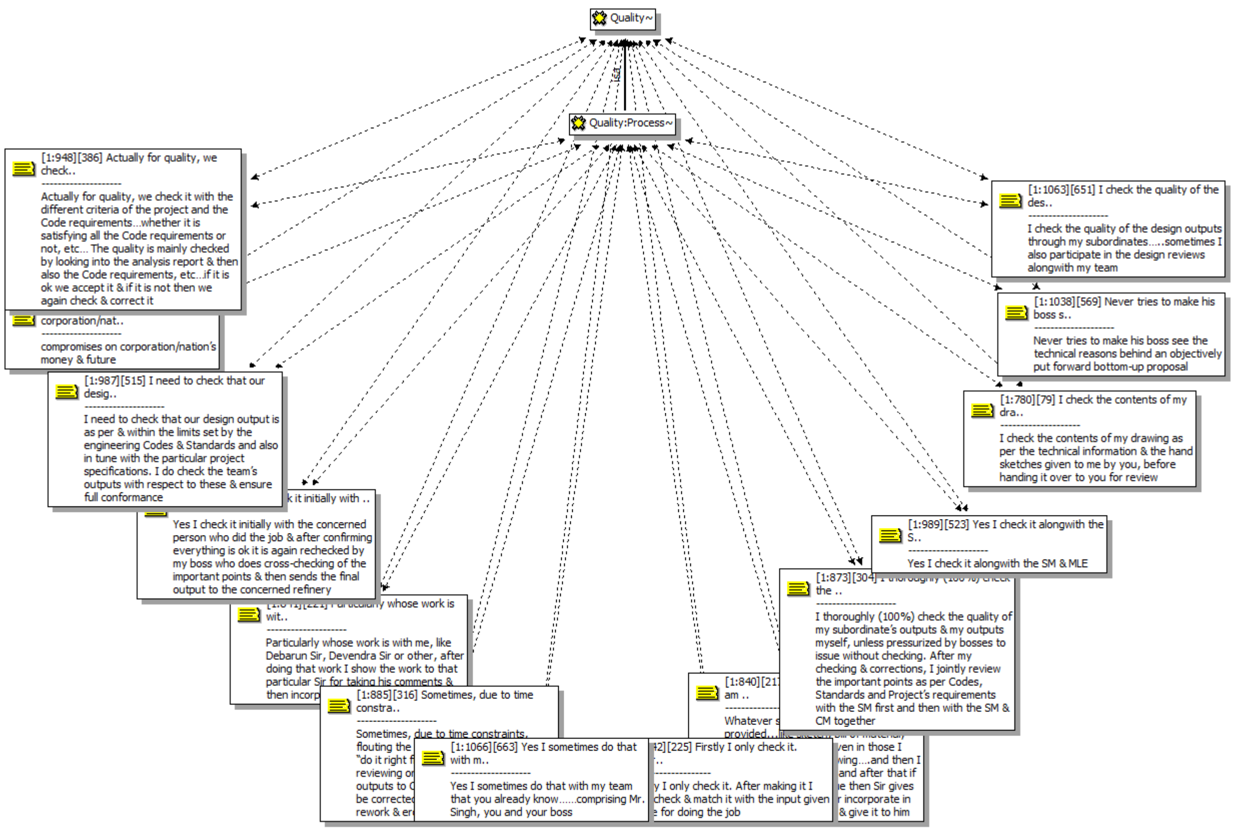


Figure C-10: One of the Codes: Quality and its one Sub-Code Quality:Depth with its Relevant Neighbours

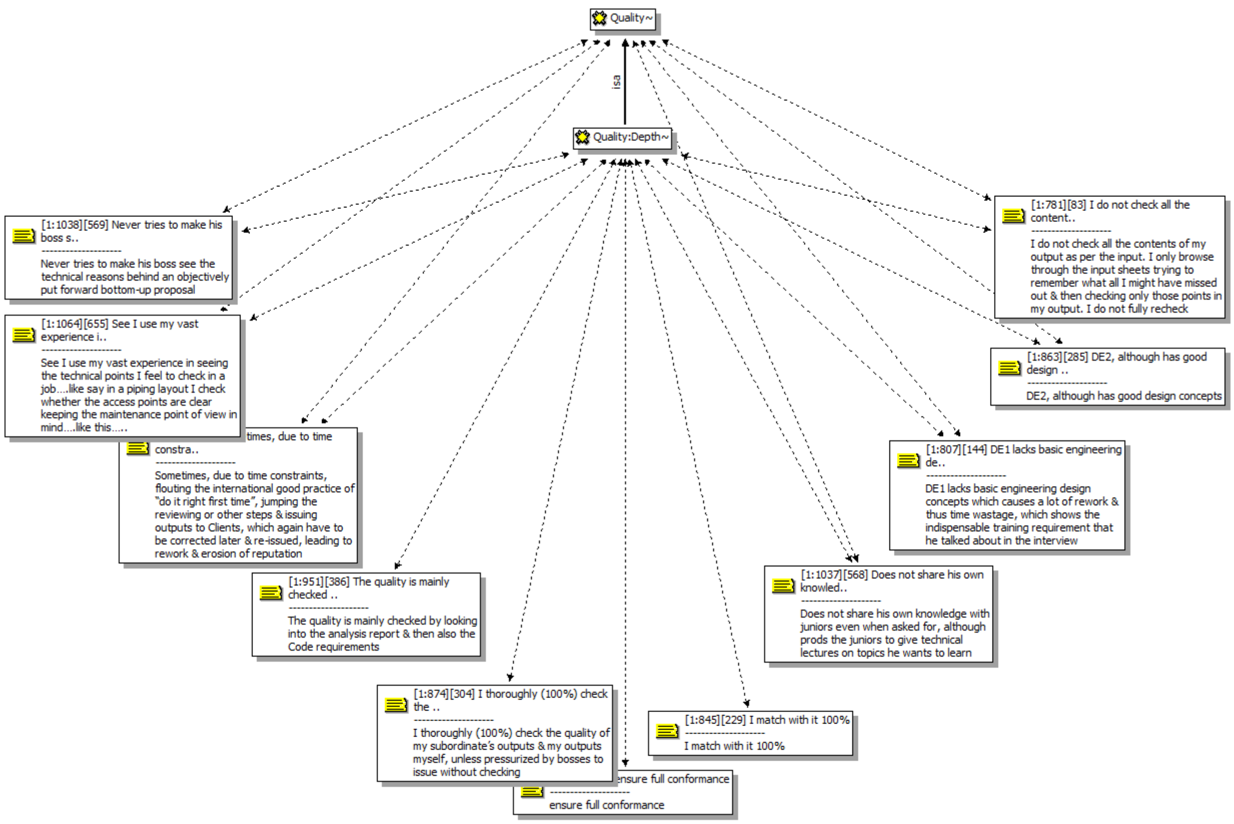


Figure C-11: One of the Codes: Quality and its one Sub-Code Quality:Breadth with its Relevant Neighbours

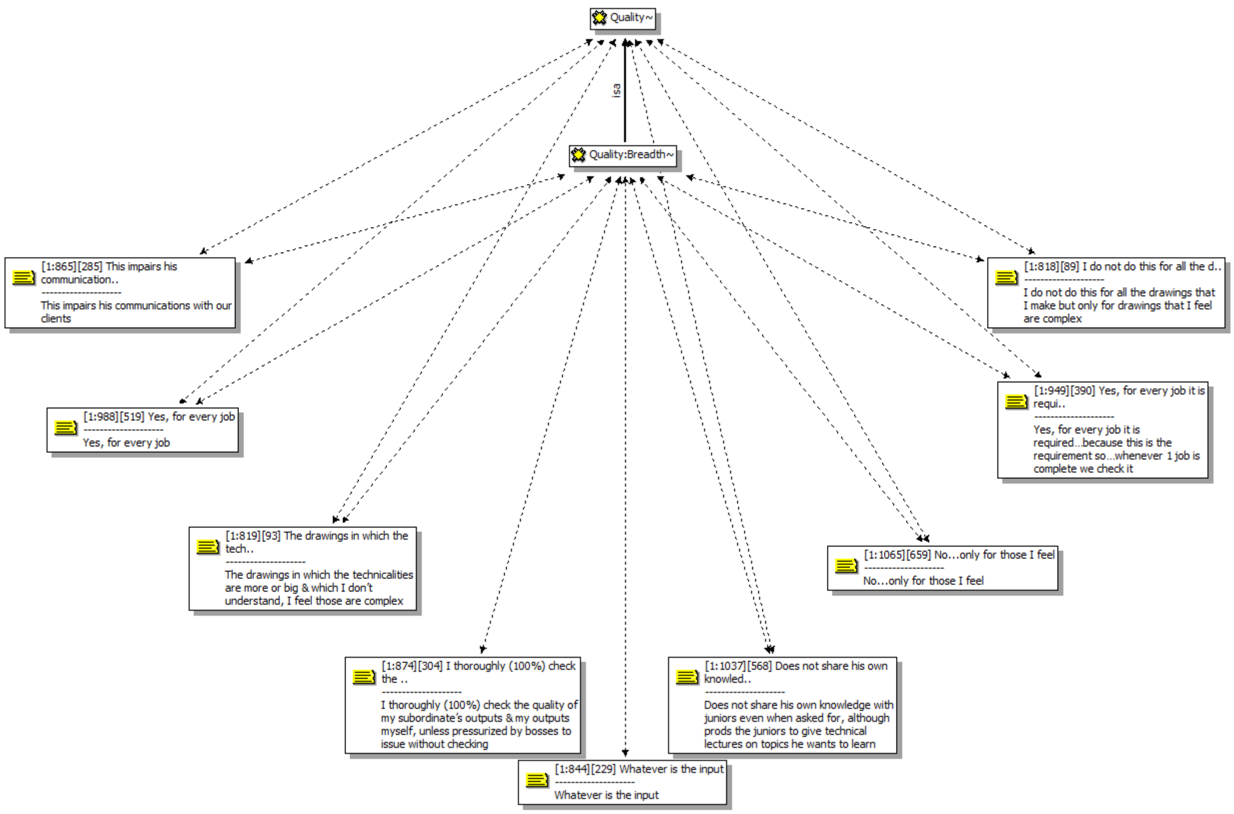


Figure C-12: One of the Codes: Challenges and its five Sub-Codes Challenges:Elements, Challenges:Basis, Challenges:Countering, Challenges: Barriers, Challenges:Elimination

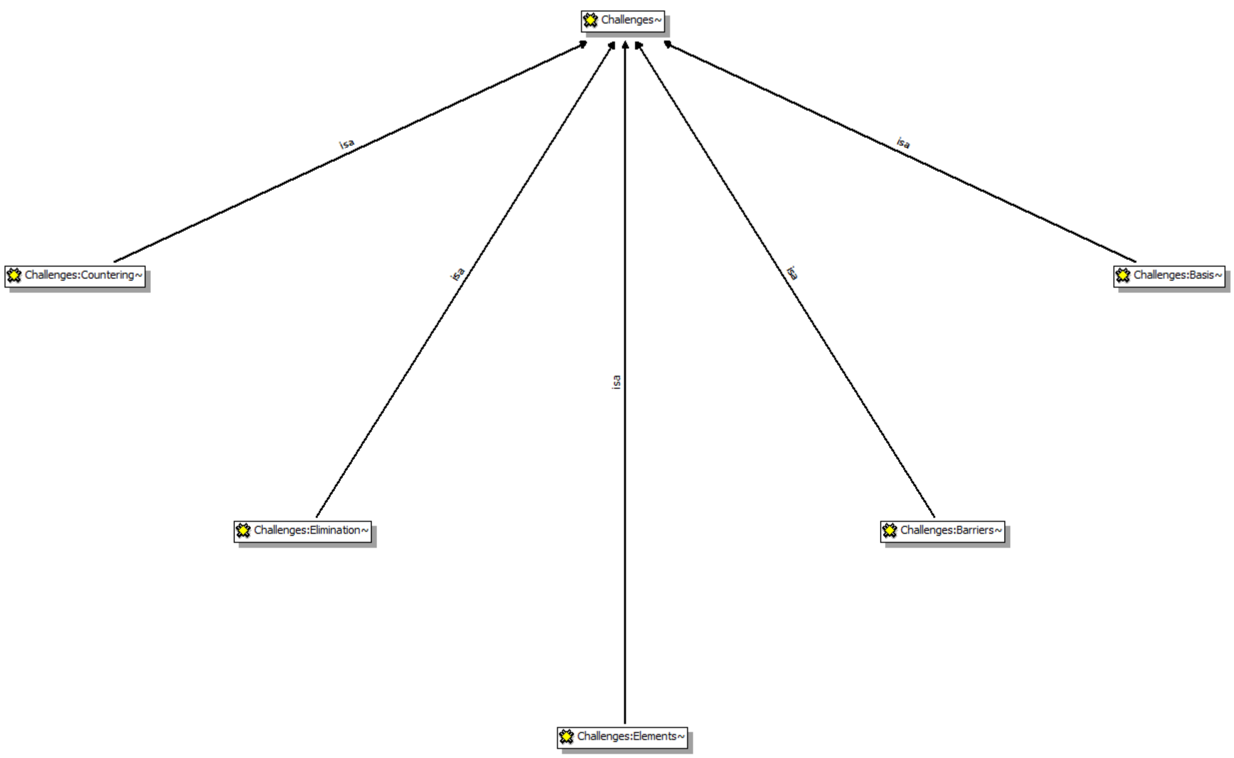


Figure C-13: One of the Codes: Challenges and its one Sub-Code Challenges:Elements with its Relevant Neighbours

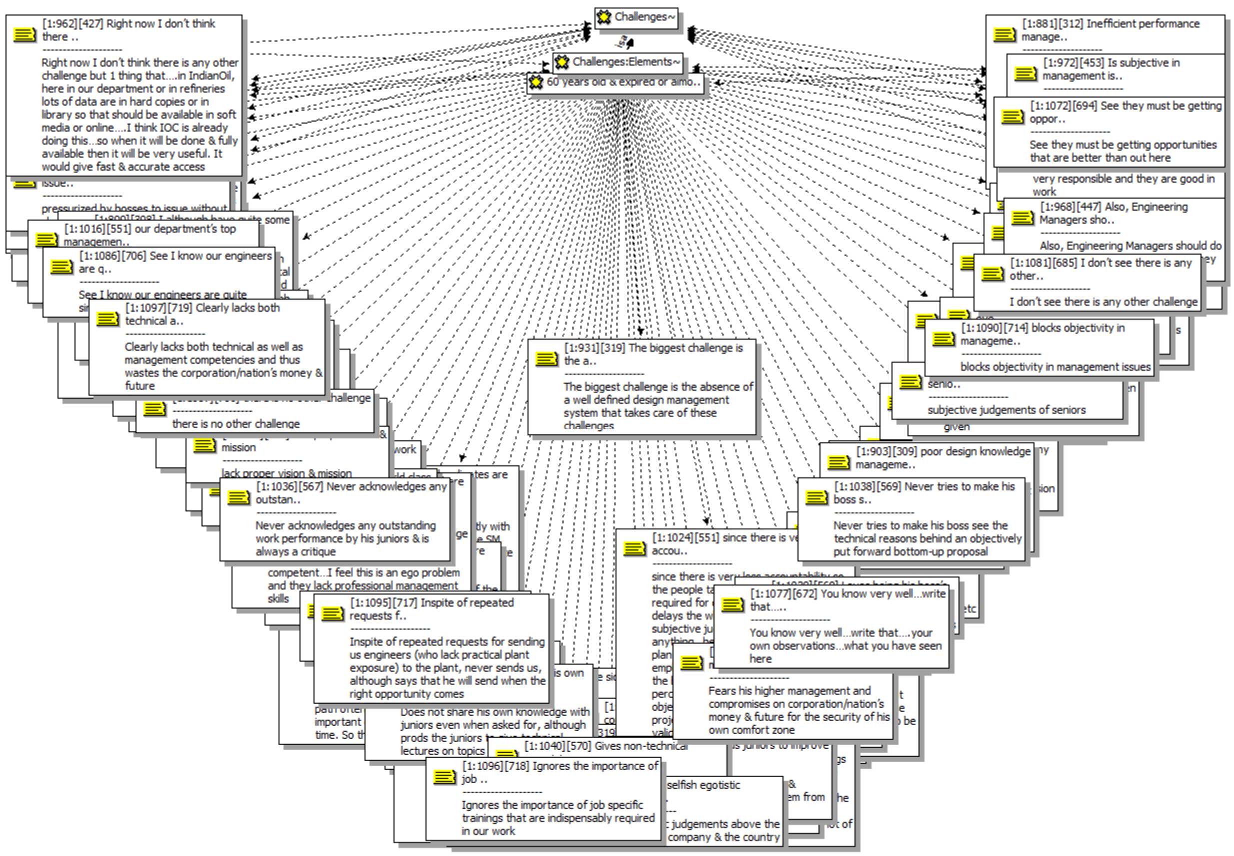


Figure C-14: One of the Codes: Challenges and its one Sub-Code Challenges:Basis with its Relevant Neighbours

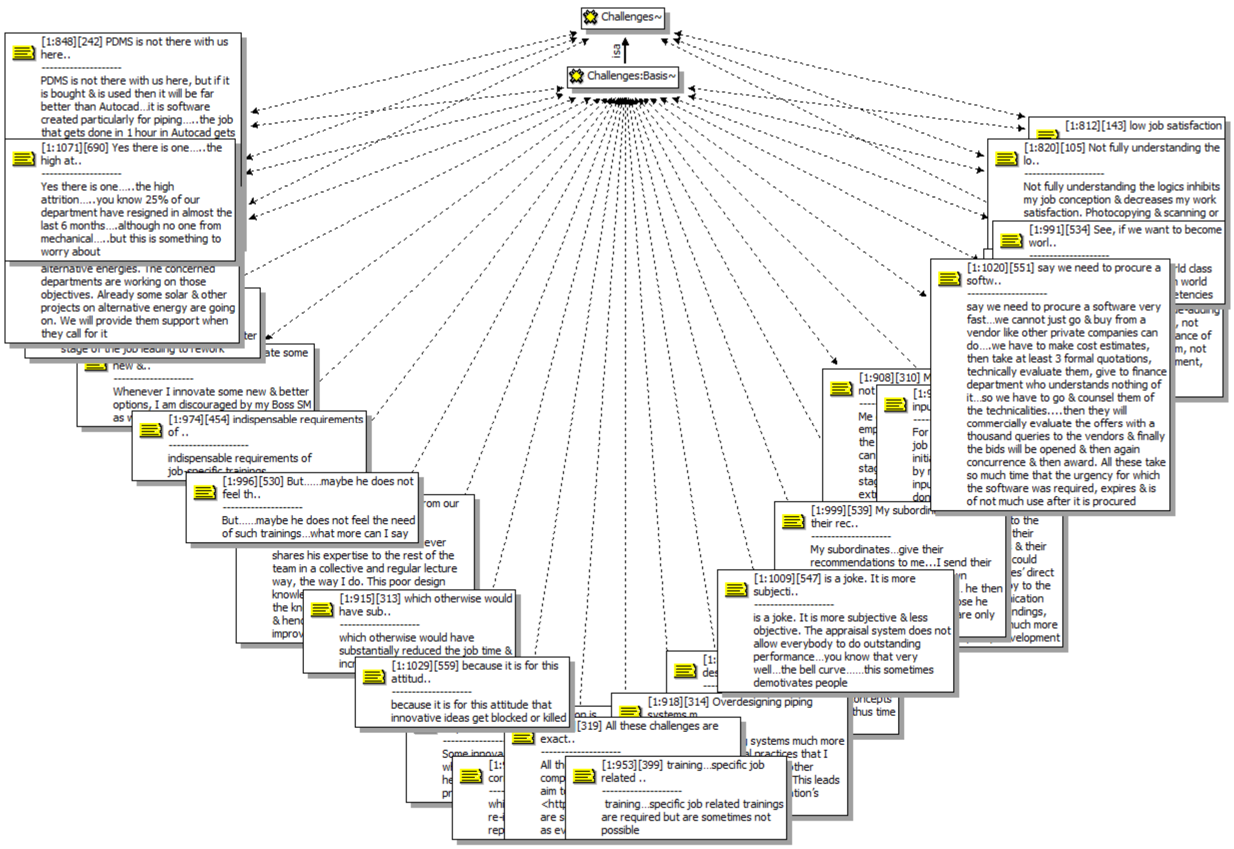


Figure C-5: One of the Codes: Challenges and its one Sub-Code Challenges:Countering with its Relevant Neighbours

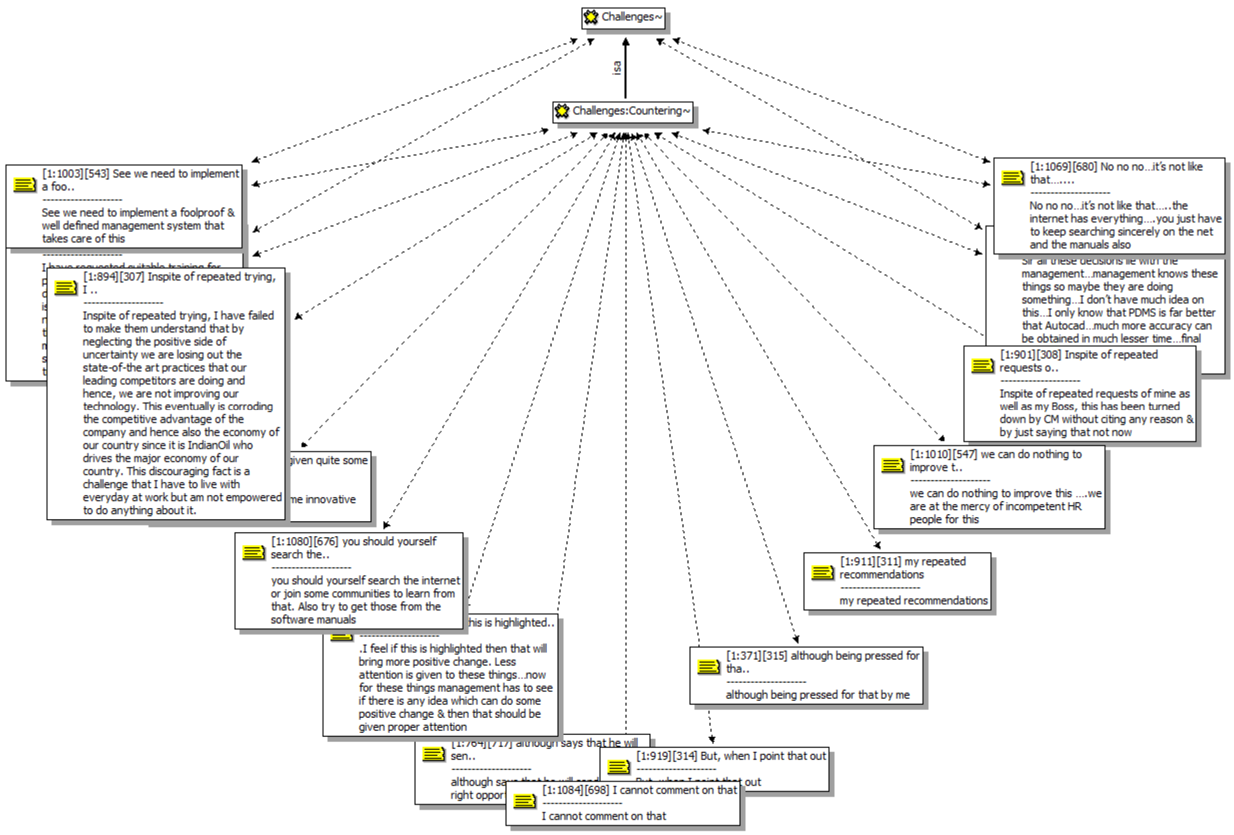


Figure C-16: One of the Codes: Challenges and its one Sub-Code Challenges:Barriers with its Relevant Neighbours

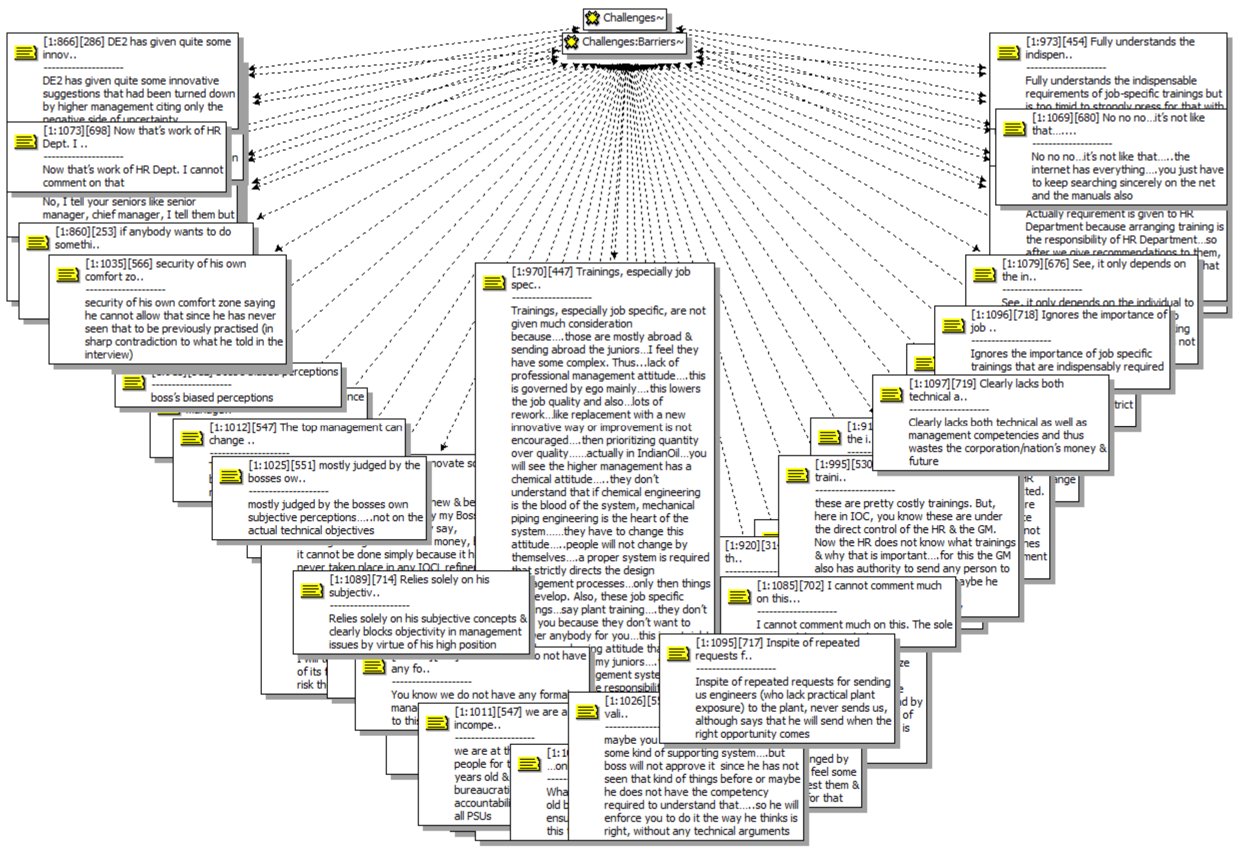


Figure C-17: One of the Codes: Challenges and its one Sub-Code Challenges:Elimination with its Relevant Neighbours

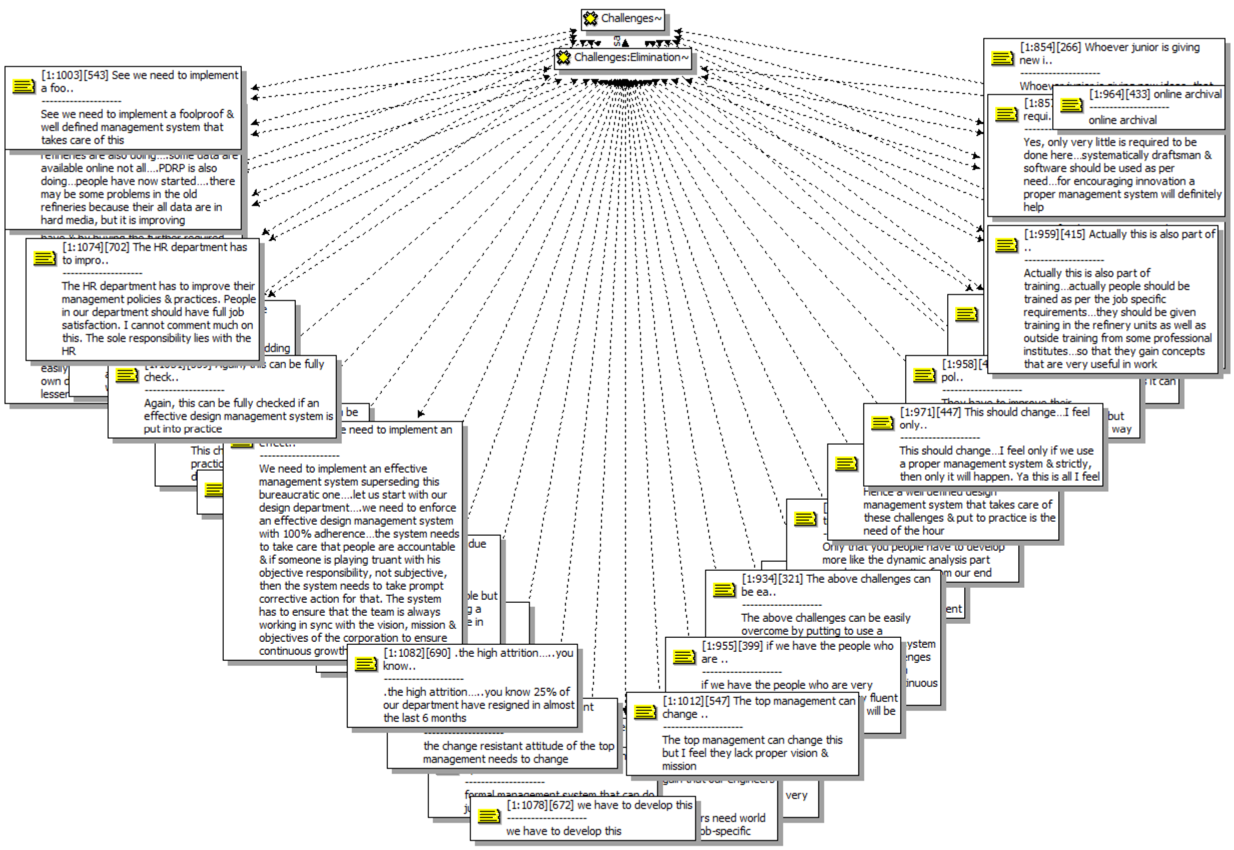


Figure C-18: The Overall Network of Code Family comprising Few Codes & Sub-Codes

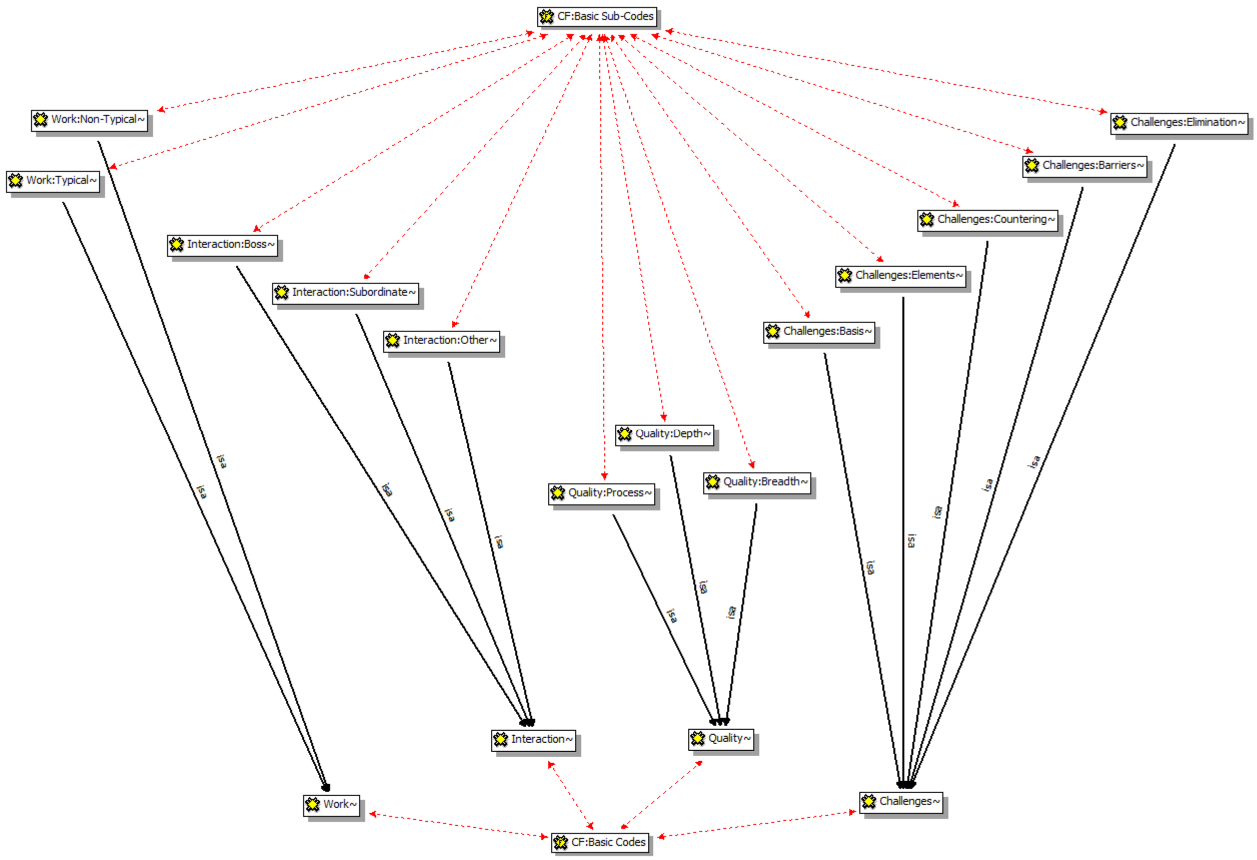


Figure C-19: The Code Family of Few Codes

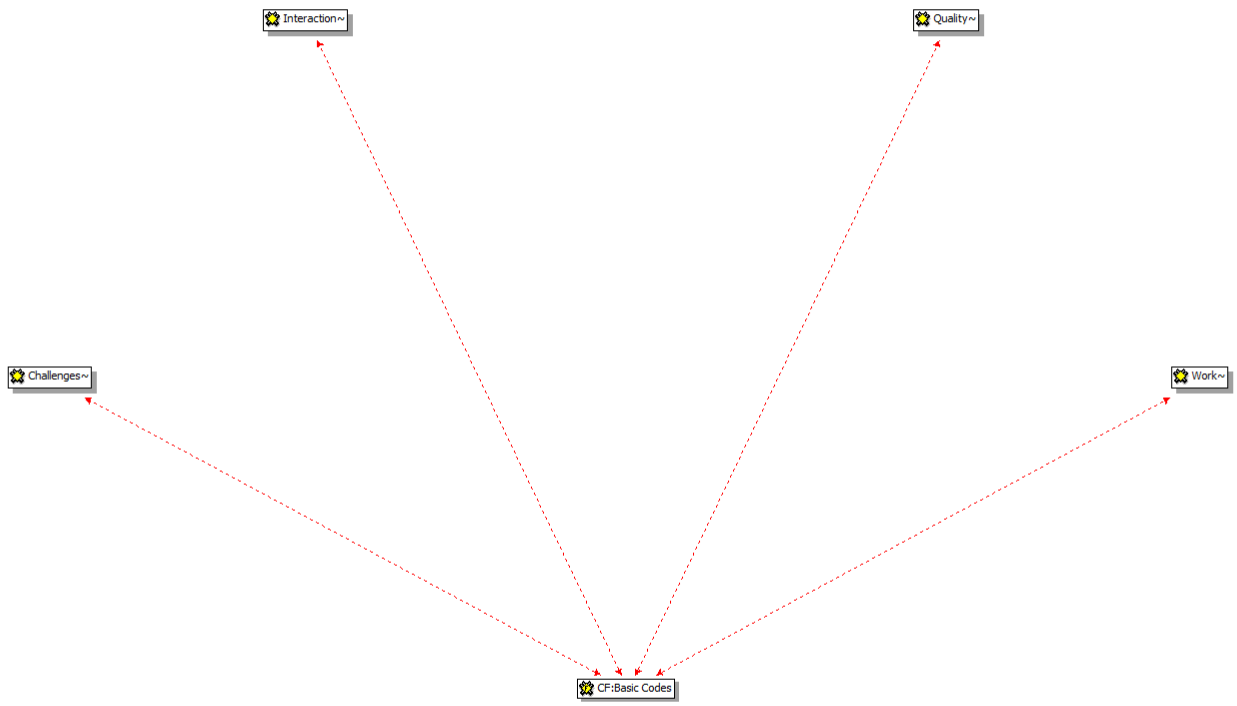


Figure C-20: The Code Family of Few Sub-Codes

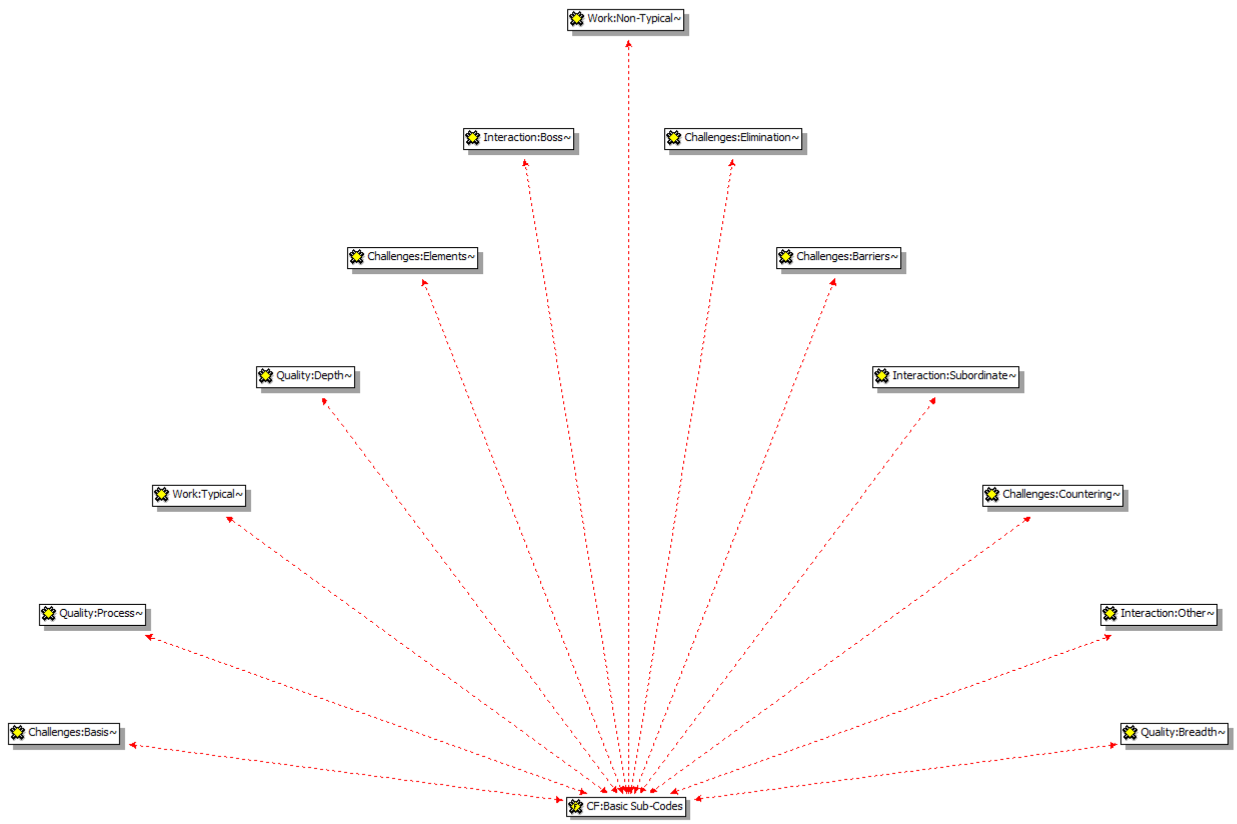


Figure C-21: The Code Family of From::GM::Interview

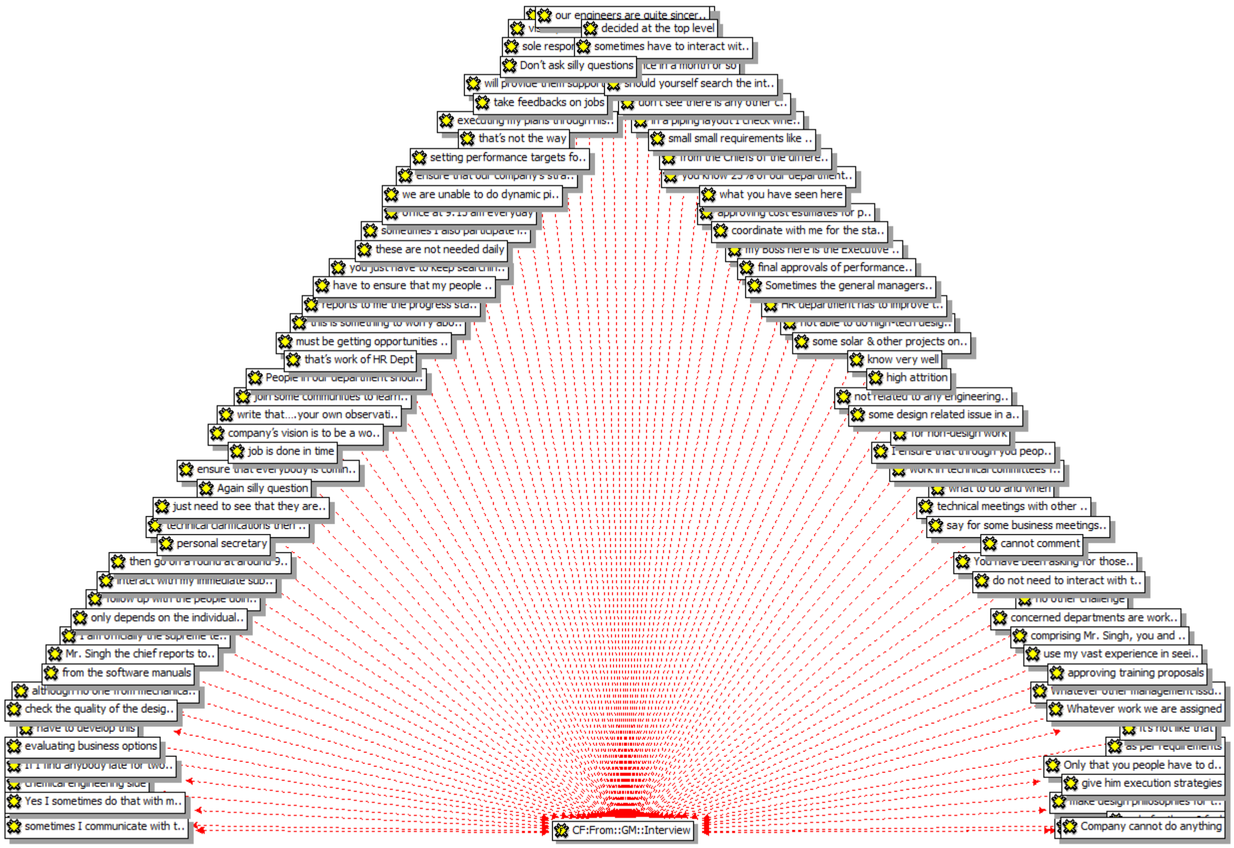


Figure C-22: The Code Family of From::GM::Observation

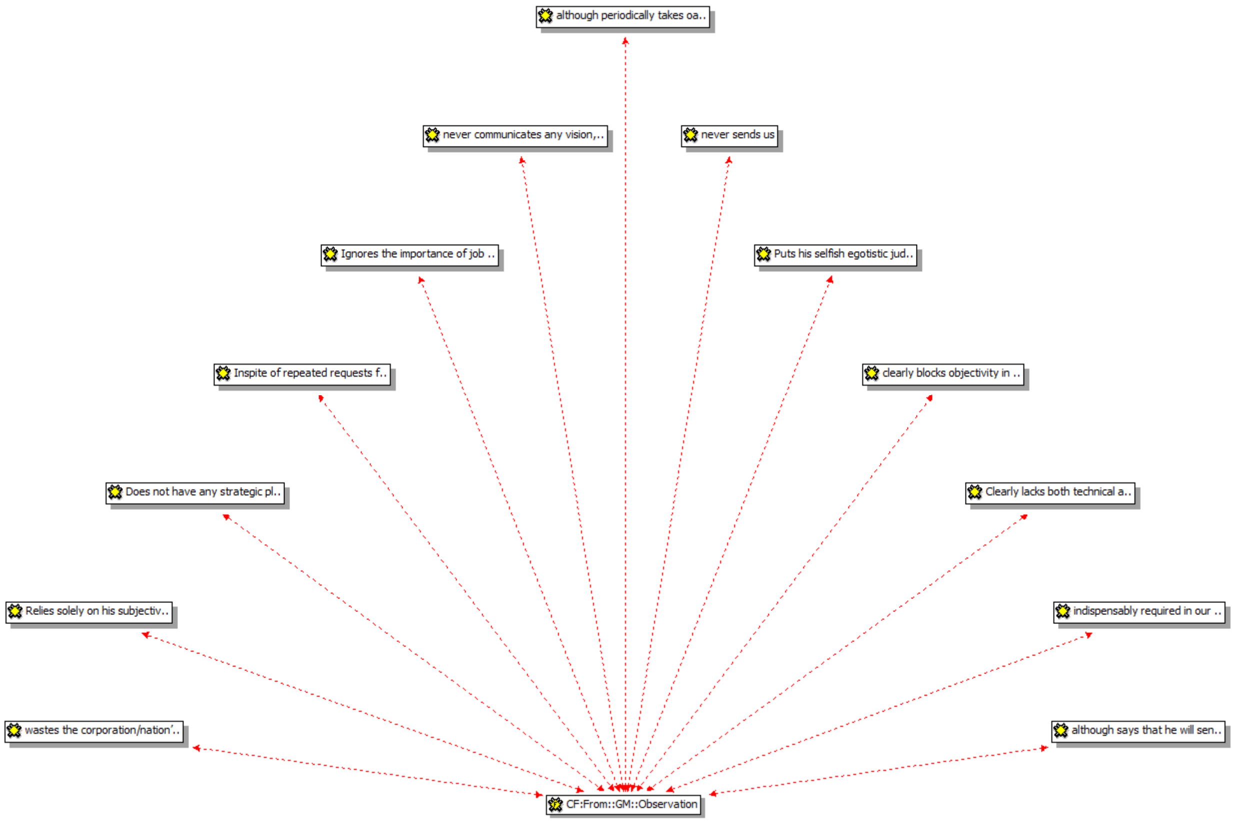


Figure C-23: The Code Family of From::CM::Interview

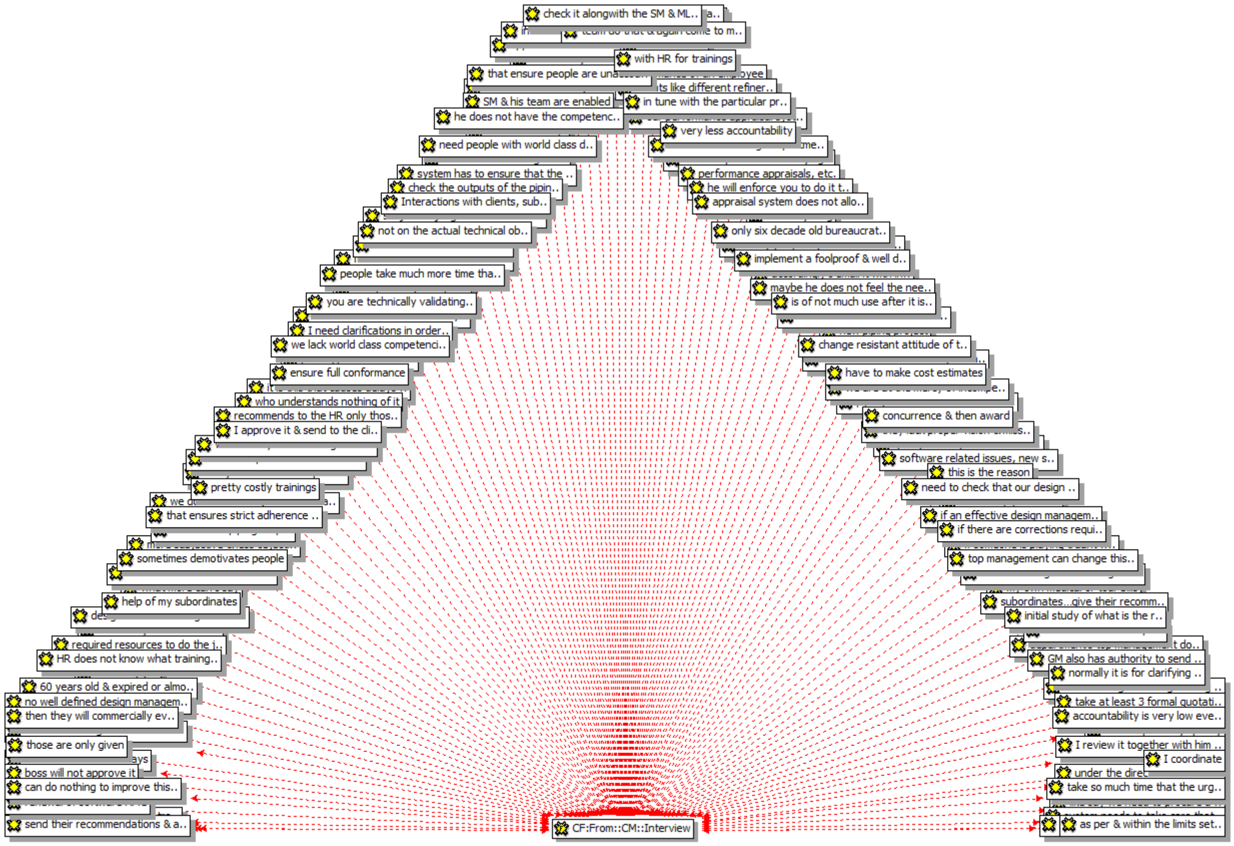


Figure C-24: The Code Family of From::CM::Observation

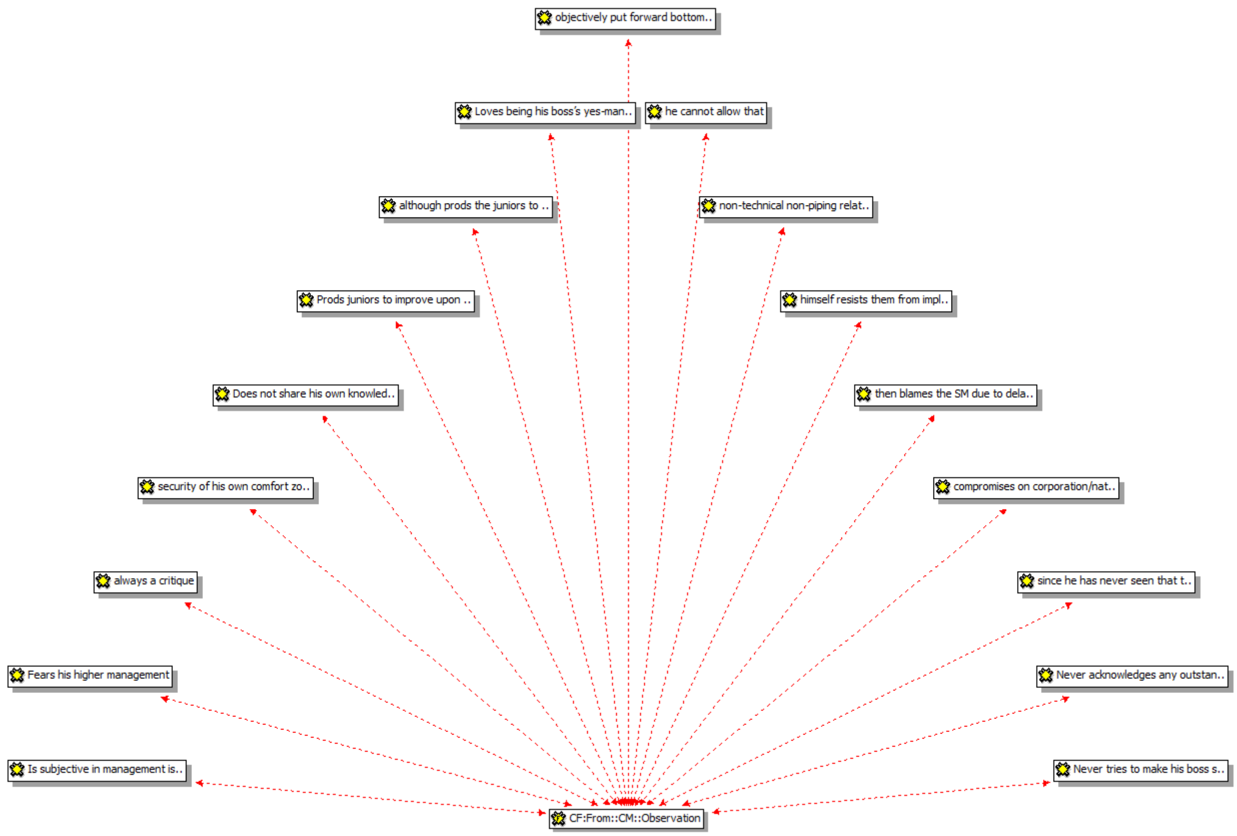


Figure C-25: The Code Family of From::SM::Interview

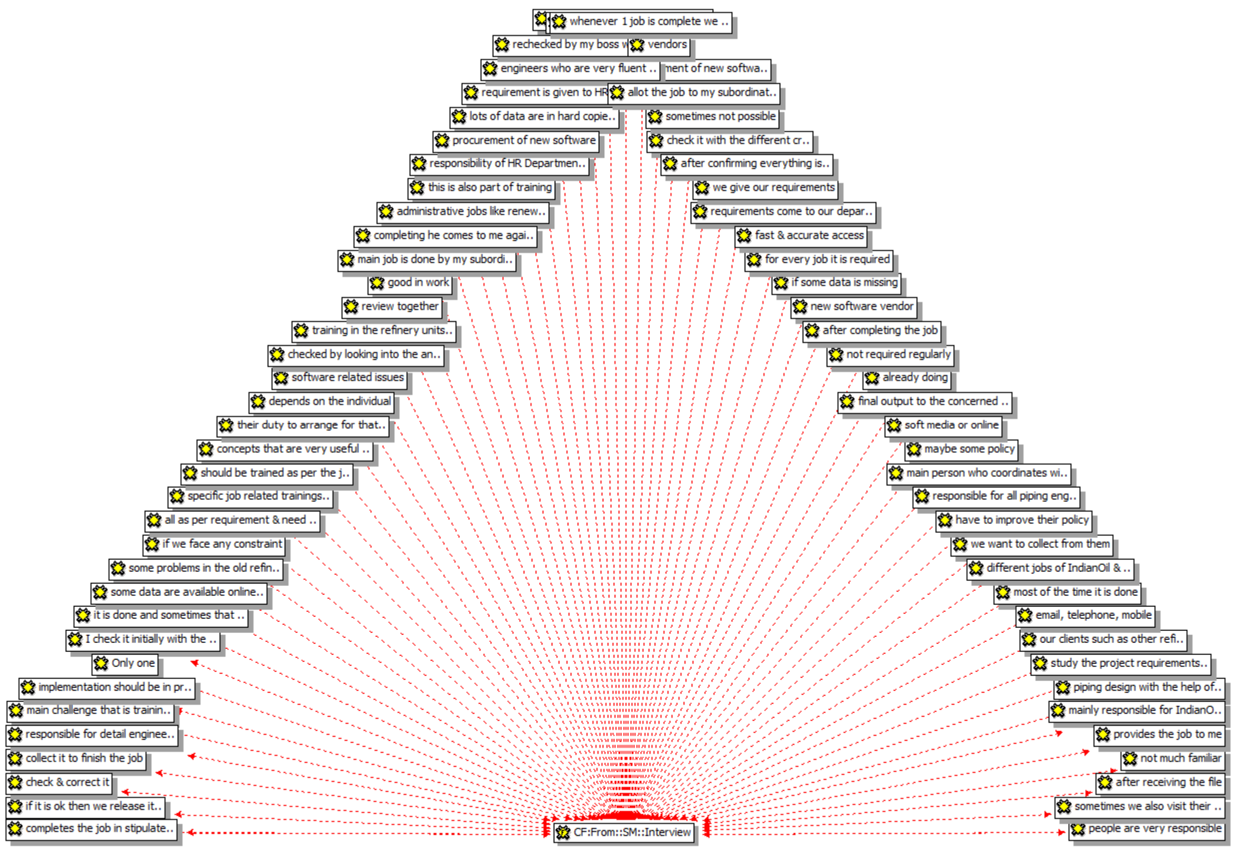


Figure C-26: The Code Family of From::SM::Observation

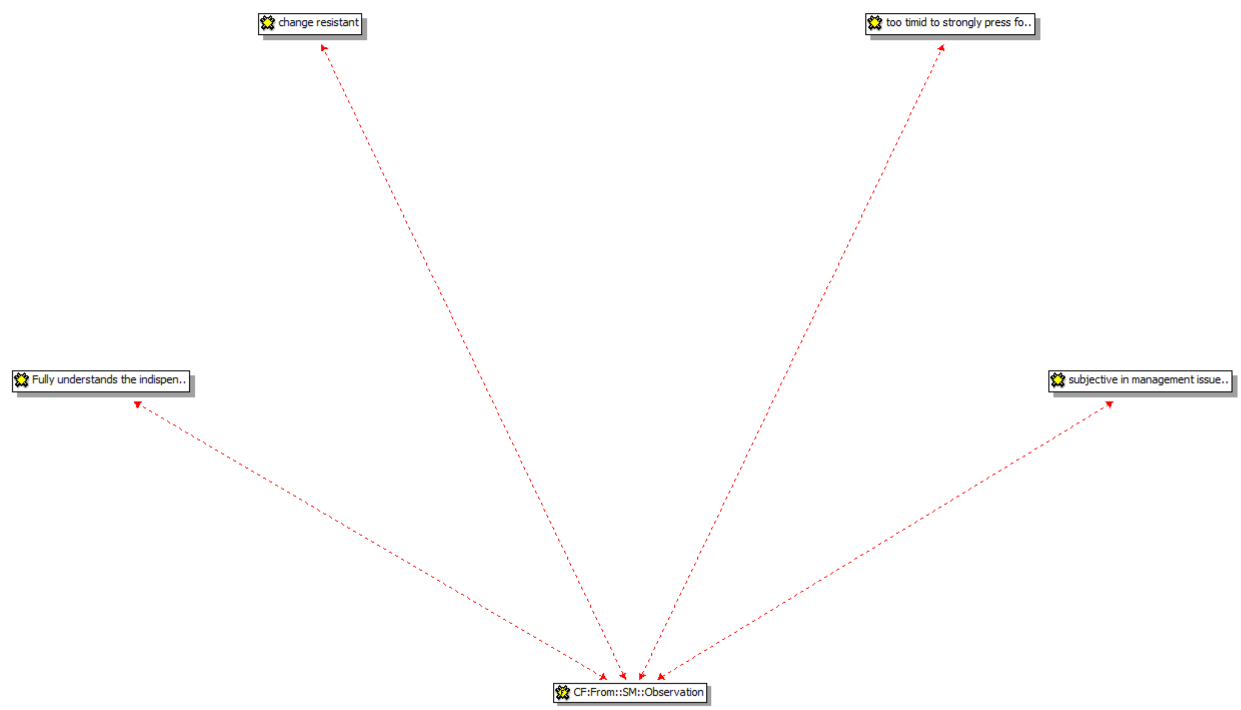


Figure C-27: The Code Family of From::SM::Interaction

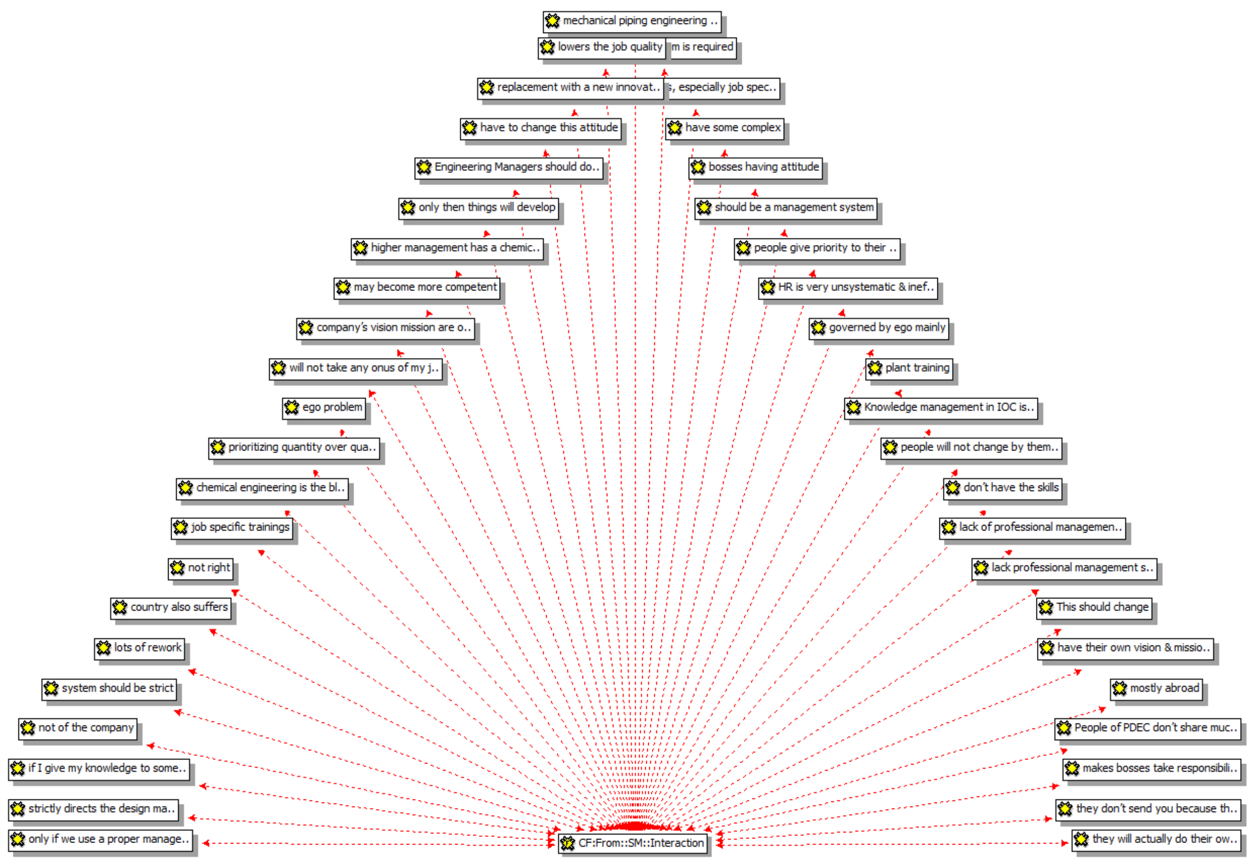


Figure C-28: The Code Family of From::MLE::Observation

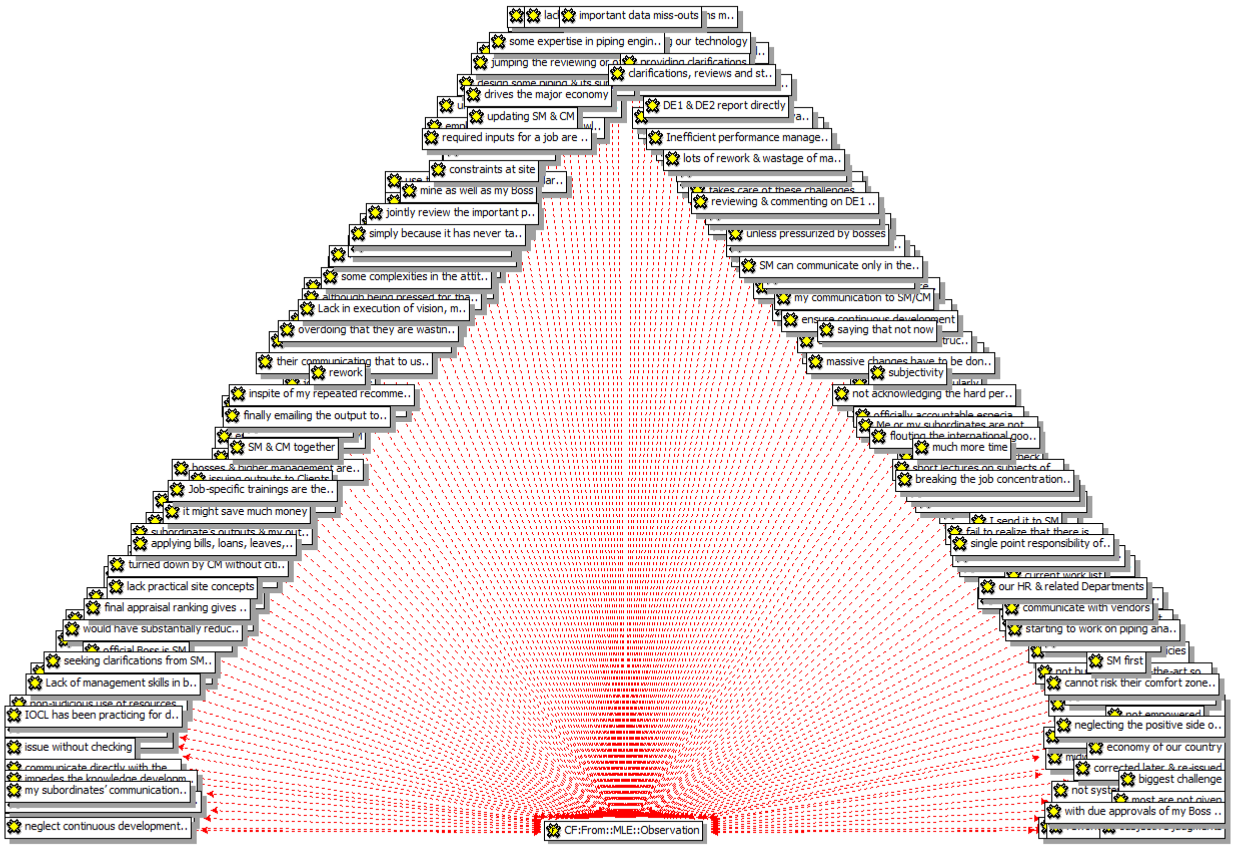


Figure C-29: The Code Family of From::DE2::Interview

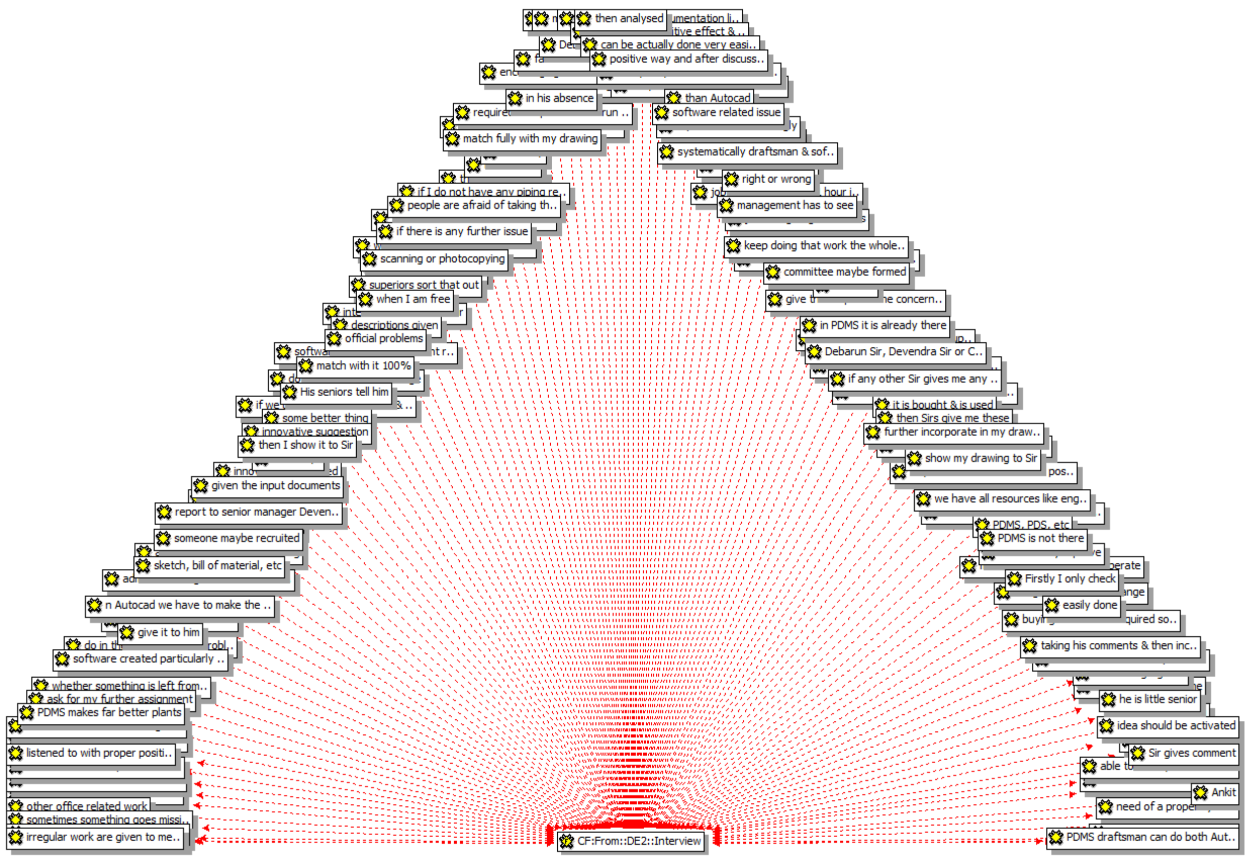


Figure C-30: The Code Family of From::DE2::Observation

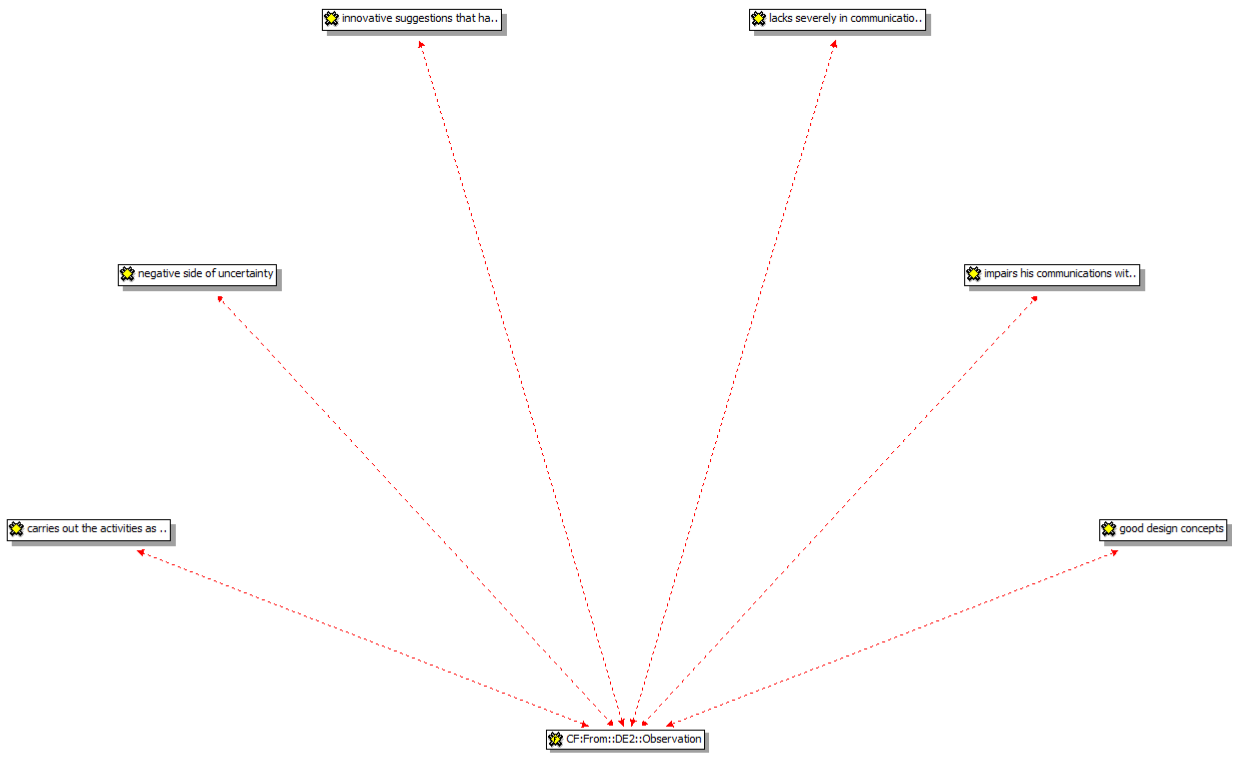


Figure C-31: The Code Family of From::DE1::Interview

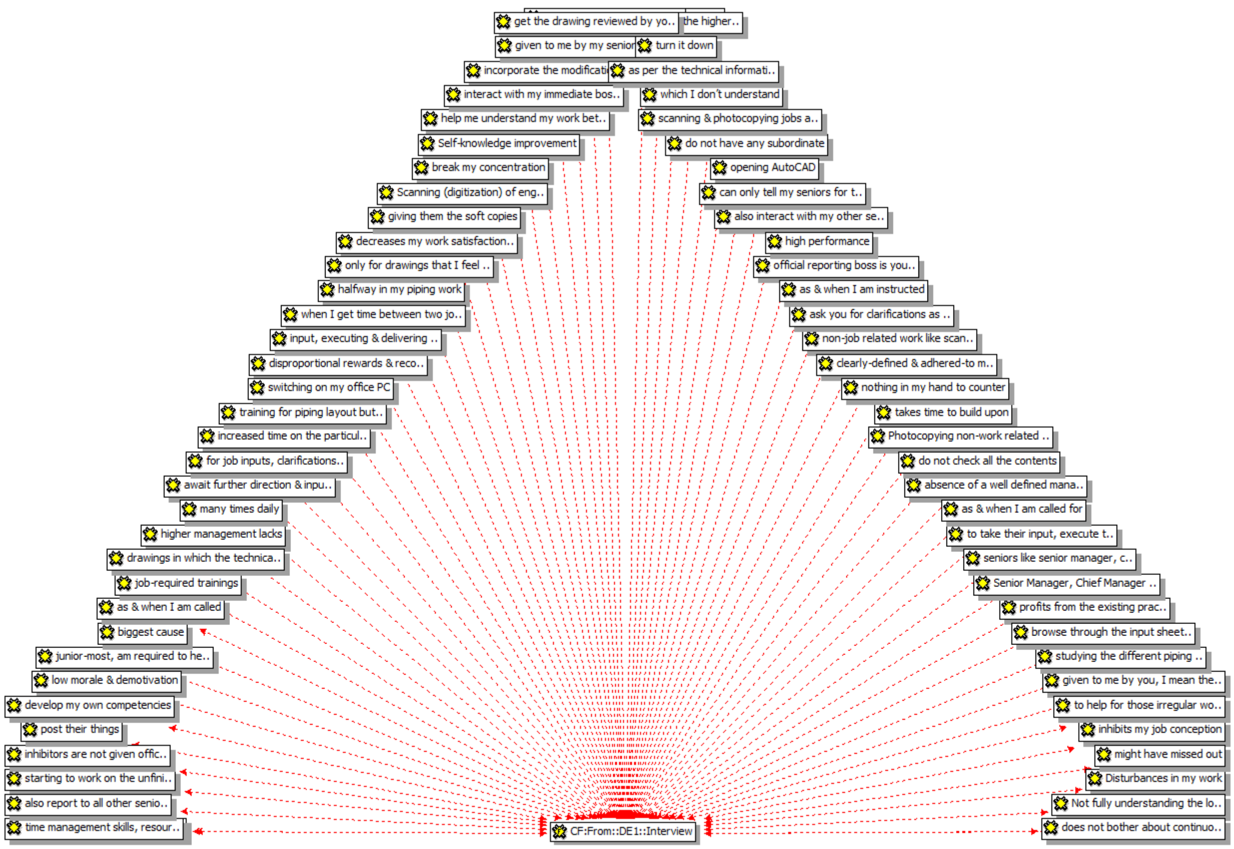
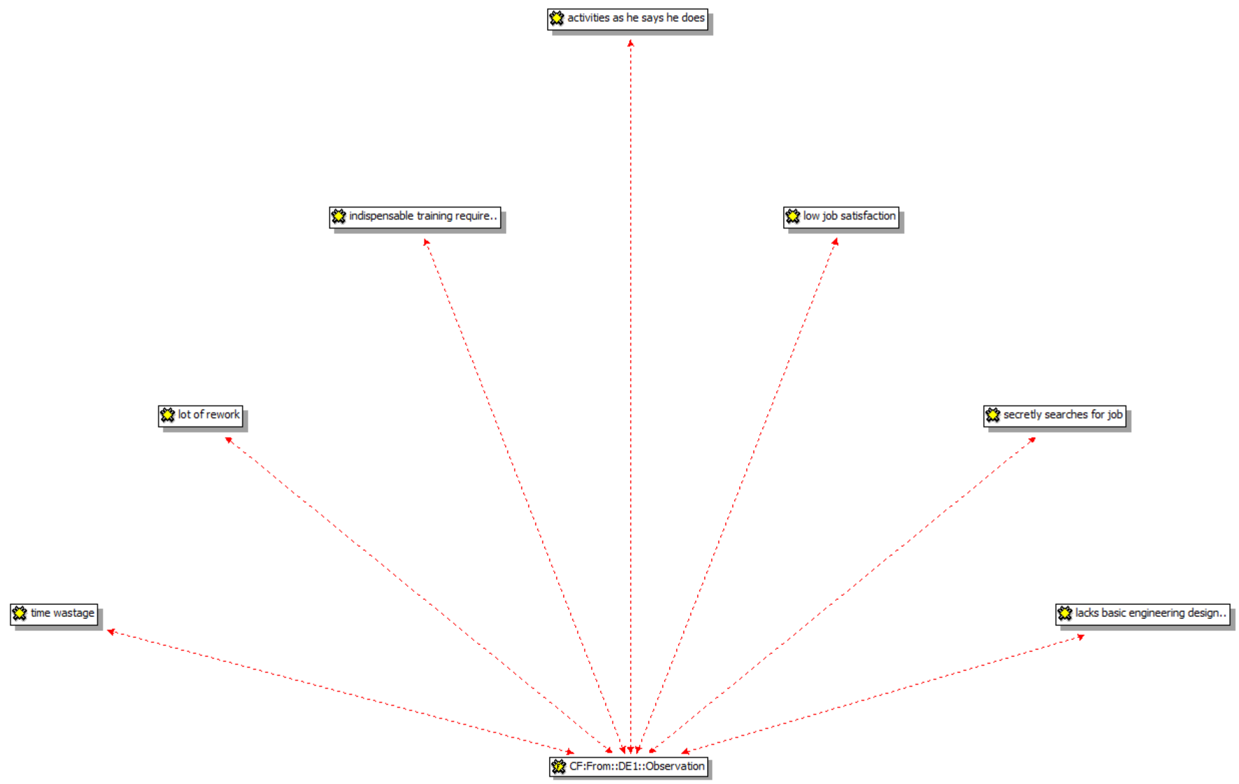


Figure C-32: The Code Family of From::DE1::Observation



Appendix D: Curriculum Vitae of the Researcher

Curriculum Vitae of the Researcher

The researcher is an Indian Chartered Mechanical Engineer with 10+ years of experience in hardcore engineering design and engineering design management. While most of his experiences have been in oil & gas, he is also experienced in other industries (power, iron & steel, etc.). He has worked with veteran & renowned global leaders of engineering & technology, including the top rung of Fortune 100 companies in India as well as abroad and is at present serving as a Process Piping and Vessels Specialist at Lloyd's Register, Malaysia. Besides continuing his passion for part-time research, he acts as a visiting faculty at University of Petroleum & Energy Studies, India. On invitation he has presented one of his published research papers at the esteemed International Mechanical Engineering Conference organized by the American Society of Mechanical Engineers and has also chaired different technical sessions.

The researcher's objective in life is to gain more knowledge, apply & continuously sharpen the gained knowledge and proactively contribute in development of the human society, especially the underprivileged young & old.

The researcher's hobbies involve ardent positivity, playing Hawaiian guitar, listening to a variety of music, playing cricket, badminton, chess, fast but safe driving and working for the humane amelioration of the society.

Appendix E: List of the Researcher’s Publications

Table E-1: Researcher's Publications

Serial No.	Title	Year	Publisher	Publication Details
1 (App. F)	Findings from a Review of Existing Approaches & Models of Engineering Design Management	2013	IFRSA, IBR	IFRSA Business Review, Volume 3, Issue 1, March, 2013, 83-89, , ISSN (Print): 2249 –8168 ISSN (Online): 2249 – 5444, http://www.ifrsa.org/images/ibrvol3issue1/12%20twelve.pdf
2 (App. G)	Piping Engineering Design Management Scenario in a Top Oil & Gas Company	2013	The American Society of Mechanical Engineers (on invitation, this paper has also been presented at ASME 2013 International Mechanical Engineering Congress)	Proceedings of the ASME 2013 International Mechanical Engineering Congress & Exposition, November 2013, Paper No. IMECE2013-62135, pp. V012T13A047; 16 pages. Proc. ASME. 56413; Volume 12: Systems and Design, V012T13A047.November 15, 2013 IMECE2013-62135 doi: 10.1115/IMECE2013-62135 or ISBN: 978-0-7918-5641-3 or http://proceedings.asmedigitalcollection.asme.org/volume.aspx?volumeid=16495 or http://proceedings.asmedigitalcollection.asme.org/
3 (App. H)	A Theoretical Model of Innovation Integrated Engineering Design Management	2013	IFRSA, IBR	IFRSA Business Review, Volume 3, Issue 1, March, 2013, 111-117, http://www.ifrsa.org/images/ibrvol3issue1/17%20seventeen.pdf, , ISSN (Print): 2249 –8168 ISSN (Online): 2249 – 5444, http://www.ifrsa.org/index.php?option=com_content&view=article&id=74&Itemid=73

Appendix F: Exhibit of Findings from a Review of Existing Approaches & Models of Engineering Design Management

IBR

Journal homepage: www.ifrsa.org

Findings from a Review of Existing Approaches & Models of Engineering Design Management

Debarun Dutta
Indian Oil Corporation Limited and University of Petroleum & Energy Studies, India

ABSTRACT

Effective management of Engineering Design is indispensable to sustain the competitive edge of any engineering company. Engineering Design Management consists of two sides - Design Product Engineering Side & Design Process Side. Previous researches in this field have found out many issues or aspects that need to be taken care of in order to make an effective design management model. However, those researches have only concentrated on some issues on a particular side of the design management cycle in a specific industry while not addressing the others. So, the models that have been built so far do not provide integrated management of all the identified issues on both the sides of the design management cycle in all industries. But the future demands an efficient design management model that caters to all the identified issues on both the sides. This paper provides the comprehensive findings from a review of existing approaches & models of engineering design management and deduces that there are 7 minimum aspects that the future engineering design management model needs to address, in order to ensure judicious management of the entire engineering design management cycle which in turn will guarantee the sustainable competitive edge of the company irrespective of the applicable industry.

1. INTRODUCTION

Engineering Design is a systematic & intelligent process in which designers focus skills & knowledge to generate, evaluate and specify concepts for devices, systems or processes whose form and function achieve clients' objectives or users' needs for an optimum engineering solution while satisfying a specified set of constraints (Dym, Agogino, Eris, Frey, & Leifer, 2005). Project Management is the art of making the right decisions in a customer-oriented way when faced with an array of alternative choices (Virine & Trumper, 2008). Engineering Design Project Management or Engineering Design Management is the business side of design involving the interfacing of Engineering Design and Management united with the common goal of creating optimum engineering solutions for a better tomorrow (Design Management Institute, 2012; Wikipedia, 2012; Acklin, 2010). Successful management of engineering design is critical to cost-effectiveness, timeliness and quality of any engineering project and competitive advantage of the company (Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010). Research has proven that the more effective the design management practices of a firm are, the more the firm is successful in business (Bruce, Cooper, & Vazquez, 1999).

What are the minimum aspects that a model needs to address in order to ensure efficient management of engineering design which will automatically upkeep the sustainable competitive advantage of any company? This paper tries to find answers to this question.

2. BACKGROUND

Management of Engineering Design can be traced back to the need based quest for bridging the gap between engineering design & corresponding business management, and this led to the birth of Design Management in 1944, when warfare & industrial needs drove the development of the British Design Council - Council of Industrial Design with the objective of promoting business practicability of engineering design (Wolf, 1993).

The crucial importance of design in any organization's capability development is a widely accepted research proven fact (Owen, 2006; Mozota, 2006; Mutanen, 2008).

Researches have time & again proved that the design engineering role is of centrally pivotal importance to organizations engaged in product development (Pahl, Beitz, & (Ed.) Wallace, Engineering design: A

Appendix G: Exhibit of Piping Engineering Design Management Scenario in a Top Oil & Gas Company

Proceedings of the ASME 2013 International Mechanical Engineering Congress and Exposition
IMECE2013
November 15-21, 2013, San Diego, California, USA

IMECE2013-62135

PIPING ENGINEERING DESIGN MANAGEMENT SCENARIO IN A TOP OIL AND GAS COMPANY

Debarun Dutta
University of Petroleum & Energy Studies, Energy Acres, Bidholi, Dehradun 248007, India.
Lloyd's Register of Shipping (M) Bhd, 21-04 Menara Tan & Tan, 207 Jalan Tun Razak, Kuala Lumpur 50400, Malaysia.
debarun.dutta@gmail.com

ABSTRACT

Piping Engineering Design Management consists of two sides – the Design Product Engineering Side & the Design Process Side. Previous researches in this field have found out many issues or aspects on the Product Side that need to be taken care of in order to build an effective piping engineering design management model. Now although there have been some researches on the Product Side, however, no evidence of research on the Process Side of Piping Engineering Design Management has been found. But since effective management of engineering design is critical to the competitive advantage of any engineering company, I am researching in this arena. During the course of my research, I have carried out a qualitative descriptive case study in a very large oil & gas company's piping engineering design department. The collected data reveals the existing piping engineering design management approaches & practices that are being used in that company. This paper directly showcases this in-vogue piping engineering design management scenario in a raw form for present &/or future researchers of this field.

INTRODUCTION

Engineering Design is a systematic & intelligent process in which designers focus skills & knowledge to generate, evaluate and specify concepts for devices, systems or processes whose form and function achieve clients' objectives or users' needs for an optimum engineering solution while satisfying a specified set of constraints [1]. Project Management is the art of making the right decisions in a customer-oriented way when faced with an array of alternative choices [2]. Engineering Design Project Management or Engineering Design Management is the business side of design involving the interfacing of Engineering Design and Management united with the common goal of creating optimum engineering solutions for a better tomorrow [3-5]. Successful management of engineering design is critical to cost-effectiveness, timeliness and quality of any engineering project and competitive advantage of the company [6-12]. Research has proven that the more effective the design management practices of a firm are, the more the firm is successful in business [13].

Piping Engineering Design is a domain of mechanical engineering design [14] that studies the efficient transport of fluid or pressure from one point to another [15, 16].

The criticality of the management of piping engineering design lies in the fact that piping consumes around 40% of any plant's design engineering activities [17]. Piping is popularly compared to the arteries in human body and, the adage that piping study is 'half science and half art' is true, the art part is visualization and creativity while the science part refers to following the established norms [18].

What is the existing piping engineering design management scenario in a top oil & gas company? This paper presents the raw data that is needed to answer this question.

BACKGROUND

Management of Engineering Design can be traced back to the need based quest for bridging the gap between engineering design & corresponding business management, and this led to the birth of Design Management in 1944, when warfare & industrial needs drove the development of the British Design Council - Council of Industrial Design with the objective of promoting business practicability of engineering design [19].

The crucial importance of design in any organization's capability development is a widely accepted and research proven fact [9, 10, 20].

Researchers have time & again proved that the design engineering role is of centrally pivotal importance to

Appendix H: Exhibit of A Theoretical Model of Innovation Integrated Engineering Design Management

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A Theoretical Model of Innovation Integrated Engineering Design Management

Debarun Dutta

Indian Oil Corporation Limited and University of Petroleum & Energy Studies, India

ABSTRACT

Innovation has always been a key factor for companies to stay ahead of competitors. Also, effective management of Engineering Design is indispensable to sustain the competitive edge of any engineering company. A review of existing researches in Engineering Design Management substantiates the business need to integrate innovation into the engineering design management cycle. There have been considerable researches on innovation management in engineering design. However, so far no model has been built that integrates innovation systematically in each stage of the entire design management cycle. This paper takes the existing research knowledge a step further by proposing a theoretical model that integrates systematic innovation into the complete cycle of engineering design management.

1. INTRODUCTION

In order to sustain the competitive advantage of a company, effective design management is indispensable (Bruce, Cooper, & Vazquez, 1999; Chua & Tyagi, 2001; Heller, Jager, Schluter, Schneider, & Westfechtel, 2004; Andersen, Nycyk, Jolly, & Radcliffe, 2005; Owen, 2006; Mozota, 2006; Mozota & Kim, 2009; Mozota, 2010).

The ever-increasing challenge of companies to remain competitive in today's extremely volatile market calls for systematic innovation alongwith optimization of cost, quality & flexibility (Willaert, Graaf, & Minderhoud, 1998; Walton, 2004; Stark, et al., 2010). Despite the obvious importance of systems innovation to continued organizational existence, research suggests that innovative efforts are ineffectively managed, cumulating in over half failing to achieve their goals (Dooley & Sullivan, 2003; Li, Li, Wang, & Liu, 2010; Xu, Houssin, Caillaud, & Gardoni, 2011). Lack of time, poor planning & management of engineering design have been found to be the main limiters to innovation, necessitating structured management techniques to integrate systematic innovation into the design management cycle in order to sustain firm's competitive advantage (Salter & Gann, 2003).

How can innovation be systematically integrated into the entire engineering design management cycle in order to reap the full benefits? This paper tries to find answers to this question.

Xu et al. (2011) showed how design innovation can be integrated into knowledge management through 4 characteristics of explicitness, novelty, importance & usability with due regards to traceability & trustworthiness of knowledge for fostering continuous innovation (Xu, Houssin, Caillaud, & Gardoni, 2011). Artificial intelligence technology still lacks basic theory about human creative thinking and decision mechanism and so existing design software systems have creative limitations, and thus human-based creativity for product innovation appears to be the most pragmatic approach (Liu, Li, Pan, & Li, 2011). More democracy in organizational structure leads to less blockages to innovation (Shoham, EranVigoda-Gadot, AyallaRuvio, & NitzaSchwabsky, 2012).

2. METHODS

The author undertook extensive literature reviews of all available publications on the subject through internet database searches till 9th July, 2012 on ScienceDirect.com, Elsevier.com, Jee.org, Ebsco.com, Scirus.com, Google.com & Wiley.com with different permutations & combinations of all / some of the following words - design, management, engineering, innovation, model, comprehensive & integrated.

The findings have been analyzed from the angle of innovation integration in design management, as discussed in the following sections. Then, taking this existing research knowledge a step further, a theoretical model of innovation integrated engineering design management is presented.