STUDY OF MAINTENANCE STRATEGY & MAINTENANCE PRACTICES AT A LARGE GAS UTILITY COMPANY IN INDIA: A CASE STUDY APPROACH

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Dehradun, 30th December, 2014 R S Velmurugan

DECLARATION

This is to certify that thesis titled "Maintenance Strategy and Maintenance Practices at a large gas utility company in India – A Case Study Approach" is my own research work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning in India or Abroad, except where due acknowledgement has been made in the text.

R S Velmurugan

30th December, 2014

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **Study of Maintenance Strategy & Maintenance Practices of a Large Gas Utility Company in India: A Case Study Approach** by **R S Velmurugan** in partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Management) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

Internal Guide

(Dr. Tarun Dhingra)

External Guide

(Dr. V K Gupta)

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EXECUTIVE SUMMARY

Indian economy has witnessed sub-5 % growth of Gross Domestic Product (GDP) during last two years. It is poised to overcome the growth rate above 5% in the year 2014-15. One among the reasons for this slow growth rate is the performance of the industry sector. The latest GDP estimates show that industry growth rate was 1% in 2012-13 and further reduced to 0.4% in the year 2013-14. Among the industries in Index of Industrial Production (IIP), India basket, core operation intensive industries have been identified for industrial growth rate study. These industries are coal, fertilizer, electricity, crude oil, natural gas, refinery, steel, and cement. The average growth rate of these industries was 5% & 6.5% in the year 2011-12 & 2012-13 respectively. The index has grown to only 2.7% during 2013-14. This is mainly due to negative growth rate in natural gas (-13%) and crude oil (-2%). Further, due to lower growth rate in coal (0.7%), fertilizers (1.5%), and refinery products (1.7%). To achieve these targets strong initiatives & growth strategies in industrial sector are crucial.

Natural gas industry is one among the operation intensive industries which contributes to the India's industrial GDP growth. Industrial growth of natural gas industry was in negative growth rate during 2013-14 due to various economic reasons. However, to support the GDP growth of the industry in the coming years, organisations within the industry should maximise the productivity and profitability in today's competitive business environment. Operations can be used as competitive advantage to achieve business objectives of the organisations in the industry. Maintenance plays a crucial role in operations. Even organisations treat maintenance as an important function and traditionally it is considered as cost centre. In spite of the consistent efforts of maintenance managers in maintaining the assets by applying best maintenance strategies & maintenance practices in the operation intensive industry, the failures of equipment/process happen and it leads to increase in downtime of plant operations and cost of operations & maintenance.

Given the above background, the ***business problem*** at an organisation level in the process/manufacturing/gas industry can be defined as:-

- Production/Operation process is continuous and any abrupt stop of whole production process cause delay and reduction in output in an organisation.
- Although organisation follows various maintenance strategies, the cost and impact (equipment safety, upstream supplier issues, and downstream customer issues) of sudden failure of equipment was found to be huge.

The above business problem motivates the researcher to perform this study. Detailed literature survey was carried out in the area of maintenance management and related processes. The detailed literature review reveals that the most of existing literatures have discussed evaluation system for setting up a particular maintenance method/approach such as Preventive Maintenance & Predictive Maintenance, linking performance with the maintenance strategy, application of specific maintenance method/approach like Preventive Maintenance, Predictive Maintenance, RCM, CBM etc. for a particular industry in a country like Italy, Belgium, Africa etc., development of Maintenance Decision Support Systems (MDSS) for selection of maintenance strategy, development of Plant level Maintenance Decision Support System (PMDSS) implementation of e-maintenance concept, maintenance polices and their impact.

Further, authors have developed frameworks/models related to maintenance strategy processes such as maintenance strategy formulation, selection of maintenance strategies and implementation of selected maintenance strategies. However, each model describes one or two processes of maintenance strategy but not in combined manner integrating all the maintenance strategy related processes. Based on these inferences, it is evident that there is a need in

Industry to develop a holistic model which combines factors such as maintenance strategy formulation, selection and implementation of formulated maintenance strategies.

It is also evident from the literature review that the maintenance strategies related frameworks established relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in an organisation, but they failed to explain how and why are these related. As explanation is essential for building theory and for improving practice, there is a need for process study of maintenance strategies & maintenance practices at an organisation level. Further, extensive literature search for maintenance strategies & maintenance practices study using qualitative research approach at an organisation level in operations intensive industry like natural gas industry in an Indian context found no references.

Business problem is further narrowed down to problem statement based on outcomes of detailed literature review and it is presented below:-

Although in the existing literature various maintenance strategies applicable for different types of operations intensive industry is well known but the process of maintenance strategies selection & maintenance practices at an organisation level have not been described in detail. Further, there is lack of holistic process model for maintenance strategies & maintenance practices planning and execution.

The research questions & research objectives formulated for this research study are presented as given under:-
Central Research Question: How the gas utility company is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as petrochemicals & pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?

Additional RQ1:- What are the common and different maintenance strategies & practices to both the business verticals (and) how the maintenance strategy & practices differ with the specific assets available in one operation process/plant/pipeline network from others business verticals?

Additional RQ2:- How the reliability of the operation process/ equipment/ assets is ensured by the maintenance strategy used for the particular operation process/equipment/assets?

Additional RQ3: What are the benchmarks being used in petrochemicals/ NG pipelines? What is extent of achievement of benchmark parameters in practices?

Research Objectives: -

1. To understand and model the existing maintenance strategies & maintenance practices planning and execution in a large gas utility company in India.
   a. To describe the common and different maintenance strategies & practices in the business verticals such as Petrochemicals & NG Pipelines of gas utility company.
   b. To describe the extent of practices regarding reliability in maintenance of equipment/assets/processes.
2. To find the gaps between maintenance strategies & practices and benchmarks in maintenance.

At an organisation level in maintenance function, the tacit and explicit knowledge in the field of best practices in maintenance management are available with maintenance managers & engineers working in the organisation. We need to gather an in-depth understanding of this knowledge in formulation of maintenance strategy & practices in the organisation. Therefore, qualitative research method will be a suitable method in capturing and reusing tacit and explicit knowledge in the field of best practices in maintenance management at the organisation studied.

Therefore, the focus of this research study is to understand & describe the maintenance strategies & maintenance practices planning and execution at an organisation level in an Indian context (a large gas utility company). It is also to understand why the specific maintenance strategy has been chosen for a particular equipment/process/operation and how these formulated strategies are being practiced in the organisation. A case study approach has been selected for this research study because, the definition of the case study method say that "*the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result*" (Yin, 2003).

A large gas utility company in India has been chosen for the study on maintenance strategies & maintenance practices since it is having 70% market share in natural gas industry and it is a No. 1 gas utility company in India. It is having 7 LPG processing plants, 1 Petrochemical processing plant & 3 Natural Gas Pipeline networks & 2 LPG pipeline networks. Based on financial parameters, two business verticals such as Natural Gas Pipelines & Petrochemicals plant have been selected for this research study.

To start with the case studies in business verticals in Natural Gas Pipelines & Petrochemicals plant, the data collection was carried out at various sites in the Natural Gas Pipelines of the large gas utility company in Delhi NCR and Petrochemicals plant at PATA (UP). Data collection was done through semi-structured interviews from maintenance managers/ engineers through structured Case Study Protocol (CSP), participant observation, collection of documentary evidences, and informal discussions with the maintenance personnel in the company. All interviews were recorded and then transcribed. After completion of the transcription of interviews, one month was spent to collect the interviewees' feedback on the transcripts. Interview scripts coding was done through Qualitative Analysis software Atlas-Ti. This software enabled the data analysis process by helping with coding, linking codes, and text segments, creating memos, searching, editing and reorganising, and for visual display of data and findings. Modified grounded theory approach (Charmaz, 2006) has been used for data analysis.

Within case analysis was carried out keeping research questions in mind. Accordingly, data analysis is aimed to identify (i) the nature of maintenance strategies & maintenance practices including benchmarking of maintenance practices and maintenance reliability of the large gas utility company, (ii) maintenance strategies selection process in the company, and (iii) the relationship between maintenance strategies selection process and the factors contributing to maintenance strategies & maintenance practices. Cross case analysis was carried out to compare and explain similarities, dissimilarities and, complimentary findings in the study of maintenance strategies and maintenance practices in the verticals NG Pipelines & Petrochemicals of the large gas utility company. Based on case comparison, the relative findings and contextual factors across the cases are brought out.

The above detailed data analysis results with the following categories which contributes to maintenance strategies selection and maintenance practices such as performance measures, planning & Scheduling, materials management, human resources, information technology, employee empowerment, maintenance tactics, reliability analysis, and maintenance policies/ maintenance budget in both the categories. Extent of application of these categories varies according to the nature and type of process/plant/equipment in NG Pipelines & Petrochemicals. One new category emerged out in both the case studies from empirical data i.e., maintenance challenges. Two new sub-categories have also been emerged out for the category maintenance tactics. They are shutdown maintenance and proactive maintenance. Further, 14 propositions have been developed from cross case analysis. The extent of achievement of benchmarking practices in the large gas utility company is also studied and presented. Finally, a model on maintenance strategies & maintenance practices in planning and execution has been developed and presented. This model holistically explains the processes related to maintenance strategies such as formulation of maintenance strategies, selection of maintenance strategies, and implementation of maintenance strategies and also with other functions of maintenance such as development of Maintenance Decision Support System (MDSS), e-maintenance, companywide integration and alignment between maintenance strategy & business strategy.

This research study showed that the large gas utility company's maintenance strategies & maintenance practices planning and execution are largely depends on targets being set by corporate operation & maintenance function. These targets are basically production targets of petrochemicals plant/NG Pipelines operations. There is no maintenance performance based targets or key performance indicators are formulated for maintenance execution. Even though the company is using basic maintenance methods such as Preventive Maintenance, Predictive Maintenance, it is not following other methods such as Reliability Centred Maintenance & Total Productive Maintenance. However, it religiously following specific maintenance strategies pertaining to particular equipment/process as recommended by Original Equipment Manufacturer (OEM) or process licensor. The large gas utility company is not using any reliability centred approach in maintenance and also not applying any maintenance benchmarks of the industry.

This research study provides rich description to the theory of processes related to maintenance strategies selection & maintenance practices in maintenance management at an organisation level in the operations intensive industry like gas industry and in general also. This study could also suggest set of maintenance guidelines & parameters for maintenance strategy formulation, selection and implementation of maintenance strategies to the maintenance managers/engineers in the industry. Such guidelines & parameters would also help them to benchmark the maintenance practices at an organisation level. It also found evidences to formalise & improve the maintenance strategy process adapted since importance attached to industry/operation/equipment specific maintenance strategies in both NG Pipelines & Petrochemicals.

LIST OF ABBREVIATIONS

PM – Preventive Maintenance

CBM – Condition Based Maintenance

TBM – Time Based Maintenance

RCM – Reliability Centred Maintenance

TPM – Total Productive Maintenance

CMMS – Computerised Maintenance Management System

BCM – Business Centred Maintenance

RCA – Root Cause Analysis

IAR – Incident Analysis Report

MOU – Memorandum of Understanding

IMOU – Internal MOU

OISD – Oil Industry Safety Directorate

PNGRB –Petroleum Natural Gas Regulatory Board

AGA – American Gas Association

ISO – International Standard Organisation

IMS – Integrated Management System

AHP – Analytical Hierarchy Process

MCDM – Multi Criteria Decision Making

C & P – Contracts & Procurement

DQM – Department Quality Manual

CSP – Case Study Protocol

SCADA – Supervisory Control And Data Acquisition System

HVJ Pipeline – Hazira- Vijaipur- Jagdishpur Pipeline

LPG – Liquefied Petroleum Gas

NG – Natural Gas

O & M – Operation & Maintenance

SOP – Standard Operating Procedures

ROU – Right of Use

OEM – Original Equipment Manufacturer

AGA – American Gas Association

API – American Petroleum Institute

OHSAS – Occupational Health Safety Audit Systems

IUSA – Inter Unit Safety Audit

OIC – Office-in-charge

ED – Executive Director

GDP – Gross Domestic Product

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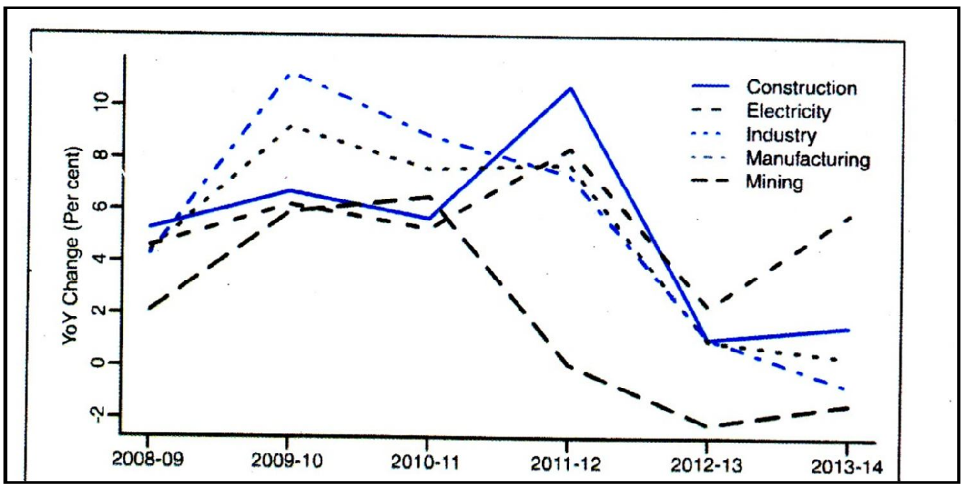
CHAPTER 1
INTRODUCTION

The chapter begins with brief background about industrial growth in India and contribution of operations intensive industries like natural gas industry to the industrial Gross Domestic Product (GDP). It highlights that effective and efficient operation processes help operation intensive industries in sustaining their productivity and profitability. The crucial role of operations & maintenance is discussed in detail. Further, the problem discussion highlights and take into account the impact of maintenance at an organisation level in gas industry within operation intensive industries. Thereafter, it is narrowed down to present the problem formulation of this research study. Potential significance of this research study is also deliberated in this chapter. In last section, thesis deposition is presented in order to explain complete thesis chapters of this research report.

1.1 BACKGROUND

Indian economy has witnessed sub 5 % growth of Gross Domestic Product (GDP) during last two years. It is poised to overcome the growth rate above 5% in the year 2014-15. One among the reasons for this slow growth rate is the performance of the industry sector. After 2008-09, the industrial sector which includes manufacturing, mining, construction, and electricity demonstrated recovery and steady growth for consecutive three years. Thereafter, industrial growth has lost its momentum due to various supply side and demand side constraints. The latest gross domestic product (GDP) estimates show that industry growth rate was 1% in 2012-13 and further reduced to 0.4% in the year 2013-14. The projected 12^{th} plan targets for manufacturing sector is 10% and 5.7% for mining sector in the remaining three years. To achieve these targets strong initiatives & growth strategies in industrial sector are crucial (Source: www.indianbudget.nic.in).

Sector wise analysis of industrial performance is presented in Figure 1. It shows that the key reasons for poor performance in industrial performance are due to contraction in mining activities and deceleration in manufacturing output. In manufacturing sector, reasons for growth slowdown are reduced fixed investment, several domestic and external factors like higher interest rate, bottlenecks in infrastructure, inflationary pressure due to rising input costs, and drop in domestic and external demand. In mining sector, reasons for growth slowdown are majorly due to lower or moderate production of goal, lignite, crude petroleum, iron ore, and natural gas (Source: www.indianbudget.nic.in).



(Source: www.indianbudget.nic.in)

Figure 1.1 Sector-wise Growth of Industry GDP (%)

Among the industries in Index of Industrial Production (IIP), India basket, core operation intensive industries have been identified for industrial growth rate study. These industries are coal, fertilizer, electricity, crude oil, natural gas, refinery, steel, and cement. The average growth rate of these industries was 5% & 6.5% in the year 2011-12 & 2012-13 respectively. The index has grown to only 2.7% during 2013-14. This is mainly due to negative growth rate in natural gas (-13%) and crude oil (-2%). Further, due to lower growth rate in coal (0.7%), fertilizers (1.5%), and refinery products (1.7%). However, Government of India promotes to achieve industrial growth to almost 14% GDP over the medium term and further by 25% GDP by 2022 from the current 15-16% GDP thorough various initiatives such as National Manufacturing Policy (Source*: www.indianbudget.nic.in*).

To achieve the targeted GDP growth set by GOI and also to sustain in global arena, it is crucial for Indian industries to sharpen the productivity, profitability and competitiveness. In order to maximise productivity and profitability in the industry, the world class best practices are to be adopted by organisations in the areas of operations & maintenance (Campbell, Andrew, Jardine, Marshall & Decker, 2001).

Operations in the industry constitute all of the activities that an organisation accomplishes in order to deliver value to its customers. It's the set of processes that transforms either materials or information into a product or service (Gits, 1994). There have been some exciting changes in recent years. Operations are no longer merely something that has to complete in order to proceed with business as common. Today, organisations can generate huge competitive advantage with their superior and novel operations (Ketokivi & Jokinen, 2006). In the context of globalization of business, the changing nature of operations in any organisation is due to the major developments such as information technology and technological advances in the production/ maintenance technology (Waeyenbergh & Pintelon, 2004).

Operations in the industry are characterised by diversity of issues of distinct nature such as technical and operational, short and long term planning, systems management, and involvement of various stakeholders (Al-Najjar, Alsyouf, Salgoda, Khosaba & Faaborg, 2001). Therefore, organisations are facing a lot of challenges such as optimisation of operations function due to the continual evolving world of technologies, global competitiveness, environmental and safety requirements.

Now is the time for operations of the organisation in the industry to step up to the stage and become a key player in achieving company profitability and growth goals (Kutucuoglu, 2001; Al-Najjar & Alsyouf, 2004). Sound operations management excels at meeting daily business requirements and builds competitive advantage. This is a much bigger vision than just being a cost-effective business enabler. It requires forward, innovative thinking and agile response to rapidly changing markets, technologies and global cost structures (Hayes et al., 2014)

The concern towards total quality and profitability of an organisation are crucial factors in the business. Availability of production equipment and ensuring production efficiency is essential to sustaining production capacity in continuous production plant (Pinjala, Pintelon, & Vereecke, 2006; Parida & Uday, 2009) in any industry like gas industry also. These fundamentals factors affect profitability of an organisation in the operations intensive industries. Studies have shown that the negligence in asset maintenance and its role in production processes results in consequential issues such as financial, technical, as well as safety in both internal and external environment of the organisation (Benett, 2006; Al-Najjar et al., 2001).

Further, organisations in operations intensive industries such as utilities, food and beverage processing, metals and mining, chemicals, oil and gas, and automotive recognize that asset maintenance is crucial to the successful operations of their organisations. Even though organisations provide the importance to effective and efficient maintenance practices in order to achieve the financial objectives, only 7% of organisations are completely satisfied with their maintenance performance (Source: Report on Collaborative Asset Maintenance Strategies by Aberdeen Group, 2006).

It is evident that industrial maintenance function has gained high recognition over the last few decades in various industries (Ben-daya & Duffua, 1995). Consequently, over the years, many different strategies have been developed to support maintenance management implementation in the industry (Swanson, 2003). In today's highly competitive business environment, management of physical assets (their selection, maintenance, inspection and renewal) plays a key role in determining operational performance and profitability of any business unit, manufacturing plant or industry that operate assets as a part of their core business (Henriques & Sadorsky, 1999; Al-Najjar et al., 2001; Vollmann, Berry, Whybark & Jacobs, 2005) . Asset Management, being the art and science of making right decisions and optimising these processes, attempts to minimise the total life cost of assets and directly or indirectly influences manufacturing/ production/operation/service cost, processes and quality, and throughput or delivery time (Pintelon, Gelders, & Vanpuyvelde, 2000).

Especially impact of maintenance in achieving business objectives has been proven as important in recent time (Duffua, Al-Ghamdi & Al-Amer, 2002). However, more research study regarding the importance of maintenance in manufacturing environment is the requirement in the industry (Alsyouf, 2007).

The cost associated with the maintenance has increased constantly over the decades. In the present scenario, depending on the type of industry, about 15-70% of production costs are attributed towards maintenance (Ilangkumaran & Kumaran, 2012). Unfortunately, due to the uncertainties and inefficiencies involved in maintenance planning, about one third of maintenance costs are wasted (Mobley, 2002). Further, the selection of an apt maintenance strategy is important as well as complex in maintenance management and the output of maintenance is hard to measure and quantify (Chris & Wang, 2001).

In general, plant maintenance function is to keep any kind of equipment or component in a working order to prevent failures so as to perform its intended function, ensuring safety, as well as protecting the environment (Al-Najjar et al., 2001; Henriques & Sadorsky, 1999). Ensuring cost effective plant operation such as efficient & quality production, equipment availability and employee & environmental safety depends on how organisations are able to effectively integrate maintenance function with other functions in the organisation. Further, for organisation to survive in the present industrial environment, healthiness of equipment with sustainable operations should be ensured (Ben-daya & Duffuaa, 1995, Al-Najjar, 2001; Bennett, 2006).

Traditionally, maintenance management was dealt with the short term issues like resources, cost, man power etc. In recent past, maintenance management has changed its concerns towards the consideration of long-term goals like competitiveness, sustainability and strategy. The maintenance management needs to be viewed in a strategic perspective (Duffuaa et al., 2002; Crespo & Gupta, 2006; Umar, 2011). Therefore, maintenance is not just ensuring healthiness of equipment in a facility but it also plays a crucial role in achieving organisation's goals and objectives with optimum maintenance cost and maximum production (Seth & Tripathi, 2006). Once maintenance is viewed as a strategic perspective in the organisation, there is a need to formulate maintenance strategy for performing maintenance function in the organisation (Kelly, 2006; Salonen, 2011).

Maintenance strategy is defined as a systematic approach to upkeep the facilities and equipment and it may vary from facility to facility. It involves identification, researching and execution of many repairs, replace and inspect decisions and is concerned with formulating the best life plan for each unit of the plant, in coordination with production and other functions concerned (Kelly, 1997; Mckone & Elliott, 1998; Sherwin, 2000; Pintelon & Parodi, 2008). It describes what events (e.g. failure, passing of time, condition) trigger what type of maintenance action (inspection, repair, or replacement).

Backlund & Akersten (2003) found lack of maintenance management strategy to be one of the obstacles for the introduction of Reliability Centred Maintenance (RCM) in a hydropower company. Similar type of conclusions is demonstrated in few other studies regarding implementation of Total Quality Management (TQM), Total Productive Management (TPM), etc. (Hansson, Backlund, & Lycke, 2003). Further, Rao (2009) asserts that one of the challenges of maintenance is to continuously improve the performance of maintenance. Despite the obvious importance of maintenance strategies, a survey among maintenance managers shows that 48% managers agreed for having written maintenance strategy and 28% had no maintenance strategy at all and also remarks that the quality standard ISO to be a maintenance strategy (Alsyouf, 2009).

There seems to be a less interest among the maintenance practitioners for a structured maintenance strategy formulation and implementation (Salonen, 2011). The reasons may be: maintenance approaches/methods/concepts are resource demanding so that SME organisations do not show much interest in using such maintenance approaches; organisations are reluctant to experiment with the new maintenance methods developed such as Total Productive Maintenance, Reliability Centred Maintenance etc.

Maintenance strategy process includes various activities such as formulation of maintenance strategies for the organisation, selection of particular maintenance strategy of the specific equipment or process and effective implementation of maintenance strategies selected. All these activities are required to be viewed strategically and to be monitored holistically (Umar, 2011).

It is also pertinent that maintenance function has gained crucial role over the last few decades in natural gas industry which is one of the operations intensive industries. Consequently, over the years, many different strategies have developed to support maintenance management implementation in the natural gas industry. With increasing automation and mechanization in natural gas/petrochemical process, production processes are becoming highly sensitive to machine/equipment and people (Carnero, 2006). Consequently, the role of equipment maintenance in controlling quality, quantity and reducing costs is more evident and important than ever (Muchiri et al., 2010; Jay, Jun, Dragan, Hai, & Haito, 2006). The natural gas industry is also characterised by expensive specialised equipment and stringent environmental consideration.

In the operations intensive industries as the case with gas industry, despite the best efforts of maintenance managers, equipment still fails, and plants are vulnerable to failures. Therefore, before adopting any maintenance strategy, maintenance managers must change the way they think about failures and understand its diversity. The implications in production and maintenance suggest the need to change the focus of maintenance polices & maintenance methodology adopted.

For example, gas processing plant of gas utility company must produce LPG at least 350 days per annum considering the 15 days scheduled maintenance. However, industry data shows that production is getting affected for at least 20-25 days due to scheduled plant shutdown maintenance and also due to emergency breakdown maintenance. Therefore, the plant runs for 340 days approx. (Source: Shutdown Report 2012, Gas Processing Plant, GAIL India Limited). If it is possible to reduce plant shutdown by a day, company can profit few crores of rupees.

The above descriptions on industrial growth with respect to Indian industry & contribution of operations intensive industry to industrial growth, role of operations & maintenance in the organisation's productivity and profitability can be summarised as: Natural gas industry is one among the operation intensive industries which contributes to the India's industrial GDP growth. Industrial growth of natural gas industry was in negative growth rate during 2013-14 due to various economic reasons. However, to support the GDP growth of the industry in the coming years, organisations within the industry should maximise their productivity and profitability in today's competitive business environment. Operations can be used as competitive advantage to achieve business objectives of the organisations in the industry. Maintenance plays a crucial role in operations. Even organisations treat maintenance as an important function nowadays but traditionally it was considered as cost centre.

But in today's industrial environment, strategic perspective of maintenance become an important aspect in organisation's growth. In spite of the consistent efforts of maintenance managers in maintaining the assets by applying best maintenance strategies & maintenance practices in the operation intensive industry, the failures of equipment/process happen and it leads to increase in downtime of plant operations and cost of operations & maintenance.

Given the above background, the ***business problem*** at an organisation level in the process/manufacturing/gas industry can be defined as:-

- Production/Operation process is continuous and any abrupt stop of whole production process cause delay and reduction in output in an organisation.
- Although organisation follows various maintenance strategies, the cost and impact (equipment safety, upstream supplier issues, and downstream customer issues) of sudden failure of equipment was found to be huge.

The above business problem motivates the researcher to perform this study. With this background, this research study undertakes study of maintenance strategies & maintenance practices at an organisation level in the industry focusing on the maintenance strategies selection processes in detail with the objective of having thick descriptions of maintenance strategy related processes at an organisation level.

1.2 TOPIC & PURPOSE

To further explore on business problem, a detailed literature review was carried out. A review of current thinking on the concepts of maintenance strategies & maintenance practices, maintenance strategies selection processes, and other maintenance management related concepts such as e-maintenance, alignment of business strategies with maintenance strategies, and companywide integration of maintenance strategies are presented in this section. Detailed literature review is presented in Chapter 2.

1.2.1 Maintenance Strategies & Maintenance Practices

Maintenance Strategy is not well defined in the literature. Maintenance strategy term is used interchangeably with maintenance policy, maintenance approach etc. Maintenance strategy is a systematic approach to upkeep the asset/facility. Authors have categorised maintenance strategies as Time Based Maintenance (TBM), Condition Based Maintenance (CBM), Corrective Maintenance (CM), Reliability Centred Maintenance (RCM), and Total Productive Maintenance (TPM) and these are also mentioned as maintenance policies/ maintenance approaches/maintenance methods in the published papers (Gallimore & Penlesky, 1988; Pintelon & Gelders, 1992; Dekker, 1996; Kelly, 1997; Mckone & Elliott, 1998; Sherwin, 2000; Bevilacqua & Braglia, 2000; Swanson, 2001; Crespo & Gupta, 2006; Carnero, 2006; Marcello, Davide, & Marco, 2013).

Few literature have discussed about maintenance practices at an organisation level in manufacturing plant. Maintenance practices are need to be updated time to time based on the changes in plant equipment, production technology, and requirement of technical expertise to perform the maintenance activities (Swanson, 1997). Maintenance must leverage information technology and implementation of e-maintenance concepts like Computerised Maintenance Management Systems (CMMS). These systems help in strategic maintenance planning, scheduling and manpower coordination in order to improve maintenance practices of an organisation (Raouf, Ali & Duffuaa, 1993; Swanson, 2003; Elliot & Tobias, 2005; Marchi & Garetti, 2006; Jay et al., 2006; Muller et al., 2007; Phillip & Ramin, 2014). Maintenance decision making & maintenance performance depends on the maintenance policy & maintenance culture of the organisation. Customisation of maintenance organisation according to current business strategies helps the organisation in successful maintenance strategy implementation (Pintelon & Gelders, 1992; Michael et al., 2000; Wang, 2001; Eti et al., 2006; Nima et al., 2010).

Literature has identified initial conceptual constructs such as Maintenance Tactics, Reliability Analysis, Performance Measures/Benchmarking, Planning & Scheduling, Materials Management, Organisation/Human Resources, Employee Empowerment, Information Technology, and Maintenance Polices/Budget. The maintenance tactics such as Preventive Maintenance/ Time Based Maintenance, Predictive Maintenance/Condition Based Maintenance, Reliability Centred Maintenance, and Total Productive Maintenance are covered in detail in the literature with specific context to industries such as Manufacturing industry, power plant, Automobile industry, etc. (Patrik, 1999; Cooke, 2003; Carnero, 2006; Mahdi, Hossein & Taha, 2010 ; Rolando, Mark, Villalobos & Graul, 2009; Pophaley & Vyas, 2010; Jafari, Jafarian, & Zaerpour, 2008; Chris & Wang, 2001 ; Ilangkumaran & Kumaran, 2012; Chitra, 2003; Mokashi, Wang, & Vermar, 2002; Gokiene, 2010; Seth & Tripathi, 2006; Sami & Ben-daya, 2010; Wilmeth & Usrey, 2000). Reliability Analysis plays a crucial role in maintenance strategy formulation, selection and implementation of the strategies into practices (Bevilacqua & Braglia, 2000; Liptrot & Palarchio, 2000; Wang, 2001; Nima, Dragan, & Jardine, 2010; Li, Ambani, & Ni, 2009; Nguyen, Brammer, & Bagajewicz, 2008). Formulation and selection of maintenance strategies are improved and modified based on the performance measures in maintenance. Maintenance performance measurement also helps to choose suitable maintenance strategy for a particular operation process/equipment Tsang, Jardine, & Kolodny, 1999; Sherwin, 2000, Kutucuoglu et al., 2001; Marchi & Garetti, 2006; Parida & Uday, 2009; Swanson, 2001; Gokiene, 2010; Ahmadi, Gupta, Karim, & Uday, 2010; Simoes, Gomes, & Yasin, 2011).

Planning & scheduling are the key activities of any maintenance strategies formulation & implementation in an organisation (Noemi & William, 1994; Bertolini & Bevilacqua, 2005; Rosqvist, Laakso & Reuanen, 2007; Rolando et al., 2009; Pophaley & Vyas, 2010; Ashayeri, Teelen, & Selen, 1996; Jin, Li, & Ni, 2009; Ilangkumaran & Kumaran, 2012; Nguyen, Brammer, & Bagajewicz, 2008; Sami & Ben-daya, 2010; Verma & Suresh, 2007; Ahmadi, Gupta, Karim, & Uday, 2010; Pinjala, Pintelon, & Vereecke, 2006). Non-availability of material, emergency procurement of material, inventory control, and integration of material management with maintenance planning affect the implementation of maintenance strategies. Therefore, material management is an integral part of maintenance strategies formulation and implementation in an organisation (Carnero, 2006; Garg & Desmukh, 2006; Jafari et al., 2008; Nguyen, Brammer & Bagajewicz, 2008, Wireman, 2010). The manpower outsourcing strategy provides flexibility in the maintenance organisation so that there is no need to create fixed assets /infrastructure. To help in such kind of decisions HR function plays inclusive role in formulation of maintenance strategy, selection and implementation of maintenance strategy in an organisation (John & Amrik, 1989, Garg & Desmukh, 2006; Eti, Ogaji, & Probert, 2006; Crespo & Gupta, 2005; Pinjala, Pintelon, & Vereecke, 2006).

Empowerment of employee helps to take faster decision during performing maintenance and to manage emergency maintenance. This helps in implementation of maintenance strategies in an organisation in a better manner (Campbell, Jardine, Marshall, & Decker, 2001; Eti, Ogaji, & Probert, 2006; Wireman, 2010). Information Technology (IT) can lead to higher work productivity, machine availability, maintenance personnel effectiveness etc. Therefore, IT can impact maintenance decision making such as formulation of maintenance strategy and this helps to optimise the maintenance cost and the equipment/asset reliability. A well formulated maintenance strategies and practices supported with the maintenance policies and maintenance culture in an organisation plays a critical role in maintenance function. Therefore, this function impacts the implementation of maintenance strategies & selection of maintenance strategies (Wang, 2001; Cooke, 2003; Carnero, 2006; Garg & Desmukh, 2006; Pintelon & Gelders, 1992; Pinjala, Pintelon, & Vereecke, 2006; Michael, Kwasi, & Jack, 2000).

1.2.2 Maintenance Strategies Selection Process

Maintenance strategies selection process includes the activities such as formulation of maintenance strategies, selection of maintenance strategies, and implementation of maintenance strategies. Frameworks related to maintenance strategy formulation have been brought out from the literature. A key point in formulation of maintenance strategy is to link the maintenance strategies to operational strategies and further to business strategies. While formulating the maintenance strategies, such strategies have to be assessed & evaluated based on major system & organisational elements. Maintenance performance measures provide key inputs to formulation of maintenance strategies (McAllister, Armstrong, & Wilson, 1999; Waeyenbergh & Pintelon, 2002; Cooke, 2003; Kelly, 2006; Campbell & Picknell, 2006; Rosqvist, Laakso, & Reuanen, 2007; Salonen, 2011).

Selection of maintenance strategies is the choice among the maintenance approaches such as TBM, CBM, RCM, TPM etc. Selection of maintenance strategy is treated by authors' as Multiple Criteria Decision Making (MCDM) problem. The MCDM problem can be solved with the techniques such as Analytical Hierarchy Process (AHP), Fuzzy AHP, VIKOR, etc. (Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy, Atrens, & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Li et al., 2009; Jinqiu & Laibin, 2014).

Decision Support System (DSS) models are used for selecting suitable maintenance methodology for specific operation/process/equipment. The maintenance method selected through DSS model helps in improvement of maintenance function and optimisation the operational/ maintenance costs. Reliability assessment, risk levels and failure management in maintenance can be effectively handled with the help of these models using tools such as fuzzy Bayesian methods, fuzzy modelling, Analytical Hierarchy Processing (AHP) etc.(Knezevic, 1994; Ashayeri et al., 1996; Crespo, 2005; Li et al., 2009; Rolando et al., 2009; Ayadi, Chaib, & Verzea, 2014).

Implementation of preventive/predictive maintenance strategies leads to improvement in maintenance function such as reduced maintenance cost, increased equipment's reliability. Corrective maintenance costs become higher than the preventive maintenance costs in a long term period. Few literature suggest for Plant-level Maintenance Decision Support System (PMDSS) for implementation of optimum maintenance strategies mix suitable to particular operation/process/equipment. (Jayabalan & Chaudhuri, 1992; David & Shahram, 1993; Crespco, 2005; Pinjala, Pintelon, & Vereecke, 2006; Ling, Jian, & Wang, 2006; Gokiene, 2010; Sami & Ben-daya, 2010; Veldman, Klingenberg, & Wortmann, 2011; Jain, Bhatti, & Singh, 2014).

The detailed literature review reveals that the most of existing literature have discussed evaluation system for setting up a particular maintenance method/approach such as Preventive Maintenance & Predictive Maintenance, linking performance with the maintenance strategy, application of specific maintenance method/approach like Preventive Maintenance, Predictive Maintenance, RCM, CBM etc. for a particular industry in a country like Italy, Belgium, Africa etc., development of Maintenance Decision Support Systems (MDSS) for selection of maintenance strategy, development of Plant level Maintenance Decision Support System (PMDSS) implementation of e-maintenance concept, maintenance polices and their impact.

Further, authors have developed frameworks/models related to maintenance strategy processes such as maintenance strategy formulation, selection of maintenance strategies and implementation of selected maintenance strategies (McAllister et al., 1999; Pintelon & Gelders, 2002; Kelly, 2006; Eti et al., 2006; Pintelon & Parodi, 2008; Muchiri et al., 2011; Umar, 2011). However, each model describes one or two processes of maintenance strategy but not in combined manner integrating all the maintenance strategy related processes. Based on these inferences, it is evident that there is a need in Industry to develop a holistic model which combines factors such as maintenance strategy formulation, selection and implementation of formulated maintenance strategies.

Literature could not explain about how the maintenance managers/engineers are ensuring smooth operation of plant by effective use of maintenance strategies in planning & execution at an organisation level. Further, no literature could reveal about why the specific maintenance strategy is selected for a particular equipment/process and how these maintenance strategies are different in different plant processes/equipment. Therefore, maintenance strategies related processes study is to be carried out to incorporate existing maintenance practices of an organisation so that maintenance strategies & maintenance practices can be described in a holistic manner.

It is evident from the literature review that the maintenance strategies related frameworks established relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in an organisation, but they failed to explain how and why are these related. As explanation is essential for building theory and for improving practice, there is a need for process study of maintenance strategies & maintenance practices at an organisation level. Further, extensive literature search for maintenance strategies & maintenance practices study using qualitative research approach at an organisation level in operations intensive industry like natural gas industry in an Indian context found no references. (As on 02-05-2014, literature in databases such as EBSCO (Business Source Premier & Business Source Elite+), Emerald, Elsevier's Business Management & Accounting Collection (Science Direct), Blackwell's HSS Collection, IEEE Online, ACM Digital Library with the following key words maintenance, maintenance strategy, preventive maintenance, predictive maintenance, condition based maintenance, reliability centred maintenance, maintenance policy, maintenance practices, Selection of maintenance strategy, Indian gas industry, maintenance decision making, maintenance effectiveness, maintenance scheduling, maintenance planning, corrective maintenance, reliability, decision support system, maintenance flexibility, maintenance management, computerised maintenance management, maintenance performance, study of maintenance practices) which lead to the identification of research problem as described in the next section.

1.3 PROBLEM STATEMENT

Although in the existing literature various maintenance strategies applicable for different types of operations intensive industry is well known but the process of maintenance strategies selection & maintenance practices at an organisation level have not been described in detail. Further, there is lack of holistic process model for maintenance strategies & maintenance practices planning and execution.

1.4 POTENTIAL SIGNIFICANCE

There is a need to describe the processes of maintenance strategies selection and maintenance practices at an organisation level in operations intensive industry like natural gas industry in an Indian context, as little work has been done in this area. Maintenance strategy formulation and selection aspects have been studied & described in few models/frameworks. (Cooke, 2003; Kelly, 2006; Campbell & Picknell, 2006). Selection of maintenance strategies is the selection among the maintenance approaches such as TBM, CBM, etc. Selection of maintenance strategy is treated by authors' as Multiple Criteria Decision Making (MCDM) problem. This problem is solved with the mathematical techniques AHP, FAHP, VIKOR, etc. (Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy, Atrens, & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Li, Ambani, & Ni, 2009). However, these models do not have feedback from maintenance performance & existing maintenance practices at an organisation level. Maintenance practices of usage of mathematical modelling for maintenance strategies selection at an organisation level found no references in literature. There is a need to understand whether mathematic modelling is practically being used in the industry & also in Indian context, if yes then how.

Implementation of maintenance strategies depends on various resources such as manpower, material etc. Few literatures suggest the Plant-level Maintenance Decision Support System (PMDSS) for optimising the resources in order to implement suitable maintenance methodology (Li, Ambani, & Ni, 2009; Ronaldo et al., 2009; Ashayeri, Teelen, & Selen, 1996; Knezevic, 1994; Crespo, 2005; Ayadi et al., 2014). However, literature in integrated study of maintenance strategy implementation along with maintenance strategy formulation, selection and maintenance performance in natural gas industry of Indian context is found no references. Based on these inferences from literature, it is evident that an immense requirement to understand on maintenance strategy formulation, selection of maintenance strategies and implementation and maintenance practices from the experiences of maintenance mangers in the industry at an organisation level and such kind of study will definitely be useful to understand the gap between the common maintenance strategies studied and proposed in the literature and maintenance strategies being actually adopted and practiced by maintenance managers in the industry.

This research study would be useful to both the academicians and practitioners. For academicians, this research would provide a new insight in terms of unit of analysis (maintenance in process plant/pipelines), empirical research methodology, and a rich description of maintenance strategies and maintenance practices in process plant and natural gas pipelines at an organisation level in operations intensive industry.

For practitioners such as maintenance managers/engineers in process plant/natural gas pipelines, this research would suggest some ways of improving maintenance strategies formulation, selection and maintenance practices in the industry, which can be tested in real life situations.

1.5 THESIS DISPOSITION

This research work is discerned in the parts of Introduction, Literature Review, and Research Design & Research Methodology. This is followed by the individual case analysis, cross case analysis, and conclusions.

This chapter discussed the context and background of this research study. Next chapter presents the detailed literature review and conceptual framework used in this research and related literature. In Chapter 2, theoretical foundations of maintenance, a literature survey on maintenance are discussed in detail and then literature have been categorised & presented on Key themes based on maintenance management processes. Thereafter, discussed on Initial Conceptual Constructs (ICC) & Sub-Constructs derived from literature and finally comparisons of various maintenance related models are also presented. Overall, Chapter 2 describes how the conceptual lens & ICC have been derived by systematically categorising literature and further analysing, synthesising the literature in a logical manner to arrive at literature gaps.

Chapter 3 discusses about research design and research methodology of this research study. It will include the sections such as research objectives and research questions, over-all research approach and rationale, case study design, data collection method, data analysis strategy, and quality of empirical research. Finally, this chapter discusses about the development of Case Study Protocol (CSP) and a copy of complete Case Study Protocol document is also presented in chapter 3 for ready reference.

In Chapter 4 & Chapter 5 analysis of data and outcomes of data analysis are presented in detail for both the case studies (Case Study 1 – Natural Gas Pipelines & Case Study 2- Petrochemicals) on maintenance strategies and maintenance practices of a large gas utility company in India. These chapters include the following sections: introduction on case, data collection, data analysis, findings of data analysis, discussion on data analysis outcomes and conclusions.

Chapter 6 explains about cross case analysis and findings. This chapter describes the similarities and dissimilarities between the two cases NG Pipelines and petrochemicals. Then, cross case comparison is discussed in detail. The findings of cross case analysis are presented along with the findings related to benchmarking in maintenance. Further, fourteen propositions have been developed from the cross case analysis and all these propositions are presented and discussed in detail.

The last chapter (Chapter 7) discusses the conclusions and significance of the findings of this research study, and then presents the limitations of the study. A model for maintenance strategy selection & maintenance practices planning and execution has been developed based on data analysis. This model is presented & explained in detail. Further, the scope for future research in the area of maintenance strategies and maintenance practices is also presented in the last chapter.

1.6 CONCLUDING REMARKS

This chapter discussed the context and background. Asset maintenance in core operations intensive industry like natural gas industry becomes the challenge at an organisation level. As described in the background, asset maintenance plays a crucial role in achieving enhanced productivity and higher profitability and this will help core operations intensive industry to achieve the targeted GDP growth. In asset maintenance, managers/engineers face a major challenge of production loss due to plant shutdown/ equipment failure/accidents. Based on this background, business problem has been developed and presented in this chapter.

This business problem leads further exploration on literature. In-depth literature review shows that literature are available on selection of maintenance strategies such as preventive maintenance, predictive maintenance, reliability centred maintenance, total productive maintenance etc. using mathematical models, maintenance performance measurements, impact of maintenance performance on maintenance strategies implementation, impact of e-maintenance, impact of maintenance policies in maintenance. Further, maintenance strategies related models/frameworks discusses on maintenance strategies formulation and implementation. The key highlights of information available on maintenance strategies selection and maintenance strategies & maintenance practices are presented in this section. Lack of literature on study of maintenance strategies related processes at an organisation level in an Indian context to understand on how the maintenance managers formulate the maintenance strategies and why they select specific strategies for a particular equipment/ process. Problem statement for this research study has been formulated based on literature gap and business problem & presented in this chapter.

Potential significances of this research study and thesis disposition are also presented in this chapter. Next, chapter presents the detailed literature review and theoretical framework/conceptual lens.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

A detailed literature review has been carried out to understand about maintenance and the processes of maintenance strategy formulation, selection of maintenance strategies, maintenance practices and implementation of maintenance strategies in the operation intensive industries. Based on literature review, definition of maintenance is explained section 2.2. Theoretical foundations of maintenance like maintenance productivity, maintenance challenges, and maintenance excellence concepts are discussed in section 2.3.

Literature related to maintenance have been reviewed, analysed, synthesised and presented in Section 2.4. These literature are further categorised into key themes such as maintenance strategy, maintenance strategy formulation, maintenance strategies selection, implementation of maintenance strategies, maintenance performance, maintenance approaches/methods development of Maintenance Decision Support System (MDSS) for selection of optimal maintenance strategy, E-maintenance & IT tools/software for maintenance strategy selection & implementation, and impact of maintenance policies, maintenance culture in maintenance. The key themes are discussed along with literature in section 2.5.

Outcome of this extensive literature review is initial conceptual constructs. The constructs conceptualised from the literature review are Maintenance Tactics, Reliability Analysis, Performance Measures/Benchmarking, Planning

& Scheduling, Materials Management, Organisation/Human Resources, Employee Empowerment, Information Technology, and Maintenance Polices/Budget. These initial conceptual constructs and sub-constructs are discussed thoroughly in section 2.6.

Various models/ frameworks on maintenance strategies formulation, selection, and implementation are identified from literature and the inferences from these frameworks/ models are explained in section 2.7 along with gaps. It can be used as a foundation of knowledge within the area of maintenance in order to develop a holistic & integrated model for maintenance strategies & maintenance practices planning and execution. Section 2.8 details about literature gaps.

2.2 MAINTENANCE

The term maintenance is well-defined in the published literature. However, the maintenance related terms are not defined properly. Few terms such as maintenance strategy, maintenance policy, maintenance tactics/approaches, maintenance concepts are used by the authors in different ways and also interchangeably.

Maintenance has been defined as the combination of technical and associated administrative actions intended to retain an item or system in, or restore it to, a state in which it can perform its required function (ISO 14224: 2004). Further, Dhillon (2002) defined maintenance as all actions appropriate for retaining an item/ part/equipment in or restoring it to, a given condition.

A proper maintenance needs technical skills, techniques, methods to properly utilize the assets like factories, power plants, vehicles, equipment and machines. The key objective of maintenance is to ensure system function (availability, efficiency and product quality), system life (asset management), and system safety with low energy consumption. Poorly maintained machines or equipment may lead to random breakdowns causing unavailability for production or service (Alsyouf, 2007).

"The main purpose of maintenance engineering is to reduce the adverse effects of breakdown and to increase the availability at a low cost, in order to increase performance and improve the dependability level" (Simeu-Abazi & Sassine, 2001).

In a manufacturing plant, task of production unit is to produce goods/products. The maintenance systems and policies influence the production capacity of the equipment used for producing these products. Therefore, maintenance function can be considered as an organisational function that working in parallel with production function (Alsyouf, 2007). Maintenance is viewed as an area of concern by the production engineers in an organisation because meeting the production target is objective of the production department. Thus, the integration of maintenance and production is very crucial for any organisation (Ben-Daya & Duffuaa, 1995).

Maintenance function is now become part of the integrated business concept. There is a shift from failure based maintenance to use based maintenance and further towards condition based maintenance. Now, organisations provide more emphasize on the key areas of maintenance functions such as availability, reliability, and safety in the production plants (Waeyenbergh & Pintelon, 2002).

Today, most of the organisations' strategy is to replace the current reactive, fire-fighting maintenance strategy with proactive strategies such as Time Based Maintenance (TBM), Condition Based Maintenance (CBM), and also with the aggressive strategies such as Reliability Centred Maintenance (RCM), Total Productive Maintenance (TPM) in order to achieve world-class maintenance performance (Swanson, 2001). In next section, theoretical foundations of maintenance are discussed in detail.

2.3 THEORETICAL FOUNDATIONS OF MAINTENANCE

Maintenance, especially industrial maintenance is the function which supports the operations/ production function. Operation/production is the primary process which transforms material with the help of manpower (input) into final products (outputs). Maintenance is the secondary process which helps operation/production function to achieve its targets as per requirement (Gits, 1994). Therefore, maintenance plays a crucial role in achieving the production targets. Maintenance function is to be transformed into smooth production/operation by ensuring the physical assets/equipment in healthy condition.

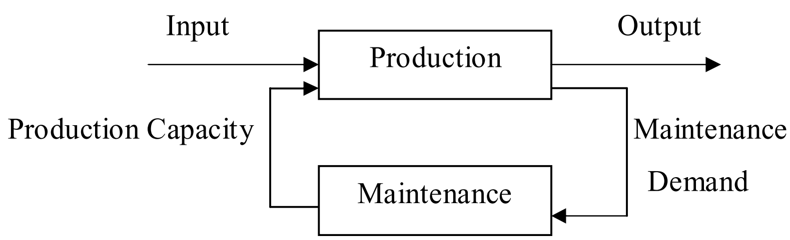


Figure 2.1: The relation between maintenance & production (Gits, 1994)

2.3.1 Maintenance Productivity

As shown above in Figure 2.1, economics of production majorly depends on maintenance productivity. However, maintenance productivity is often ignored and the production process is treated as primary function (Singh et al., 2000). The impact of maintenance productivity has been recognized by the industry and also been considered as integral part of the business since it add values to the business process (Liyanage & Kumar, 2003). Maintenance productivity is required to be measured properly and the same is being followed in several years by the industry (Andersen & Fagerhaug, 2007). The challenge in keeping high maintenance productivity is depending upon the holistic and integrated measurement approach of maintenance performance.

2.3.2 Challenges in Maintenance

Nowadays, organisations view maintenance as a critical support function which helps to sustain productivity and promote growth in organisation. Effective maintenance targets the following: maximisation of uptime, reduction in cost, improvisation in accuracy, prevention of safety hazards, risk mitigation, and more environment friendly orientation. These are the strategic needs of business in any organisation. Maintenance challenges are to optimise the maintenance decisions. The ultimate aim is to accomplish control over maintenance decisions (Campbell et al., 2001).

Continual effort is required to manage and control maintenance decisions otherwise random failures of assets/equipment controls costs. Such huge costs are not affordable in today's competitive business environment. In many organisations, maintenance managers/engineers are performing maintenance activities in a ''fire fighting'' mode. Without proactive maintenance actions, the organisations can only respond after the occurrence of the failure only. The results of such approach lead to low reliability, availability, and productivity which are the factors responsible to lower profitability (Campbell & Picknell, 2001)

2.3.3 Maintenance Excellence

Optimisation of maintenance effectiveness cannot be achieved by uncontrolled environment in the organisation. This can be accomplished with informed and intelligent decisions by the managers in the organisation. For the same, accurate and relevant data are required. Therefore, it is essential that maintenance system and process must under control in order to optimise the maintenance performance. The necessary elements for maintenance excellence are, (i) best leadership practices, (ii) control over day-to-day maintenance activities, and (iii) after having control, application of continuous improvement methods. The factors contributing to maintenance excellence and sub-elements are shown in Figure 2.2.

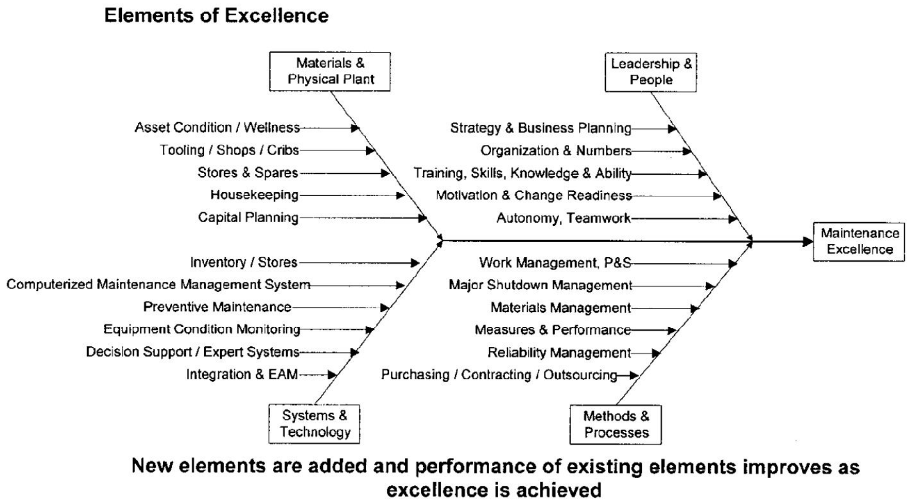


Figure 2.2 Elements of Maintenance Excellence (Campbell et al., 2001)

2.4 Maintenance – A Literature Survey

A detailed literature survey was carried out in the databases such as EBSCO (Business Source Premier & Business Source Elite+), Emerald, Elsevier's Business Management & Accounting Collection (Science Direct), Blackwell's HSS Collection, IEEE Online, ACM Digital Library with the following key words maintenance, maintenance strategy, preventive maintenance, predictive maintenance, condition based maintenance, reliability centred maintenance, maintenance policy, maintenance practices, Selection of maintenance strategy, Indian gas industry, maintenance decision making, maintenance effectiveness, maintenance scheduling, maintenance planning, corrective maintenance, reliability, decision support system, maintenance flexibility, maintenance management, computerised maintenance management, maintenance performance, study of maintenance practices. The summary of literature related to maintenance methods/approaches/strategies, formulation of maintenance strategies, selection and implementation of maintenance strategies, e-maintenance etc. is presented in the Table 2.1.

Table 2.1 Summary of Literature Survey on Maintenance

Study/Authors	Year	Context (Country/Industry)	Themes/Messages
Patrik, J.	1999	Manufacturing firms from Swedish Industry	Companywide integration and long term plans of maintenance both have impact on preventive maintenance and quality improvement in manufacturing capabilities.
Bevilacqua, M., & Braglia, M.	2000	Italian Refrigeration Manufacturing firm	Failure modes and effects on maintenance in a refrigerator manufacturing firm using fuzzy logic AHP are identified. Failures of maintenance can be reduced using this model at firm level.
Wang, H.	2002	Single unit & Multi unit systems	Optimal maintenance policy in single unit & multi-unit systems impact the system maintenance cost rate and system reliability measures.
Waeyenbergh, G., & Pinetelon, L.	2002	Automobile industry	A framework for maintenance concept development proposes five modules for establishing maintenance concepts. The modules include identification of objectives and resources, identification of most important systems (criticality analysis), maintenance policy decision, performance measurement, and continuous improvement.
Bertolini, M., & Bevilacqua, M.	2005	Oil Refinery	'Lexicographic' Goal Programming (LGP) methodology is used to select optimum maintenance strategy for critical centrifugal pumps in an oil refinery.
Carnero, M. C.	2006	Petrochemical Plant/food industry in Spain	Developed an evaluation system for setting up preventive maintenance program & tested the evaluation system in a petrochemical plant & food industry. This helps to take practical decision in the firm.
Ling, W., Jian, C., & Wang, J.	2006	Power plant in China	Selection of maintenance strategies for power plant boilers using Analytical Hierarchy Process is demonstrated. It is an effective tool to solve uncertainty and imprecision associated with

			Multiple Criteria Decision Making (MCDM) Problem.
Muller, A., Crespo, M. A., & Lung, B.	2007	Spanish Industry based study	E-maintenance concepts & and issues are becoming more important in technical, organisational & managerial aspects of maintenance function.
Mahdi, B., Hossein, B., & Taha, H. H.	2010	NA	Maintenance strategies can be ranked through mathematical modelling using qualitative & quantitative data related to maintenance function.
Rolando, Q., Mark, T. L., Villalobos, J. R., & Graul, M.	2009	Mexico based company	Maintenance Brigade System (MBS), a team based mechanic assignment system can be used to achieve higher reliability of machine/equipment in a production unit.
Nima, S., Dragan, B., & Jardine, K. S.	2010	Cellular Manufacturing Industry	Use based maintenance policy in a cellular organisation helps to optimise the maintenance activities.
Pophaley, M., & Vyas, R. K.	2010	Automobile Industry	Theory of Constraints (TOC) principle in an Automobile company helps to improve maintenance planning and execution.
Li, L., Ambani, S., & Ni, J.	2009	Automotive Assembly line of Automobile Industry	Plant level Maintenance Decision Support System (PMDSS) is developed by combining the short term and long term decision making process to improve overall system performance with profit maximization in short term for a local automotive corporation. i.e., improvement in throughput comparing with the conventional maintenance policies.
Garg, A., & Deshmukh, S. G.	2006	Telecommunication/ Military	Organisational case is proving that flexibility in maintenance management helps to streamline maintenance process in telecommunication industry.
Eti, M. C., Ogaji, S. O., & Probert, S. D.	2006	Nigerian Industry	Organisations with a good maintenance culture will incur relatively low running cost with respect to the end-product costs.
Eti, M. C., Ogaji,	2006	Nigerian Industry	Preventive maintenance is based on

S. O., & Probert, S. D.			condition of equipment/assets. Inputs from equipment/assets conditions are basis for development and implementation of PM practices in the industry.
Marchi, M., & Garetti, M.	2006	E-maintenance	Provided benchmark study in complex production systems using e-maintenance strategic maintenance planning
Crespo, M. A., & Gupta, J. N.	2005	Spanish Industry	A framework for managing the maintenance function with the tools, trappings, practices & prescriptions in maintenance management is demonstrated.
Jay, L., Jun, N., Dragan, D., Hai, Q., & Haito, L.	2006	Prognostic tool like watchdog agent	Intelligent prognostics tools and e-maintenance can be used effectively in maintenance function to asses planning and execution of activities in that area.
Pintelon, L. M., & Gelders, L. F.	1992	Maintenance Management	Maintenance management has been neglected for a long time even though company business gets affected due to poor maintenance management. Good knowledge on operation research techniques will help to understand maintenance practices in an organisation.
Ashayeri, J., Teelen, A., & Selen, W.	1996	Belgium Process Industry	A Production and Maintenance Planning Model for the Process Industry in Belgium suggests the integration of both production & maintenance function for betterment of maintenance.
Swanson, L.	2003	Primary metals; a fabricated metal products; industrial & metal working; precision instruments; chemical & food processing (US Industries)	Computerised Maintenance Management System (CMMS) is used to understand complexity in maintenance so as to provide better solutions in maintenance. Further, coordination among work force can also be achieved.
Swanson, L.	2001	US Industries	There is a strong positive relationship exists between proactive & aggressive maintenance strategies and also

			performance of the plant can be improved by studying such relationship.
Jayabalan, V., & Chaudhuri, D.	1992	Transport Industry	The number of PM interventions and their time schedules could minimize the expected mean cost rate over an infinite time horizon for the preventive maintenance policies. The same was tested for the bus engines of a transport network.
Umar, A.	2011	Strategic Maintenance Planning	A framework for strategic maintenance planning suggests for involvement of all stakeholders and top management commitment are crucial factors in strategic maintenance planning.
Jafari, A., Jafarian, Z. M., & Zaerpour, F. A.	2008	Manufacturing Industry	Maintenance Strategy Selection Problem (MSSP) has been dealt with the new approach fuzzy Delphi method using Simple Additive Weighing (SAW). Accuracy in MSSP is demonstrated based on determining the correct maintenance goals in the decision making process.
Jin, Z., Li, L., & Ni, J.	2009	Manufacturing Industry	Coordination between Production & Preventive maintenance systems helps to improve maintenance performance in the manufacturing industry.
Chris, K. M., & Wang, Z.	2001	Maintenance Strategy Selection	Fuzzy Linguistics is used to select optimum & condition based maintenance strategies in the industry.
Ilangkumaran, M., & Kumaran, S.	2012	Textile Industry	Selection of maintenance strategy using Hybrid VIKOR model is an effective method in applications of textile industry.
Chitra	2003	Life-Based Maintenance Policy	Life Based Maintenance policy ensures better reliability & reduce maintenance cost in maintenance management of the industry.
Mokashi, A. J., Wang, J., & Vermar, A. K.	2002	Maritime Operations	Application of Reliability Centred Maintenance (RCM) as a maintenance methodology in maritime operations helped to improve their maintenance performance. It is suggested that RCM should be taught as philosophy to the

			seafarers.
Gokiene, R.	2010	Automobile Industry	Discussed about cost benefits of two main asset maintenance strategies such as preventive maintenance & predictive maintenance. Over the long run corrective maintenance costs become higher than the preventive maintenance costs.
Muchiri, P. N., Pintelon, L., Martin, H., Anne, M., & De, M.	2010	Belgium Industry/Manufacturing companies	Key Performance Indicators (KPI) for maintenance activities have been developed and tested based on industrial survey from Belgian industries. It shows a strong positive relation between satisfaction and process changes through KPI.
Liu, Y., Li, Y. F., Huang, H. Z., Zuo, M. J., & Sun, Z.	2010	Power Generators	Usefulness of optimal preventive maintenance strategy under a fuzzy Bayesian environment for power generators is demonstrated.
Dekker, R.	1996	Maintenance Optimisation Models	Maintenance optimisation models are very effective in maintenance decision making. However, the usage of these models in maintenance organisations is limited.
Kodali, R., & Chandra, S.	2001	Indian Industry	Application Total Productive Maintenance (TPM) for Indian industries have been described through multi attribute decision model using AHP.
Alsyouf, I.	2009	Swedish Paper Industry	Changes in productivity affect the profitability of the organisation. Maintenance is shown as profit generating function instead of cost centre through a case study of a Swedish paper mill.
Seth, D., & Tripathi, D.	2006	Indian Manufacturing Industry	Total Quality Management (TQM) & Total Production Management (TPM) application could improve business performance in Indian manufacturing industry mainly with automobile, engineering & process industries.
Nguyen, D. Q.,	2008	Chemical Processing	Using Monte Carlo based simulation

Brammer, C., & Bagajewicz, M.		Plant	method, benefits of preventive maintenance scheduling in chemical process plants has been proved.
Sami, E., & Ben-daya, M.	2010	Batch process industry	A proposed integrated maintenance model would help the batch process industry to perform PM activities effectively. Here, the PM activities are carried out at the end of the production operation.
Wilmeth, R. G., & Usrey, M. W.	2000	Battery Manufacturing Industry	The RCM analysis of Battery Supplier illustrates that the existing battery maintenance program can be improved by applying RCM.
Verma, A. K., & Suresh, P. G.	2007	Shipping Industry	Higher Modular Assemblies (HMA) in shipping industry preventive maintenance scheduling optimisation problem could be solved effectively using Genetic Algorithm (GA).
Ahmadi, A., Gupta, S., Karim, R., & Kumar, U.	2010	Air Craft System in Aviation Industry	MCDM problem of Air Craft System can be solved using mathematical techniques such as AHP, TOPSIS & VIKOR in order to select suitable maintenance methodology.
Simoes, J. M., Gomes, C. F., & Yasin, M. M.	2011	Maintenance Performance	Based on literature review related to maintenance performance, it is concluded that the more systematic research is required to identify the theoretical constructs and testing of these constructs in the area of maintenance performance.
Murthy, D. N., Atrens, A., & Eccleston, J. A.	2002	Australian Industry	Strategic Maintenance Management (SMM) approach is used to demonstrate the key decisions in maintenance such as selection of optimal maintenance strategy, continuous improvement in business performance.
Sherwin, D.	2000	Maintenance Performance	Review of maintenance management models shows that the Life Cycle Profit (LCP) perspective is a fair measure in assessing maintenance performance.
Liptrot, D., & Palarchio, G.	2000	Maintenance Practices/Canada Steel Industry	Using information technology advances, a Canadian steel company had implemented the Intelligent

			Condition Monitoring System (ICMS) with integration through Computerised Maintenance Management System (CMMS). Increase in profit has been achieved by the company.
Campbell, J. D., Jardine, A., Marshall, K. S., & Decker, A. G.	2001	NA	Book on Maintenance Excellence, Optimizing Equipment lifecycle decisions.
Rosqvist, T., Laakso, K., & Reunanen, M.	2007	Finland gasification plant	Value Driven Maintenance Planning (VDMP) approach is used to support continuous improvement and better maintenance planning in order to achieve the maintenance cost effectiveness. The same is demonstrated with Finland gasification plant.
Crespo, M. A.	2005	Mining Industry	Using maintenance modelling tools, simulation model for mining industry has been developed & validated. This model helps to optimise the maintenance practices in the industry.
Pinjala, S. K., Pintelon, L., & Verreecke, A.	2006	Manufacturing Industries in Belgium & Netherlands	More proactive maintenance policies, better planning and control systems have been implemented by quality competitors in the manufacturing industry in Belgium/Netherlands. This is achieved by using Advanced Maintenance Technologies (AMT), Automation, more budget spending and effective maintenance personnel.
Cooke, F. L.	2003	British Manufacturing /Processing Industry	The case study on British processing companies shows that pressure in achieving production targets leads to reactive maintenance in the companies. This is counterproductive in long-term performance of the process plant in those companies.
Veldman, J., Klingenberg, W., & Wortmann, H.	2011	Process Industry/ Netherlands	Empirical perspective of condition based maintenance strategy in the industry shows that implementation of prognostic condition-based maintenance will help maintenance

			mangers to improve maintenance performance in their organisations.
Waeyenbergh, G., & Pinetelon, L.	2002	Manufacturing company	Maintenance concept development has been done for a manufacturing company using 7-step modular framework. This framework helps maintenance managers to understand the maintenance of their own company and manage resources effectively.
Parida, A., & Uday, K.	2009	Maintenance Performance	Maintenance Performance Indicators (MPI) is useful measures to assess the maintenance performance in operations intensive industries. Maintenance Performance Measurement (MPM) in the organisations can be done with various multi-criteria frameworks suggested in this paper.
Benchmark Study Report of GAIL India Limited	2002	Benchmark study has been conducted by M/S. A T KERNEY for various operating parameters in operations of Natural Gas pipelines, LPG Plants & Petrochemicals. The proposed Benchmark parameters by M/S. A T KERNEY are Fuel Gas Consumption (2.4% of Gas Delivered in Energy Terms), Maintenance Cost (0.83% Gross Block), G & A Cost (2.62% of Gross Block), Unaccounted Gas (0.3% of Gas Handled in terms of volume & energy), Loss of Liquid Hydrocarbons (0% of production in the units measured & sold)	

Based on above literature survey few key inferences regarding maintenance approaches/ methods, maintenance strategies and maintenance practices are discussed below.

In general the maintenance of any system is classified under two categories: Failure based maintenance (i.e., corrective maintenance, CM) and Life based maintenance (i.e. Regular Preventive Maintenance, RPM). However, the CM cannot be avoided when a random failure of a component occurs and cost depends on the number of components replaced during the entire operating period of system and the respective cost involved in maintenance actions (Chitra, 2003; Wang, 2001, Patrik, 1999; Jayabalan & Chaudhuri, 1992).

The original maintenance strategy is failure based which indicate that equipment would be repaired each time it breaks down and no action is performed to detect or prevent the failure. However, in this case the cost of maintenance is usually high but sometimes it is cost effective also (Jafari et al., 2008).

In the case of Regular Preventive Maintenance (RPM), maintenance activities are executed as per time schedule or based on predetermined running of equipment/machine. Spare parts are changed before the end of their service life. The maintenance cost remains high. Therefore, to avoid the frequent failure of equipment/machine, RPM is used regardless of the condition of equipment (Eti et al., 2006). It may appear to be unnecessary cost in doing maintenance.

Even though preventive maintenance does not immediately reflect in terms of breakdown cost or production down time cost, it can be considered as counter-productive. RPM cost is actually an investment to prevent against emergency shutdown of plant/equipment and major damages to individual equipment. This method will be more advantageous in following conditions (i) if failure rate increases with the age; (ii) RPM downtime is less compare to repair after failure (Gokiene, 2010).

Nowadays, many manufacturing organisations have shifted to a new methodology known as Predictive Maintenance (PM). However, predictive maintenance costs are higher while results are difficult to predict (Carnero, 2006). A PM approach attempts to detect equipment degradation online. Maintenance requirements are based on the actual condition (normally measured quantitatively or qualitatively) of the equipment/machine. It is not based on some predetermined schedule. It involves predicting the failure before it occurs by identifying the root causes for those failure symptoms. Failures are avoided before they cause extensive damage to equipment (Jafari et al., 2008). In contrast, condition-based maintenance can be a better and more cost effective than time-based maintenance (Parida, 2007).

To evaluate different maintenance strategies (such as corrective maintenance, time-based preventive maintenance, condition-based maintenance, and predictive maintenance) for various equipment/machine, mathematical modelling methods such as Analytical Hierarchy Process (AHP), Fuzzy AHP, Lexicographic' Goal Programming (LGP), and VIKOR models are being used in the industry. These techniques are used to select best maintenance strategy for a particular industry/ equipment/ process (Bevilacqua & Braglia, 2000; Bertolini & Bevilacqua, 2005; Mahdi, Hossein, & Taha, 2010). Further, these techniques are also used to tackle uncertainty & imprecision associated with MCDM problems (Ling, Jian, & Wang, 2006).

E-maintenance becomes one of the important aspects of maintenance. Even though implementation of this new concept in the industry during last decade has lot of challenges, e-maintenance is an inevitable system to perform the maintenance activities in the industry (Muller, Crespo, & Lung, 2007). Further details on e-maintenance are discussed in the next section.

Literatures are further classified based on key themes and is presented in next section. Each key theme is discussed in detail.

2.5 Theme Based Literature Classification

The literature have been categorised into different key themes with respect to maintenance strategies and maintenance practices in the industry. The details are presented in the below given Table 2.2.

Table 2.2 Categorisation of literature based on Key Themes

S No.	Key Themes	Select Author(s)	Inferences	Gaps
1	Maintenance Strategy	Gallimore & Penlesky, 1988; Pintelon & Gelders, 1992; Dekker, 1996; Kelly, 1997; Mckone & Elliott,	Maintenance strategy is not well defined in the literature. Maintenance strategy term is used	Maintenance strategy is treated by authors in various contexts such maintenance approach/

		1998; Sherwin, 2000; Swanson, 2001; Bevilacqua & Braglia, 2000; Cooke, 2003 ; Crespo & Gupta, 2006 ; Veldman, Klingenberg, & Wortmann, 2011; Pinjala, Pintelon & Vereecke, 2006; Yung-Hisang & Hou-Lei, 2014	interchangeably with maintenance policy, maintenance approach etc.; Maintenance strategy is a systematic approach to upkeep the asset/facility; Authors have categorised maintenance strategies as Time Based Maintenance (TBM), Condition Based Maintenance (CBM), etc. and these are also mentioned as maintenance policies/ maintenance approaches by few authors in the published papers.	maintenance method/ maintenance policy etc. How maintenance strategy is treated at an organisation level in operations intensive industry like natural gas industry is unknown?
2	Formulation of Maintenance Strategy	McAlister, 1999; Waeyenbergh & Pintelon, 2002; Cooke, 2003; Kelly, 2006; Campbell & Picknell, 2006; Rosqvist, Laakso & Reuanen, 2007; Salonen, 2011	Three frameworks related to maintenance strategy formulation brought out from the literature; A key point in formulation maintenance strategy is to link the maintenance strategy to operational & business strategies; While formulating the maintenance strategies, these strategies have to be assessed & evaluated based on major systems specific to organisations & organisational elements;	Maintenance strategy formulation aspects have been studied in few models as described above. However, these models do not have feedback from maintenance performance & existing maintenance practices at an organisation level.

			Maintenance performance measures provide key inputs in formulation of maintenance strategies.	
3	Maintenance Strategy Selection	Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy , Atrens, & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Li et al., 2009; Jinqiu & Laibin, 2014	Selection of maintenance strategies is the selection among the maintenance approaches such as TBM, CBM, etc.; Selection of maintenance strategy is treated by authors' as Multiple Criteria Decision Making (MCDM) problem. The same was solved with the techniques AHP, FAHP, VIKOR, etc.	Maintenance Practices of usage of mathematical modelling for maintenance strategies selection at an organisation level found no references in literature. There is a need to understand whether mathematic modelling is practically being used in the industry & also in Indian context, if yes then how.
4	Implementation of Maintenance Strategy	Campbell & Picknell, 2006; Eti et al., 2006; Crespco, 2005; Pinjala , Pintelon, & Vereecke, 2006; Veldman, Klingenberg , & Wortmann, 2011; Jain, Bhatti, & Singh, 2014	Implementation of maintenance strategies depends on various resources such manpower, material etc.; Few literature suggest the Plant-level Maintenance Decision Support System (PMDSS) for implementation of suitable maintenance methodology.	Lack of literature in integrated study of maintenance strategy implementation along with maintenance strategy formulation, selection and maintenance performance.
5	Maintenance Performance	Tsang, Jardine, & Kolodny, 1999; Sherwin, 2000; Swanson, 2001; Kutucuoglu et al., 2001; Visser & Pretorious,	Key Performance Indicators (KPIs) are helpful in measuring maintenance performance gaps; Balance Scored Card	Lack of study on implementation of maintenance performance measures in operations intensive industry like

		2003; Weber & Thomas, 2006; Parida & Chattopadhyay, 2007; Parida & Uday, 2009; Muchiri et al., 2011 ; Simoes, Gomes, & Yasin, 2011	(BSC) approach helps organisations to translate the business strategies into operational strategies; Benchmarking is integral part of maintenance performance measurement.	natural gas industry in Indian context.
6	Maintenance Approaches/ Tactics/ Policies	Jayabalan & Chaudhuri, 1992; David & Shahram, 1993; Cooke, 2003; Carnero, 2006; Ling, Jian, & Wang, 2006; Gokiene, 2010; Sami & Ben-daya, 2010; Jin, Li, & Ni, 2009; Angelica & Jose Luis, 2014	Implementation of Preventive/ Predictive Maintenance strategy leads to improvement in maintenance function such as reduced maintenance cost, increased equipment's Reliability; Corrective maintenance costs become higher than the preventive maintenance costs in a long term period.	No reference is found in the literature regarding selection of optimum mix of maintenance methods in operations intensive industry like natural gas industry in Indian context.
7	Development of Maintenance Decision Support Systems (MDSS) for selection of Optimal maintenance strategy	Li, Ambani & Ni, 2009; Ronaldo et al., 2009; Ashayeri, Teelen, & Selen, 1996; Knezevic, 1994; Crespo, 2005; Ayadi, Chaib, & Verzea, 2014	Decision Support System models prove that the implementation of suitable maintenance methodology helps in improving maintenance function & optimise the operational/ maintenance costs; Reliability assessment, risk levels and failure management in maintenance can be effectively handled with the help of	Study on practical implications of Maintenance Decision Support Systems (MDSS) in operations intensive industry like natural gas industry in Indian context found no references.

			models using tools such as fuzzy Bayesian methods, fuzzy modelling, Analytical Hierarchy Processing etc.	
8	E-maintenance & IT tools/software for maintenance strategy selection & implementation	Raouf , Ali, & Duffuaa, 1993; Liptrot & Palarchio, 2000; Marchi & Garetti, 2006; Muller, Crespo, & Lung, 2007; Jay et al., 2006 ; Swanson, 2003; Elliot & Tobias, 2005; Phillip & Ramin, 2014	Maintenance Environment responds to the IT environment & implementation of e-maintenance concepts like CMMS helps in strategic maintenance planning, scheduling and work force coordination.	Lack of study on practical implications & maintenance practices with reference to e-maintenance implementations in operations intensive industry like natural gas industry in Indian context.
9	Impact of Maintenance Policies, Maintenance Culture in maintenance strategy implementation	Pintelon & Gelders, 1992; Eti, Ogaji & Probert, 2006; Wang, 2001; Charles & Alan, 2005; Michael, Kwasi & Jack, 2000; Pinjala, Pintelon & Vereecke, 2006; Nima, Dragan & Jardine, 2010	Maintenance decision making & maintenance performance depends on the maintenance policy & maintenance culture of the organisation; Customization of maintenance organisation according to current business strategies helps organisation for successful maintenance strategy implementation.	Study on impact of maintenance policies and maintenance culture in operations intensive industry like natural gas industry in Indian context has found no references.

2.5.1 Maintenance Strategy

Maintenance strategy is not well-defined in the literature. Few authors define the maintenance strategy as the selection between the Condition Based Maintenance and Time-Based Maintenance. However, definitions & meaning of maintenance strategy collected from various literatures are as given under:-

Maintenance strategy is a systematic approach to upkeep the facilities and equipment and it varies from facility to facility. It involves identification, researching and execution of many repairs, replace and inspect decisions and is concerned with formulating the best life plan for each unit of the plant, in coordination with production and other functions concerned (Kelly, 1997). It describes what events (e.g. failure, passing of time, condition) trigger what type of maintenance action (inspection, repair, or replacement).Thus, selecting the best sustainable maintenance strategy depends on several factors such as the goals of maintenance, the nature of the facility or the equipment to be maintained, work flow patterns (process focus, product focus), and the work environment (Gallimore & Penlesky, 1988; Pintelon & Gelders, 1992). Maintenance strategy consists of mix of maintenance policies and maintenance techniques which vary from facility to facility (Dekker, 1996).

The maintenance strategy requires to be supported by tactical plans. These tactical plans must be the executable plans (Campbell & Picknell, 2006). Further, maintenance strategy needs to be reviewed periodically due to the changing environment and business requirements (Waeyenbergh & Pintelon, 2002).

Presently, most widely used maintenance strategies (maintenance approaches/tactics) includes Reliability Cantered Maintenance (RCM), Total Productive Maintenance (TPM), Business Cantered Maintenance (BCM), Capital Asset Management (CAM), and Integrated Logistic Support (ILS). Review and more description of some of these maintenance concepts are available with the literature (Al-Najjar, 1999; Waeyenbergh & Pintelon, 2002; Carnero, 2006; Gokiene, 2010; Nima et al., 2010).

Stakeholder involvement may lead to an undisputed view of achieving the expected deliveries to the production. This will lead to higher cooperation between production and maintenance function. Therefore, such kind of maintenance strategy would lead to higher productivity and organisation will in turn benefit from this (Salonen, 2009).

2.5.2 Formulation of Maintenance Strategy

Formulation of maintenance strategy must consider the following points (Campbell & Picknell, 2006).

1. Organisation should know the base line of maintenance strategy so that the vision of the organisation can be rebuilt in line with the successful practices.
2. Once the vision of the organisation is formulated, then the employees must be encouraged to understand the vision and think big to achieve the vision.

The key points in formulation of maintenance strategy are (Waeyenbergh & Pintelon, 2002) as given under:-

1. Holistic approach is required to formulate maintenance strategy.
2. Structured development of maintenance strategy is must in almost every case.
3. Apart from the structure maintenance strategy, flexible strategy is must so that it allows feedback, improvement and adjusts to changes in requirement of maintenance.

2.5.3 Selection of Maintenance Strategies

In published literature, many authors presented the selection of maintenance strategy as a selection suitable maintenance tactic/approach for an organisation i.e., about selection or evaluation of maintenance strategies such as Corrective Maintenance, Time Based Maintenance, Condition Based Maintenance etc. (Even though CM, TBM & CBM are termed as maintenance tactics/approaches by many authors, in case of maintenance strategy selection related papers these are termed maintenance strategies).

To select/choose these maintenance strategies for different equipment or system for particular industry, various models have been developed by researchers in this field. Selection of maintenance strategies for particular equipment/system in any industry is a typical Multiple Criteria Decision Making (MCDM) problem (Ahmadi et al., 2010). To deal with such kind of problem authors used Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP) etc. (Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Bertolini & Bevilacqua, 2005; Ling et al., 2006; Li, Ambani, & Ni, 2009; Rolando et al., 2009).

2.5.4 Maintenance Approaches/Methods

In early literature, several maintenance approaches i.e., strategies and concepts, have been discussed by various authors (Dekker, 1996; Moubray, 1997; Mckone & Elliott, 1998; Sherwin, 2000; Swanson 2001). Commonly reviewing maintenance strategies referred in published literature are such classification of maintenance strategies: Corrective Maintenance, Preventive Maintenance, and Predictive Maintenance. Swanson (2001) in his paper differentiates Reactive Maintenance (Corrective Maintenance), Planned Maintenance (Preventive Maintenance & Predictive Maintenance), and other maintenance types such as Total Productive Maintenance (TPM). Bevilacqua & Braglia (2000) consider each maintenance strategy as a separate strategy.

Maintenance Management concepts have to be reviewed with perspectives of business activities such as Operational, Tactical and Strategic. Therefore, maintenance strategies are the methods of transforming business objectives into maintenance objectives. A maintenance plan can be developed by identifying the current potential gaps in maintenance performance (Crespo & Gupta, 2006).

Maintenance Tactics or Approaches are the activities required to implement the strategy. This deals with the management processes, human resource, and physical asset infrastructure (Campbell & Picknell, 2006). The maintenance strategy is to create a direction of how to accomplish the maintenance objectives such as availability, reliability with a structured approach (Waeyenbergh & Pintelon, 2002). Further, they points out critical success factors such as maintenance personnel must have through knowledge to prevent failures in early stages, management skills including planning, human resource management and task management, ability to exploit maintenance history trends and opportunities.

A maintenance concept can be defined as the set of maintenance interventions such as Corrective Maintenance, Preventive Maintenance, and Condition Based Maintenance etc. and these interventions provide general framework from which the maintenance strategies are developed (Waeyenbergh & Pintelon, 2002).

2.5.5 Maintenance Decision Support Systems

Further, few literature discuss about Decision Support System (DSS) models which will help for implementation of suitable maintenance methodology so that improving maintenance performance & optimizing the operational/maintenance costs. For example, such kind of plant level maintenance decision support system (PMDSS) proposed (Lin, Ambani, & Ni, 2009; Mahdi et al., 2010) by combining the short term and long term decision making process in maintenance function reduces the unplanned down time, increases the equipment availability, and ensures the allocation of resources for maximum throughput of equipment.

Maintenance optimisation is considered as a mathematical discipline within operation research and it may be considered as an effective tool for maintenance strategy selection & optimisation by maintenance managers. But, presently its impact on decision making within maintenance organisations is limited so far (Dekker, 1996).

2.5.6 Maintenance Strategies Implementation

Implementation of maintenance strategy is the great challenge for the maintenance managers in the organisation. Every organisation has its own challenges and face different problem depends on its maintenance philosophy. Further, organisation puts best efforts to follow maintenance standards but it is difficult due to the environment exists in maintenance function (Alsyouf, 2007). There is a need to adopt different maintenance practices when the technology of process changes or when new equipment replaces the old equipment. Further, technical expertise of maintenance staff in the new process/equipment plays a crucial role in maintenance practices (Swanson, 1997).

Implementation of maintenance strategy consists of three steps (Eti et al., 2006) as given under:-

1. Maintenance program formulation of each equipment/component i.e., work identification
2. Resources for executing particular maintenance strategy effectively such as manpower, spares, tools etc.
3. Executing of the maintenance strategy by properly deploying the manpower, operate the systems required to manage all the resources efficiently.

The major obstacles in strategy implementation (Aaltonen & Ikavalko, 2002) are as given under:-

1. A lack of understanding of maintenance strategy among the maintenance organisation. This can be explained in a way that the importance of applying the strategic issues in every day decision making is a major obstacle in the organisation.

Other obstacles are conflicting activities, lack of time, lack of alignment between strategy and organisational compensation systems.

2.5.7 Maintenance Performance

Performance measurement is a fundamental principle of management. The measurement of performance is important because it identifies current performance gaps between current and desired performance and provides indication of progress towards closing the gaps. Carefully selected key performance indicators identify precisely where to take action to improve performance. Maintenance performance contributes to manufacturing performance. The key Performance Indicators for maintenance are factors of the manufacturing key performance indicators. Key Performance Indicators (KPI) of maintenance is selected ensuring a direct correlation between the maintenance activity and the Key Performance Indicator measuring it (Muchiri et al., 2011).

Swanson (2001), in his paper presented the results of a study of the relationship between maintenance strategies and performance. This paper also analysed the relationship between proactive and aggressive maintenance strategies and performance. This analysis showed positive result. Maintenance performance is the result of how the performance objectives are aligned with the business objectives. Therefore, effective maintenance performance measurement systems (PMS) plays a vital role in achieving the business needs. (Kutucuoglu et al., 2001). Further, Balance Score Card (BSC) that translates the business strategy into operational measures in order to achieve organisation's success by highlighting the pitfalls in using maintenance performance indicators (Tsang, Jardine, & Kolodny, 1999).

Maintenance performance measures of maintenance process are multifaceted as it involves various inputs, outputs and stakeholders. Further, measuring the contribution and performance of maintenance will always be a complex issue especially when intangibles such as quality of service, repair and maintenance are involved (Parida & Uday, 2009). The most important step in developing maintenance performance metrics is involving the maintenance personnel who are responsible for the work to be measured because they are the most knowledgeable people about the work (Brown, 1996).

In maintenance performance, benchmarking integral part of the maintenance performance measurement framework (Muchiri et al., 2011). Benchmarking is the process to adopt the best practices from the best performers in order to achieve world class maintenance. In addition to that benchmarking help the organisations to identify the critical maintenance issues also. The successful implementation of predictive maintenance based plans will help the organisation to achieve its break through improvement in the identified benchmarks of that particular plant operations & maintenance (Richard & Murdock, 2001). Maintenance performance measurement is dominated by lagging indicators such as equipment cost, maintenance cost and safety performance. But, it was found that there is lesser use of leading indicators such as maintenance work process in maintenance performance measurement (Muchiri et al., 2011).

2.5.8 e-Maintenance

The important of the maintenance function has increased in operations/production because it plays an important role in keeping and improving equipment/system availability, safety, product quality and e-procurement. To support this role, the new maintenance concept e-maintenance has emerged from the development of communication & information technologies (Elliot & Tobias, 2005; Karim & Parida, 2010).

To prevent equipment breakdowns, proactive e-maintenance system using intelligent prognostic technologies and tools is to be the part of maintenance strategy implementation. These tools are being used for continuous assessment and prediction of a particular product performance (Jay et al., 2006). A better performance of equipment can be achieved through reduced number of preventive maintenance stops with the planning of an e-maintenance service in order to properly device the maintenance logistic support (Marchi & Garetti, 2006).

Today, e-maintenance is a new scientific discipline and plays a vital role in maintenance function. There are various industrial/academic actors involved in the technological, organisational or management issues related to the development of e-maintenance. Therefore, implementation of e-maintenance concept involves a lot of challenges in this area (Muller, Crespo & Lung, 2007).

In maintenance function, gathering and analysing data manually requires a tremendous efforts in terms of both time and cost. Due to this recently, many organisations develop computer applications to perform the data collection and analysis. These computer applications are named as Computerised Maintenance Management System (CMMS) and these applications are deigned to gather all data related to maintenance and record the data corresponding to the asset/equipment in computer so as to retrieve the historical data any time when requires (Wireman, 2010).

The key observations from literature review on implementation of e-maintenance concept in maintenance function with a reference to various industries are as given under:-

(i) e- maintenance is not only helps in implementation of a maintenance strategy; it can be implied as a maintenance plan or a maintenance type.

(ii) The identified needs for information flow of e-maintenance service are, a) information flow from the plant management level, to production system level, for analysis; b) information is required with regard to the production logistic operation and the costs of logistic inefficiencies of the production system.

2.5.9 Impact of Maintenance Policies, Maintenance Culture

Maintenance and production interface is emphasised because of importance of integration of organisation design and strategic planning with strategic maintenance. Based on data gathered from Swedish Maintenance managers, integration and long term planning of maintenance both affect prevention, quality improvement and manufacturing capabilities of the firm. This means that companywide integrated maintenance and long term maintenance plans is important for most firms (Patrik, 1999).

Crespo & Gupta (2005), in their research paper presented a holistic framework for managing the maintenance function. Maintenance Management concepts are reviewed with perspectives of business activities such as Operational, Tactical and Strategic. The maintenance management characterized and supported with three main pillars like Information Technology (IT), Maintenance Engineering (ME) and Organisational Techniques (OT).

The key observations on impact of maintenance policies, maintenance culture in maintenance function based on literature review are as given under:-

(i) Maintenance organisation needs to be customized based on company's evolving business strategies as product mix, supply chain scenarios, technologies or product development opportunities change.

(ii) Condition and failure monitoring needs to be integrated with e-maintenance framework so that comprehensive model for failures could be developed. Based on this model, maintenance policy can be formulated for the company.

(iii) Optimal Maintenance policy should cover the following objectives such as minimization of maintenance cost, maximization of system reliability, minimization of maintenance cost while system reliability requirements are satisfied and maximization of reliability when the requirements for the system maintenance costs are satisfied.

(iv) Long term maintenance plans and companywide integrated maintenance plays vital role on manufacturing capabilities of an organisation.

2.6 Initial Conceptual Constructs & Sub-constructs

Major constructs contributing to maintenance strategy formulation, selection, and implementation are drawn from the frameworks related maintenance strategy formulation presented in the previous section (Kelly, 2006; McAllister, Armstrong, & Wilson, 1999; Salonen, 2011) and other published literature (Shown in Table 2.2). The constructs conceptualised from the literature review are Maintenance Tactics, Reliability Analysis, Performance Measures/Benchmarking, Planning & Scheduling, Materials Management, Organisation/Human Resources, Employee Empowerment, Information Technology, and Maintenance Polices/Budget. Sub-constructs related to all these constructs have also been drawn from the published literature.

Table 2.3 Categorisation of Initial Conceptual Constructs identified from literature

Authors/ References	Constructs & Sub-constructs	Context (Country/Industry)	Inference
Patrik, 1999; Cooke, 2003; Carnero, 2006; Mahdi et al., 2010 ; Rolando et al., 2009; Pophaley & Vyas, 2010; Jafari, Jafarian & Zaerpour, 2008; Chris & Wang, 2001 ; Ilangkumaran & Kumaran, 2012; Chitra, 2003; Mokashi , Wang & Vermar, 2002; Gokiene, 2010; Seth &Tripathi, 2006; Sami & Ben-daya, 2010; Wilmeth & Usrey, 2000	**Maintenance Tactics:** Predictive Maintenance/ Condition Based Maintenance (CBM); Preventive Maintenance/ Time Based Maintenance (TBM); Total maintenance hours devoted to Predictive Maintenance / Preventive Maintenance ; Compliance of PM Schedules; OEM (Original Equipment Manufacturer) Recommendations ; Reliability Based Maintenance (RBM);	Manufacturing firms from Swedish Industry; Petrochemical Plant/food industry in Spain ; Power plant in China; Mexico based company; Automobile Industry; Manufacturing Industry; Textile Industry; Maritime Operations; Indian Manufacturing Industry; Batch Process Industry; Battery Manufacturing Industry	Maintenance Tactics (MT) is the techniques that guide how maintenance activities are implemented; The right approach to determining maintenance tactics is to better understand exactly how equipment failed. Then, based on these understanding of failure modes, what the effects and consequences of the failure would be and hence determine the most appropriate maintenance tactics to manage those failure consequences; The maintenance tactics are methods which decide an appropriate maintenance

	Total Productive Maintenance (TPM); Emergency/breakdown maintenance		strategy for a firm in an industry.
Bevilacqua & Braglia, 2000 ; Liptrot & Palarchio, 2000; Wang , 2001; Nima, Dragan, & Jardine , 2010; Li, Ambani & Ni, 2009; Jayabalan & Chaudhuri, 1992; Jafari, Jafarian, & Zaerpour, 2008; Chitra, 2003; Liu, Li, Huang , Zuo, & Sun, 2010; Nguyen, Brammer, & Bagajewicz, 2008	**Reliability Analysis:** Documentation of Equipment History; Equipment Criticality; Root Cause Analysis (RCA)/Incident Analysis (IA); Mean Time Between Failures (MTBF); Value Risk Study of maintenance program; Reliability statistics of equipment/assets; Reliability Centred Maintenance (RCM) based analysis	Italian Refrigeration Manufacturing firm; Single unit & Multi unit systems; Cellular Manufacturing Industry; Automobile Industry; Power Industry; Chemical Processing plant	Reliability can be defined as the probability that a given item will perform its intended function for a given period of time under a given set of conditions; Reliability analysis is to identify failures, root cause of the failures and maintenance issues related to these failures; Reliability Analysis plays a crucial role in maintenance strategy formulation, selection & implementation of the strategies into practices.
Tsang et al., 1999; Sherwin, 2000, Kutucuoglu et al., 2001; Li , Ambani & Ni, 2009; Marchi & Garetti, 2006; Parida & Uday, 2009; Swanson, 2001; Gokiene, 2010; Ahmadi, Gupta, Karim & Uday, 2010; Simoes, Gomes, & Yasin, 2011	**Performance Measures:** Labour and material cost; Maintenance Performance Measures; Key Performance Indicators; Downtime Records; Training man hours of maintenance staff; Internal Norms & Industry Norms; Benchmarking measures & targets	Automobile Industry; e-maintenance; US Manufacturing industries; Aviation Industry	Maintenance performance measures reflect achievement and progress in meeting an agreed maintenance benchmark; in measuring maintenance performance, it is concerned not only with doing good maintenance job. It is also concerned that the maintenance job successfully removes risk of failure of plant and equipment; Formulation & Selection of Maintenance strategy based on the factors of maintenance performance.
Noemi & William, 1994; Bertolini & Bevilacqua, 2005;	**Planning & Scheduling :** Plant Equipment Register;	Oil Refinery; Automobile Industry; Manufacturing Industry;	The objectives of planning & scheduling in maintenance are

Rosqvist, Laakso & Reuanen, 2007; Rolando et al., 2009; Pophaley & Vyas, 2010; Ashayeri, Teelen & Selen, 1996; Jin, Li & Ni, 2009; Ilangkumaran & Kumaran, 2012; Muchiri et al., 2010; Nguyen, Brammer & Bagajewicz, 2008; Sami & Ben-daya, 2010; Verma & Suresh, 2007; Ahmadi, Gupta, Karim & Uday, 2010; Pinjala, Pintelon & Vereecke, 2006	Standard written work order; Availability of PM Schedules; Priorities of work order ; Availability of Work schedule for a week ahead; Shutdown Maintenance Schedule; Measurement of work backlog; Long Term Plans to forecast major shutdown/maintenance work	Belgian Process Industry; Textile Industry; Belgium Industry/Manufacturing companies; Chemical Processing Plant; Batch process industry; Shipping Industry; Aviation Industry	minimizing the idle time of maintenance workers, maximizing the efficient use of work time, material, and equipment & maintaining the operating equipment at a responsive level to the need of production in terms of delivery schedule and quality; Planning & scheduling are the key activities of any maintenance strategy. Therefore, formulation of maintenance strategy depends on this function.
Carnero, 2006 ; Garg & Desmukh, 2006; Jafari et al., 2008; Nguyen, Brammer & Bagajewicz, 2008; Yung-Hisang & Hou-Lei, 2014	**Materials Management:** Spares availability; Identified spares; Inventory analysis; Emergency purchase of spares; Average Inventory Turnover; Availability of Stores; Inventory control through computerised system ; Integration of Inventory Control with maintenance planning	Petrochemical Plant/food industry in Spain; Telecommunication manufacturing industry; Manufacturing Industry; Chemical Processing Plant	Materials management is the process of planning, organizing and controlling of the procurement and availability of spare parts; In proactive maintenance environment, while fire fighting and panics are much rarer, the same fast speed of response and repair is often required when a critical item goes down. Again, spares availability is top priority; Non-availability of material may delay the executing of maintenance strategy. Therefore, material management is an integral part of development of maintenance strategy.

John & Amrik, 1989, Garg & Desmukh, 2006; Eti, Ogaji & Probert, 2006; Crespo & Gupta , 2005; Pinjala, Pintelon & Vereecke, 2006	**Organisation/ Human Resources:** Maintenance staff level; Maintenance organisation; Responsibility of first line supervisors; Adequacy of support staff; Regular Technical training; Apprenticeship program; Deployment of Contractors	Telecommunication manufacturing industry; Nigerian Industry; Spanish Manufacturing Industry; Nigerian Power Industry	In order to meet the changing corporate philosophy and manufacturing strategy, the outsourcing of maintenance jobs/ activities can be adopted by an organisation; The outsourcing strategy provides flexibility in the maintenance organisation so that there is no need to create fixed assets /infrastructure. Therefore, HR function plays inclusive role in formulation of maintenance strategy, selection and implementation of maintenance strategy in an organisation.
Campbell et al., 2001; Eti, Ogaji & Probert, 2006; Wireman, 2010	**Employee Empowerment:** Multi-skilled Trade People; Operators Based Maintenance; Regular discussion with the staff by supervisors; Self-directed work teams; Minor modifications done by maintenance teams; Partnership with key suppliers/contractors	Organisation level	Empowerment of employee helps to take faster decision during performing maintenance and to manage emergency maintenance. This helps in implementation of maintenance strategies in an organisation in a better manner.
Ling, Jian, & Wang, 2006; Muller, Crespo, & Lung, 2007; Crespo & Gupta, 2005; Jay et al., 2006; Swanson, 2003; Raouf et al.,	**Information Technology :** Availability of computerised system for maintenance management ; Availability of	Power plant in China; Spanish manufacturing Industry; Prognostic tool like watchdog agent; Primary metals; a fabricated metal products; industrial &	The improvements in work processes are such as methods to perform work, communication about work, decision making process and monitoring of work

1993, Elliot & Tobias, 2005; Liptrot & Palarchio, 2000; Phillip & Ramin, 2014	computerised system for materials management; Integration of maintenance management & materials management modules; Scheduling of major Shutdown using project management system; CBM supported with automated programs for data analysis; Expert systems for diagnosis	metal working; precision instruments; chemical & food processing (US Industries)	activities by employees. This improvement in work process can be achieved by Information Technology; IT can lead to higher work productivity, machine availability, maintenance personnel effectiveness etc. Therefore, IT also impact maintenance decision making such as formulation of maintenance strategy and this helps to optimise the maintenance cost and the equipment/asset reliability.
Wang , 2001; Cooke, 2003;Carnero, 2006; Garg & Desmukh, 2006; Pintelon & Gelders, 1992; Pinjala, Pintelon & Vereecke, 2006; Michael, Kwasi & Jack, 2000, Wireman, 2010	**Maintenance Policies/ Maintenance Budget:** Maintenance mission & objectives; Long term maintenance plans integrated with business plans; Maintenance Policies; Maintenance budget	Single unit & Multi unit systems; Petrochemical Plant/food industry in Spain; Telecommunication manufacturing industry	A well formulated maintenance strategies and practices supported with the maintenance policies and maintenance culture in an organisation plays a critical role in maintenance function. Therefore, this function impacts the implementation of maintenance strategies and selection of maintenance strategies.

The construct and sub-constructs derived each construct altogether form basis for formulation of maintenance strategies formulation selection and implementation are shown in the Table 2.2. The definitions and literature inferences including critical observations are discussed in detail below for all these constructs & sub-constructs.

2.6.1 Maintenance Tactics

The maintenance tactics aspects are covered in detail in the literature in past few years with specific context to industries such as Manufacturing industry, power plant, Automobile industry, etc. The sub-constructs identified (Refer Table 2.2) from the literature are discussed as given below.

Condition Based Maintenance (CBM) or predictive maintenance is a technology that strives to identify initial faults before they become critical. CBM is a set of maintenance actions based on real-time assessment of equipment condition which is obtained from embedded sensors and/or external tests & measurements taken by portable equipment and then processed through software. CBM enables more accurate planning of preventive maintenance. The traditional inspection based maintenance is in fact a primitive form of CBM. Kelly (1993) detailed out the widely used CBM techniques.

Preventive Maintenance (PM) is the planned maintenance of plant infrastructure and equipment with the goal of improving equipment life by preventing excess depreciation and impairment. This maintenance includes, but is not limited to, adjustments, cleaning, lubrication, repairs, replacements, and the extension of equipment life (Verma & Suresh, 2007).

Both option based mathematical based preventive maintenance model and basic preventive maintenance model can eliminated the risk of equipment stoppage from operating status and also reduce the shortage or overage of demand (Jin, Li & Ni, 2009). Further, optimal preventive maintenance can be used to develop preventive maintenance strategy using fuzzy Bayesian tools for power generator maintenance (Liu et al., 2010). Therefore, these examples of study show that the mathematical models are used in developing preventive maintenance strategies in plant maintenance.

Nowadays, many manufacturing organisations have shifted to a new methodology known as Predictive Maintenance. However, its installation is often costly while results are difficult to predict. A Predictive Maintenance approach strives to detect the onset of equipment degradation and to address the problems as they are identified. Thus, in Predictive Maintenance, maintenance needs are based on the actual condition (normally measured quantitatively or qualitatively) of the equipment, rather than on some predetermined schedule. Hence, it involves predicting the failure before it occurs, identifying the root causes for those failure symptoms and eliminating those before they result in extensive damage to equipment. In contrast, condition-based maintenance can be a better and more cost effective than time-based maintenance (Jafari et al., 2008).

Reliability-Based Maintenance (RBM) is an advanced maintenance philosophy which prioritizes plant systems in terms of their impacts on capacity and availability. RBM balances the available strategies such as reactive, preventive, predictive, and proactive so as to ensure maximum capacity and availability while minimizing costs. The seven primary breakthrough concepts provided by Reliability Based Maintenance include: prioritization of plant systems and failure modes in terms of their impact on capacity and availability, business decision of where to invest maintenance resources, infusion of available maintenance technologies, developing core competency in maintenance function, redefinition of the maintenance function whose mission is to pursue productivity and capacity improvement solutions, increased awareness throughout the plant of the implications of maintenance decisions, and establishment and acceptance of suitable business performance metrics for maintenance (Smith, 1993).

TPM (Total Productive Maintenance) is a maintenance philosophy designed to integrate equipment maintenance into the manufacturing process. The goal of any TPM program is to eliminate losses tied to equipment maintenance or, in other words, keep equipment producing only good product, as fast as possible with no unplanned downtime. Maintenance has traditionally been viewed as a separate entity outside of the manufacturing process. As companies began to identify the role of maintenance in the production process a gradual shift in thinking occurred. TPM emerged out of the need to integrate maintenance with manufacturing to improve productivity and asset availability. The culmination of change from a reactive/corrective maintenance environment to one that is based on preventative maintenance through predictive maintenance is the process of TPM. TPM is used to drive waste out of the manufacturing process by reducing or eliminating production time lost to machine failures. The goal of any TPM program is to ensure that machinery and equipment is always available to manufacture products for the end customer. By minimizing rework, slow running equipment and downtime, maximum value is added at the minimum cost (Kelly, 1993).

Seth & Tripathi (2006) highlighted in their paper that a combined application of TPM along with Total Quality Management (TQM) brings out significantly higher improvements than application of individual. This paper also provides empirical evidence on the contributions of these two principles TQM & TPM to improve business performance in the context of Indian manufacturing industry. TPM framework concepts like Overall Equipment Effectiveness (OEE) impact the TPM implementation practices (Ahuja & Khamba, 2008).

OEM recommendations are the maintenance procedures/methods suggested by Original Equipment Manufacturer (OEM) of particular equipment. The details of OEM recommendations regarding maintenance of the particular equipment are available in operation & maintenance manuals supplied by OEM along with the equipment.

2.6.2 Reliability Analysis

Reliability Analysis is a necessity when you want to maximise your operational plant availability and uptime. The tools and techniques of reliability analysis provide insights on why events happen and on the options that you have available to you in order to address them. This construct have been further classified in to sub constructs (Refer Table 2.2), the key sub-constructs have been discussed subsequently.

A root cause is a factor that caused a non-conformance and should be permanently eliminated through process improvement. Root Cause Analysis (RCA) is a collective term that describes a wide range of approaches, tools, and techniques used to uncover causes of problems.

RCM process has been effective analysis tool to identify the root cause problem of failures. Once RCM program is implemented, the maintenance activities need to be revisited periodically. Based on failure modes and failure causes identified through RCM program, exiting Preventive Maintenance should be adjusted accordingly. To realise the benefits of RCM, Computerised Maintenance Management System (CMMS) needs to be in place (Wilmeth & Usrey, 2000).

Further, Reliability Centred Maintenance (RCM) can be defined as an industrial improvement approach focused on identifying and establishing the operational, maintenance, and capital improvement policies that will manage the risks of equipment failure most effectively (Mokashi et al., 2002).

“Mean Time Between Failure” (MTBF) is a reliability term used to provide the amount of failures per million hours for a product. This is the most common investigation about a product’s life span, and is important in the decision-making process of the end user. MTBF is more important for industries and integrators than for consumers. Most consumers are price driven and will not take MTBF into consideration, nor is the data often readily available. Based on the reliability criteria and choice of decision maker, work load threshold of each equipment type is a linear function of its MTBF with a coefficient (Nima et al., 2010).

The equipment criticality can be defined as, a system or equipment is a function of the system’s or equipment’s impact on the business when the system or equipment fails, regardless of how often the failure occurs. For example, a set of criticality ranking numbers might range from 1 to 10. Criticality rank number 10 represents the highest rank while number 1 represents the lowest.

Equipment History is one of the most required records that help to maintenance department of each equipment details & its history to understand when equipment was breakdown, why it was happen & what was done to repair, how much cost calculated for this particular maintenance on that equipment.

History of breakdown help to prepare preventive maintenance schedule, consumed parts inspection or expands inspections with extra required criteria, re-analysis on part if breaking again & again or breaking part due to other equipment parts (Knezevic, 1994). Provide training to technicians, maintenance engineers, service operators, equipment operators, electrical personnel & helpers who are associated with the equipment maintenance.

2.6.3 Performance Measures/Benchmarking

Performance measure is an importance conceptual construct in developing maintenance strategy. In this section various sub constructs related to performance measures (Refer Table 2.2) are discussed.

Developing useful maintenance KPIs starts by creating KPI strategies from top to bottom of the organisation so that activities across the operation integrates together with a corporate purpose (Visser & Pretorious, 2003).

A useful maintenance KPI is to collect and present why failures of equipment/operation are occurring. These failures have root causes in the past and across maintenance functions. Collecting the causes of failures (i.e. corrective and breakdown maintenance) under separate life cycle categories helps to identify focus area for reliability improvement efforts by maintenance personnel. This is a business quality system and life cycle management indicator that drives failure avoidance and the adoption of better asset life cycle practices (Patrik, 1999). Benchmarking is a basis of establishing rational performance goals through the search for best industry practices that will lead to superior performance.

2.6.4 Planning &Scheduling

Planning & Scheduling is the conceptual construct are classified in sub constructs based on literature review (Refer Table 2.2) and each of these sub constructs is discussed in detail as given under:-

Maintenance efficiency of machines can be improved through proper maintenance planning and scheduling in an automobile industry using the maintenance approach Total Productive Maintenance (TPM). TPM tools helps to accomplish improved efficiency by enabling optimum use of machine capabilities (Pophaley & Vyas, 2010).

In process industry the planning of production and maintenance within an integrated process manufacturing system plays a vital role. Now a day, the implementation of Computer Integrated Manufacturing (CIM) concepts in the industry provides better solutions. In addition to that preventive maintenance decisions impact the available plant capacity and company profits in the production/manufacturing industry. Ashayeri et al., (1996) developed a model to minimize such production and maintenance related cost factors during long or medium term planning horizons which would also take care of probability of break downs.

Planning is the process by which the elements required to perform a task are determined in advance of the job start. It comprises all the functions related to the preparation of Work order, Bill of material, Purchase requisition, Necessary drawings, Labour planning sheet including standard times, All data needed prior to scheduling and releasing the work order. Good planning is a prerequisite for sound scheduling (Wireman, 1990).

Scheduling in very crucial in implementation of maintenance plan and it leads to achieve the maintenance to manufacturing competence of an industry (Noemi & William, 1994). Scheduling is the process by which jobs are matched with resources and sequenced to be executed at a certain points in time. Scheduling deals with the specific time and phasing of planned jobs together with the orders to perform the work, monitoring the work, controlling it, and reporting on job progress. Successful planning needs a feedback from scheduling (Wireman, 2010).

2.6.5 Material Management

Material management aspects are covered in detail in the literature in past few years. In this section, various sub constructs related to material management (Refer Table 2.2) identified from the literature are discussed in detail.

Maintenance Material Management consists of identifying, scheduling, purchasing, managing stock and the supply of materials according to plant (manufacturing unit) requirements. The processes that make up this service line are stores management, purchasing process of management of materials, stock management and scheduling of materials, optimisation and rationalization of material processes, flows and stock (Jardine & Tsang, 2005). The above identified sub constructs are dealt with such materials management processes. Based on these sub constructs, the assessment of an organisation can be done with respect to implementation of maintenance strategy. In order to fulfil the maintenance plan of a production plant, it is very critical to assign one among the maintenance resource i.e., material at tactical level of maintenance work (Crespo & Gupta, 2005).

In maintenance, there is no greater priority than ensuring the ready availability of spare parts. Competent materials management is a precondition of maintenance management success. Because of the complexity of the challenge in maintenance management, an integrated materials management system is essential (Pintelon & Van, 1990).

2.6.6 Organisation/Human Resources (HR)

Organisation/ Human Resource(s) are a crucial construct derived from literature which is contributing majorly for maintenance performance. This construct is further classified into sub constructs (Refer Table 2.2) and each of these sub constructs is discussed in detail.

In order to meet the changing corporate philosophy and manufacturing strategy, the outsourcing of maintenance jobs/activities can be adopted by an organisation. This provides flexibility in the maintenance organisation so that there is no need to create fixed assets/infrastructure. (Garg & Desmukh, 2006). Further, in their paper it is discussed that the maintenance staff should be capable of dealing with multi-functional activities in maintenance.

Knowledge can be acquired through training and this knowledge is used to do job in an effective and efficient manner. If jobs are being done with the thorough knowledge, person doing job become skilled. The skills acquired by maintenance personnel will be further used to improve the performance of assets and equipment's. Therefore, it is the maintenance personnel who improve the maintenance performance. Every industry should consider Training as one of the most important and strongest areas in any organisation (John & Amrik, 1989). It must never be the subject of any cost reduction efforts.

Maintenance Organisation depends on many determinants such as Maintenance capacity, Centralization Vs. De-centralization & In-house maintenance Vs. Outsourcing. Further, Human Resources planning for maintenance organisation also depend on many criteria. The criteria include defined roles and responsibilities, effective span of control, facilitation of good supervision and effective reporting structure and minimization of costs (Eti et al., 2006)

In addition to above, creating division of labour for maintenance tasks to be performed and coordination of results to achieve a common maintenance goal must be capabilities of maintenance managers (Campbell et al., 2001). Therefore, selection of right maintenance personnel with the appropriate capabilities supported by continuous training and good incentive schemes is must for an organisation to achieve performance effectiveness and efficiency.

2.6.7 Employee Empowerment

The first area of change towards employee motivation should be employee empowerment. In the traditional maintenance departments, maintenance managers carry out the planning & controlling of all maintenance activities. Nowadays, this tradition changes that the maintenance supervisors are responsible for maintenance task management, budgeting and maintenance scheduling. To achieve this objective, maintenance mangers should delegate the micro detailing of maintenance jobs such job order allocation, scheduling preventive maintenance etc. Instead, managers should provide directions and point out the desired results, empowering maintenance supervisors to achieve the desired results within their capacity. There are limited research literatures available in the area of maintenance which discussed about maintenance aspect of employee empowerment. However, maintenance management related books are discussing about employee related concepts (Wireman, 2010).

Operator based maintenance is nothing but the operators of the plant/equipment are trained to perform regular maintenance of that particular plant/equipment. This will help the organisation to create multi skilling work environment among the operators so that plant operation efficient can be improved. Further, supervisors should have regular discussing with the maintenance staff and also with the operators so that the work team can become self-directed work teams. This finally provides the more empowerment to the maintenance staff and operators (Campbell & Picknell, 2006).

2.6.8 Information Technology

Information Technology functionalities are to be leveraged in maintenance function. Therefore, IT has been identified as an initial conceptual construct for a maintenance strategy selection. In this section various sub constructs (Refer Table 2.2) related to Information Technology identified from the literature are discussed in detail.

Raouf et al. (1993), in their paper discussed in detail about evaluation of various Computerised Maintenance Management Systems (CMMS) available and explained their functions. Further, they have shown the importance of implementing such kind of systems in the industry for effective utilization of manpower & material. CMMS helps maintenance function to respond more quickly and also helps in improving maintenance performance by managing the equipment. Further, it also allows production and maintenance departments to improve their communication and coordination in their activities (Swanson, 2003). In addition to that his research also showed that the CMMS and lateral relations suggest the successful implementation of new manufacturing technologies leads to world class maintenance practices.

Nguyen et al. (2008), in their paper presented a new methodology to assess the economic value of scheduling rules for preventive maintenance in a chemical process plant. This methodology was tested in a chemical process plant and the results confirmed the benefits of using preventive maintenance. Therefore, such kind of new tools and methods are useful in data analysis and diagnostics. This paper further investigated the effect of maintenance performance in terms spare parts inventory policy, maintenance policy etc.

Recent days many organisations in the industry become more competitive by reduction of maintenance/production costs and increasing productive through the improvement in work processes by using e-maintenance tools (Muller et al., 2007). The improvements in work processes are such as methods to perform work, communication about work, decision making process and monitoring of work activities by employees. This improvement in work process can be achieved by Information Technology. IT can lead to higher work productivity, machine availability, maintenance personnel effectiveness etc. Therefore, IT also impact maintenance decision making and this helps to optimise the maintenance cost and the equipment/asset reliability.

Advanced Information and Communication Technology provides benefits such as improved communication among plant workers and outside experts and supports the team approach in problem solving even though distances often separate maintenance personnel/vendors/service providers.

2.6.9 Maintenance Policies/Maintenance Budget

Maintenance Policy and Maintenance Budget related aspects are covered in detail in the literature in past few years. In this section various sub constructs (Refer Table 2.2) related to Maintenance Policies are discussed in detail.

It is very importance for an organisation to have a robust and effective maintenance and maintenance policy in place (Wang, 2001). Maintenance of an organisation ensures the following (Michael et al., 2000):-

- Equipment's are always in ready and reliable condition. i.e., company is able respond to any sudden change in demand.
- Equipment's are always calibrated to provide good quality products and competitive advantage. i.e., there are no sudden and frequent breakdowns and reduce production of defective products.
- There are no major breakdowns. i.e., there is no losing of inventory or market share for companies following JIT philosophy.

- Maintenance costs are always controlled.

The central importance of maintenance budgeting is related to the formulation of maintenance strategy of an organisation. The maintenance budget should be an expression of the forecasted short term (i.e. annual) and long term maintenance jobs in terms of the cost of internal manpower, contract manpower and the materials needed to deal with them. It is also emphasized that in plants requiring major shutdowns there is also the need for a specific turnaround budget. Budgeting procedures appropriate for large process plants are compared with those for individual manufacturing units and, finally, it is explained that, all too often, maintenance budgeting is rarely as rational as described, senior management seeing maintenance only as a cost and ignoring the linkage between maintenance expenditure and production output (Mobley, 2008). Further, the need for a maintenance budget arises from the overall budgeting need of corporate management and involves estimation of the cost of the resources (manpower, spares etc.) that will be needed in the next financial year to meet the expected maintenance jobs.

2.7 MAINTENANCE STRATEGY MODELS/FRAMEWORKS

In this part of literature review various maintenance strategy models/ frameworks are presented below. In these frameworks/models, authors have included major components related to maintenance strategy such as maintenance strategies formulation, maintenance strategies selection, and implementation of selected maintenance strategies.

According to McAllister, Armstrong, & Wilson (1999), an asset mainteannce strategy is based on a set of objectives and maintenance polices of the plant operation. These objectives are having targets and goals to achieve better mainteance. Few related points to this model are as given below:-

1. Business targets for plant performance, product quality, cost savings, etc., are based on customer needs
2. Resources must be available to fulfill the strategy objectives

3. Outputs of functional capabilities and mainteance personnel needs to be monitored & measured for their expected delivery
4. Adoptability of maintenance function to quick changes in the environment

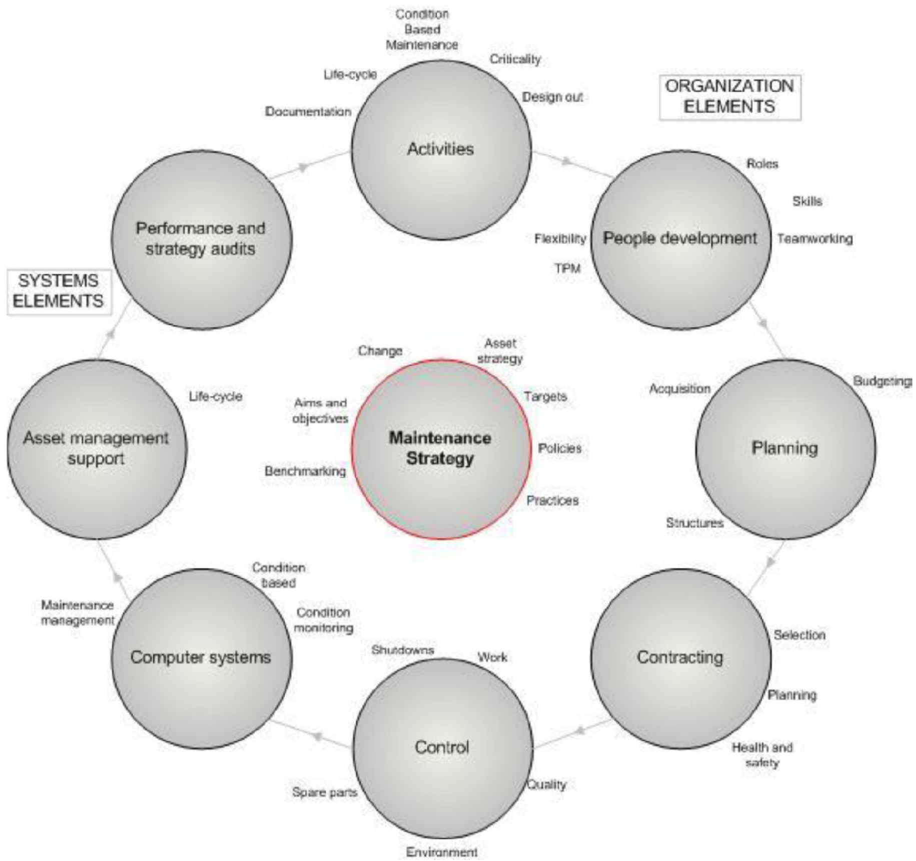


Figure 2.3- The range of maintenance policy sectors and corresponding practices (McAllister et al., 1999)

McAllister, Armstrong, & Wilson (1999), has also presented a model for the formulation and review of a maintenance strategy. In his paper, it is described that the maintenance must be considered a partner within the business so that overall objective of the organisation is shared in order to achieve production with an acceptable margin of profit. For achieving this objective, there is a need to integrate all the functions in the organisation. Thus, maintenance strategy should be aligned with the business or corporate strategy (Figure 2.3). He also suggested the following steps in formulating effective maintenance strategy.

Step 1: Maintenance strategy development starts with the maintenance philosophy which describes the roles of maintenance

Step 2: Maintenance philosophy chosen should fulfil the maintenance objectives/aims developed for the organisation which are derived from corporate/production objectives.

Step 3: Assess & evaluate the maintenance practices and issues in the maintenance

Kelly (2006) presented a BCM (Business Centred Model) for the formulation of maintenance strategy. The same is shown in the Figure 2.4 given below. This model depicts that the business objectives of the organisation are identified and then the same are translated into maintenance and this supports the formulation of maintenance strategy. It is critical to under the operation of the plant and its relation with the market. Thus, maintenance objectives are derived from the production & business objectives. The large circle in figure below shows that the strategic thought process of the maintenance manager starts with the maintenance objective.

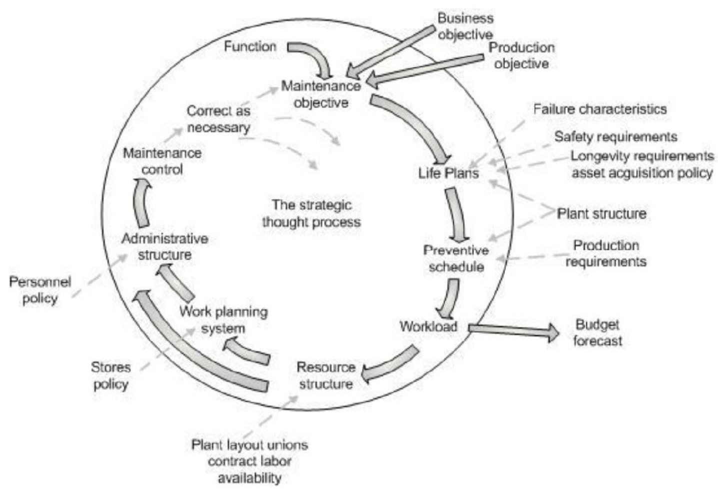


Figure 2.4- A Business Centred Maintenance Methodology (Kelly, 2006)

For formulation of a maintenance strategy a model proposed by Salonen (2011) is shown in the below given Figure 2.5. This model is a schematic view of the maintenance processes when formulating a maintenance strategy.

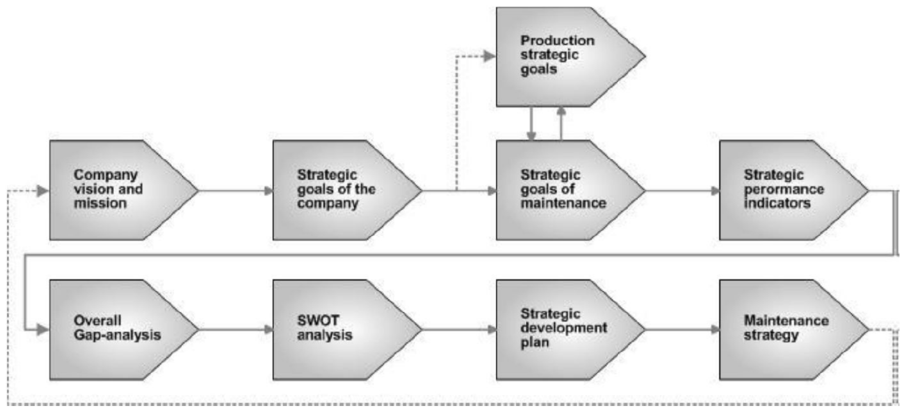


Figure- 2.5 A Schematic view of the Work Process when formulating a Maintenance Strategy (Salonen, 2011)

Further, Salonen (2011) proposes a structure to follow while formulating the maintenance strategy. The same is shown in the below Figure 2.6.

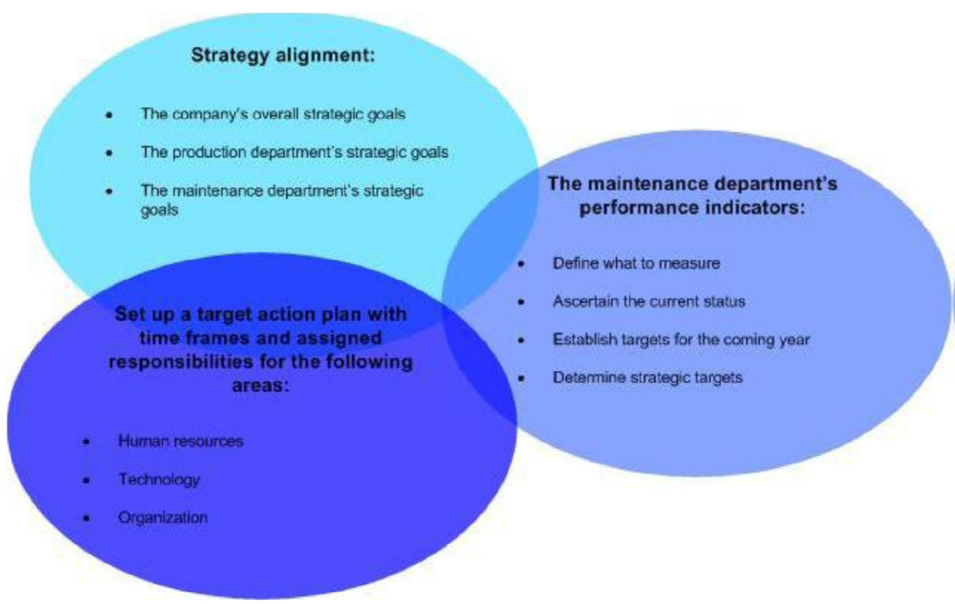


Figure 2.6 Structure to follow while formulating the Maintenance Strategy

The maintenance strategy must be a road map for maintenance which includes alternatives, provides direction, flexible enough to adjust with the changing environment. This road map has to be created from benchmarking and the practices of the organisation's own plant/ operation process.

According to Campbell & Picknell (2006) the implementation on the tactical level is based on the maintenance strategy. This includes various components such as mission, vision, maintenance tactics, targets and rules. The same is depicted in the Figure 2.7 given below:-

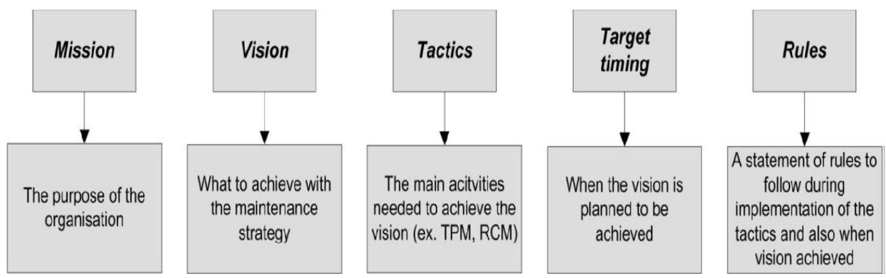


Figure 2.7 Components included in the Strategy (Campbell & Picknell, 2006)

The comparison of above frameworks/models is detailed out in Table 2.4 along with key concepts, inferences and gaps. A common thread in all these frameworks is alignment between business strategies and maintenance strategies. Few gaps in these frameworks are what the outcomes of maintenance strategy formulation are?; How to select the best among the maintenance strategy methods/approaches formulated? ; How to optimise among the selected maintenance strategy methods/approaches? ; How to measure the impact on maintenance function after implementing the specific maintenance strategy? Even these aspects are discussed specifically in the framework but the same is not discussed integrating all the maintenance strategy related processes in a holistic manner.

Table 2.4 Comparison of Maintenance Strategy Models

Author(s)	Description about maintenance strategy related framework/ model	Key concepts from the framework/model	Inferences & Gaps
McAllister et al., 1999	Authors proposed a model for the formulation and review of maintenance strategy	Maintenance strategy is based on the factors asset strategy, targets, policies, practices, aims & objectives, and benchmarking; Maintenance strategy as on overall depends on various maintenance policy sectors & practices which consists of system elements such as asset management support, performance and strategy audits, etc. & organisation elements such as people development, planning etc.	Overall framework suggests for proper business targets, sufficient resources, monitoring of outputs and adoptability to quick changes in the environment; This model does not support the maintenance strategies selection & optimisation among maintenance function
Kelly, 2006	A business centred maintenance methodology	This model supports translation of business objectives into maintenance objectives so that formulation of maintenance strategy can be done effectively; It also provides various factors that make maintenance strategic in an efficient manner. The factors are life plan, preventive schedule, resources, work planning system, administrative structure, maintenance control etc.	The key point is alignment of business objectives, production objectives with the maintenance objectives; This model does not describe about the outcomes of the maintenance strategic process such as maintenance tactics and selection of maintenance strategies selected for implementation; This model is not having performance measurement aspects of maintenance.
Salonen, 2011	This model provides schematic view of the	The key elements in this model are strategy alignment, performance	Maintenance strategy alignment with business strategy is the key factor in

	maintenance processes when formulating a maintenance strategy & structure while formulating the maintenance strategy	indicators for maintenance performance, target action plan along with time frames.	formulating maintenance strategy; This model does not explain about implementation of maintenance strategies and optimisation of the maintenance strategies. However, it describes about maintenance performance indicators.
Pintelon & Gelders, 2002	Maintenance management framework	This model describes about system design aspects such as maintenance philosophies, production control systems, etc., planning and control such as maintenance objectives, resources, performance reporting etc., and managerial tool kit such as failure modelling techniques and computer support.	The key concept in this model is decision making process in maintenance involves strategic planning, tactical planning and operational planning. Integration & optimisation of these planning processes are critical; This model does not explain about the maintenance strategies formulation, selection & performance evaluation of maintenance function.
Eti et al., 2006	Strategic Maintenance Performance Management framework	This model describes about the alignment of maintenance strategy with the corporate strategy; This model also explains implementation plans, performance measurement and feedback to corporate strategy.	Authors suggests few key elements related to maintenance strategy such as maintenance organisation, measure of effectiveness, work control, maintenance management information system, personnel records, logistic support, maintenance tasks & maintenance engineering; This model does not explain about outcomes of maintenance strategies & optimisation of maintenance strategies. It does not also explain about the implementation aspect of maintenance strategies.

Muchiri et al., 2011	The performance measurement framework for the maintenance function	This framework also describes about alignment of corporate strategy with the maintenance strategy while formulating the maintenance strategy; This framework proposes leading performance indicators such as work execution, scheduling, planning and work identification. It also proposes lagging performance indicators such as performance targets, benchmarks, maintenance results like equipment performance and maintenance cost.	This framework is much related to maintenance performance. However, the concept of maintenance strategy formulation is included in this framework; This framework does not explain about maintenance strategies outcomes such as maintenance tactics, maintenance policy etc.
Pintelon & Parodi, 2008	Gap between maintenance and business strategy	Author in his paper describes about the link between maintenance and business strategy; Main focus on maintenance management is still on the tactical and operation planning; Bridging the gap between business strategy and maintenance strategy is the key challenge in maintenance.	The framework describes of outcomes of maintenance strategy as maintenance concepts such as RCM, TPM, BCM, LCC, etc., maintenance policies as PM, Pd.M., FBM, etc.; This framework does not explain about selection of maintenance strategies, optimisation and implementation aspects in maintenance function.
Umar, 2011	A framework for maintenance strategic planning	This framework describes about the nine functions such as identification of major stakeholders, formulation mission statement, setting of the strategic objectives of maintenance, analysis of the current situation, identification of the strategic issues, strategic	This framework covers the all major elements related to strategic issues of maintenance strategy formulation to implementation. However, it does not explain in-depth about maintenance decision support systems used for maintenance strategy selection, outcomes of

		options, strategy selection, development of performance measures, and implementation planning.	maintenance strategies and underlying factors contributing for maintenance strategy formulation in the operational & tactical level.

The inferences from the above detailed literature review can be summarised as given under:-

The detailed literature review reveals that the most of existing literature have discussed evaluation system for setting up a particular maintenance method/approach such as Preventive Maintenance & Predictive Maintenance, linking performance with the maintenance strategy, application of specific maintenance method/approach like Preventive Maintenance, Predictive Maintenance, RCM, CBM etc. for a particular industry in a country like Italy, Belgium, Africa etc., development of Maintenance Decision Support Systems (MDSS) for selection of maintenance strategy, development of Plant level Maintenance Decision Support System (PMDSS) implementation of e-maintenance concept, maintenance polices and their impact.

Further, authors have developed frameworks/models related to maintenance strategy processes such as maintenance strategy formulation, selection of maintenance strategies and implementation of selected maintenance strategies (McAllister et al., 1999; Pintelon & Gelders, 2002; Kelly, 2006; Eti et al., 2006; Pintelon & Parodi, 2008; Muchiri et al., 2011; Salonen, 2011; Umar, 2011; Sohrab et al., 2013). However, each model describes one or two processes of maintenance strategy but not in combined manner integrating all the maintenance strategy related processes. Based on these inferences, it is evident that there is a need in Industry to develop a holistic model which combines the maintenance strategy related processes such as maintenance strategy formulation, selection and implementation of formulated maintenance strategies.

Literature could not explain about how the maintenance managers/engineers are ensuring smooth operation of plant by effective use of maintenance strategies in planning & execution at an organisation level. Further, no literature could reveal about why the specific maintenance strategy is selected for a particular equipment/process and how these maintenance strategies are different in different plant processes/equipment. Therefore, maintenance strategies related processes study is to be carried out to incorporate existing maintenance practices of an organisation so that maintenance strategies & maintenance practices can be described in a holistic manner.

2.8 GAPS IN LITERATURE

It is evident from the literature review that the maintenance strategies related frameworks established relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in an organisation, but they failed to explain how and why are these related. As explanation is essential for building theory and for improving practice, there is a need for process study of maintenance strategies & maintenance practices at an organisation level.

Extensive literature search for maintenance strategies & maintenance practices study providing rich description based on tacit and implicit knowledge available with maintenance managers at an organisation level in operations intensive industry like natural gas industry in an Indian context found no references to the best of researcher knowledge. (As on 02-05-2014, literature in databases such as EBSCO (Business Source Premier & Business Source Elite+), Emerald, Elsevier's Business Management & Accounting Collection (Science Direct), Blackwell's HSS Collection, IEEE Online, ACM Digital Library with the following key words maintenance, maintenance strategy, preventive maintenance, predictive maintenance, condition based maintenance, reliability centred maintenance, maintenance policy, maintenance practices, Selection of maintenance strategy, Indian gas industry, maintenance decision making, maintenance effectiveness, maintenance scheduling, maintenance planning, corrective maintenance, reliability, decision support system, maintenance flexibility, maintenance management, computerised maintenance management, maintenance performance, study of maintenance practices).

Based on above literature review, the gaps in literature can be summarised as given below:-

- Study on maintenance strategies & practices related to processes of maintenance strategies selection & maintenance practices at an organisation level in operations intensive industry like natural gas industry in Indian context found no literature references.
- Lacking in literature related to study of tacit knowledge & implicit knowledge available with the maintenance managers in order to provide rich description on maintenance strategies selection processes & maintenance practices.
- Lack of holistic & integrated maintenance model which describes the processes & relations of all the aspects of maintenance strategies & maintenance practices planning and execution.

2.9 CONCLUDING REMARKS

As first step in literature review, a detailed literature survey was carried out related to maintenance management. Then, literature were analysed and categorised based on key themes such as maintenance strategy, maintenance strategies formulation, selection of maintenance strategies, implementation of maintenance strategies, maintenance performance, maintenance approaches /tactics, development of Maintenance Decision Support Systems for optimal maintenance strategy selection, e-maintenance, and impact of maintenance policies in maintenance management. Further, nine constructs have been conceptualised from literature such as Maintenance Tactics, Reliability Analysis, Performance Measures/Benchmarking, Planning & Scheduling, Materials Management, Organisation/Human Resources, Employee Empowerment, Information Technology, and Maintenance Polices/Budget.

Detailed comparison of various maintenance strategy related frameworks/ models identified from literature is also presented in this chapter. Finally, literature gaps are arrived from this detailed literature review and presented.

Next section discusses on research design & research methodology adopted for this research study.

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter details the research design and methodology for conducting the research study. Research design describes the connection between empirical data to the study's initial research questions logically and finally to the conclusions of the research study (Yin, 2003). It specifically addresses various scientific paradigms, scientific approaches, research approaches, research methods, research strategy, data collection method and data analysis strategy. Next to this section the research focus, research questions, research objectives, and the nature of research questions are presented. Section 3.3 describes overall approach and rationale for the selection of case study research strategy. Further, it discusses about the specific methods used in conducting this research and their relevance to the study. Section 3.4 discusses the case study design aspects such as number of cases, selection of cases, structure of case study design, and sampling. Section 3.5 explains the data collection methods followed in this research study. Section 3.6 describes about data analysis strategy which includes data analysis using grounded theory (Charmaz, 2006), within case analysis (Tsang, 1997), and cross-case analysis (Miles & Huberman, 1994). Further, in section 3.7 quality of empirical research is discussed in terms of four tests relevant to qualitative research method such as construct validity, internal validity, external validity, and reliability (Yin, 2003). Finally, section 3.8 discusses the use of Case Study Protocol (CSP) during data collection and presents complete protocol document used in this research study.

3.2 RESEARCH OBJECTIVES & RESEARCH QUESTIONS

3.2.1 RESEARCH FOCUS

The focus of research is on maintenance strategies related processes such as formulation, selection, implementation of maintenance strategies, and maintenance practices at an organisation level in Indian gas industry context. In early literature, several maintenance approaches i.e., maintenance strategies/concepts/methods have been discussed by various authors (Dekker, 1996; Moubray, 1997; Mckone & Elliott, 1998; Sherwin, 2000; Swanson 2001; Crespo & Gupta, 2006; Carnero, 2006; Marcello et.al., 2013). Further, the researchers have conceptualised maintenance strategy processes and various maintenance strategy related frameworks/models have also been developed (McAllister et al., 1999; Kelly, 2006; Salonen, 2011; Pintelon & Gelders, 2002; Eti et al., 2006; Muchiri et al., 2011; Pintelon & Parodi, 2008; Umar, 2011; Salonen, 2011). To select/choose these maintenance strategies for different equipment or system for particular industry, various mathematical models have been developed by researchers in this field. Selection of maintenance strategies for particular equipment/system in any industry is treated as typical Multiple Criteria Decision Making (MCDM) problem (Ahmadi et al., 2010). To deal with such kind of problem, the analytical techniques have been used such as Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (FAHP), VIKOR etc. by researchers in their papers (Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Bertolini & Bevilacqua, 2005; Ling et al., 2006; Li et al., 2009; Rolando et al., 2009; Murthy, Atrens & Eccleston, 2002).

It is evident from the literature review that the maintenance strategies related frameworks established relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in an organisation, but they failed to explain how and why are these related. As explanation is essential for building theory and for improving practice, there is a need for process study of maintenance strategies & maintenance practices at an organisation level. Further, extensive literature search for maintenance strategies & maintenance practices study using qualitative research approach at an organisation level in operations intensive industry like natural gas industry in an Indian context found no references. (As on 02-05-2014, literature in databases such as EBSCO (Business Source Premier & Business Source Elite+), Emerald, Elsevier's Business Management & Accounting Collection (Science Direct), Blackwell's HSS Collection, IEEE Online, ACM Digital Library with the following key words maintenance, maintenance strategy, preventive maintenance, predictive maintenance, condition based maintenance, reliability centred maintenance, maintenance policy, maintenance practices, Selection of maintenance strategy, Indian gas industry, maintenance decision making, maintenance effectiveness, maintenance scheduling, maintenance planning, corrective maintenance, reliability, decision support system, maintenance flexibility, maintenance management, computerised maintenance management, maintenance performance, study of maintenance practices).

Therefore, the focus of this research study is to understand & describe the maintenance strategies & maintenance practices planning and execution at an organisation level in an Indian context (a large gas utility company). It is also to understand why the specific maintenance strategy has been chosen for a particular equipment/process/operation and how these formulated strategies are being practiced in the organisation. A case study approach has been selected for this research study because, the definition of the case study method say that "*the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result*" (Yin, 2003).

At an organisation level in maintenance function, the tacit and explicit knowledge in the field of best practices in maintenance management are available with maintenance managers & engineers working in the organisation. We need to gather an in-depth understanding of this knowledge in formulation of maintenance strategy & practices in the organisation.

Therefore, qualitative research method will be a suitable method in capturing and reusing tacit and explicit knowledge in the field of best practices in maintenance management at the organisation studied. For this research, to study on maintenance strategies & maintenance practices related processes at organisation level in an Indian context; a large gas utility company is selected for this study. Selection of the company and business verticals discussed in detail Section 3.4.

3.2.2 PROBLEM STATEMENT

Although in the existing literature various maintenance strategies applicable for different types of operations intensive industry is well known but the process of maintenance strategies selection & maintenance practices at an organisation level have not been described in detail. Further, there is lack of holistic process model for maintenance strategies & maintenance practices planning and execution.

3.2.3 RESEARCH QUESTIONS

How the gas utility company is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as petrochemicals & pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?

This question is exploratory and it seeks to explore and find out the existing maintenance practices of a large gas utility company i.e., GAIL (India) Limited and the formulation of maintenance strategies by maintenance managers of the company in two business verticals such as petrochemicals & NG Pipeline systems. Further, it seeks to understand the selection of specific maintenance strategy for a particular operation process/equipment.

From the main research question one can derive a more exploratory and descriptive sub question of the "what" type (Yin, 1994).

Additional RQ1:- What are the common and different maintenance strategies & practices to both the business verticals (and) how the maintenance strategy & practices differ with the specific assets available in one operation process/plant/pipeline network from others business verticals?

This question is definitional and exploratory in nature. It seeks to find out the similarities and dissimilarities among the various maintenance strategies and maintenance practices being used in the business verticals of a large gas utility company. Further, it is to understand the specific maintenance strategies being in practice for a particular equipment/process/operation.

Additional RQ2:- How the reliability of the operation process/ equipment/ assets is ensured by the maintenance strategy used for the particular operation process/equipment/assets?

This question focuses not only on exploring and describing effect of reliability in maintenance strategies & maintenance practices, but seeks to understand a more causal pattern of impacts. We seek to build a theory that explains the process of impacting, the impacts themselves (i.e., effects), and how people respond to these impacts.

Additional RQ3: What are the benchmarks being used in petrochemicals/ NG pipelines? What is extent of achievement of benchmark parameters in practices?

This question is exploratory and descriptive. It seeks to develop an understanding of casual relationships, if any between benchmarking in maintenance and maintenance strategy planning & execution in business verticals of the company.

3.2.4 Nature of research questions

The central research question is exploratory in nature as it seeks to understand a pattern of relationships and impacts (Yin, 2003). To support this question, the first sub question is definitional and exploratory. The second & third sub-questions are exploratory and descriptive, oriented towards making an inventory of effects.

Research Questions are exploratory in nature and seeks to understand the pattern of relationship among maintenance strategies and maintenance practices planning & execution, reliability in maintenance, and benchmarking in maintenance. The study is aimed to study the existing maintenance processes of an Indian large gas utility company. Therefore, the temporal focus of the study is a current situation as shown in the below given Table 4.1 (Highlighted in Grey Colour)

Table 3.1 Research Questions: Type and Temporal Orientation

	Temporal Orientation of Research Questions		
Type of research question	**Backward looking**	**Current**	**Forward looking**
Exploratory Less factual, more oriented towards understanding a trend/ pattern	**Exploratory backward looking** What could have been done? What would have made more effective? Yin (2003) Exploratory what questions	**Exploratory current** What could be done in this situation? What is the background of this trend? Yin (2003) Exploratory what Questions	**Exploratory forward Looking** What will happen? What will be the impact of this initiative? How will people respond? Yin (2003) Exploratory what Questions
Descriptive and Predictive	**Descriptive backward looking**	**Descriptive current**	**Descriptive forward Looking**

Factual representation or estimation of study object	What were the outcomes of this strategy? How many projects have met expectations? Yin (2003) Inventory what questions, Who what where questions	How many firms employ these processes? Who are currently involved in this project? Yin (2003) Inventory what questions, Who what where questions	What will be the outcome of adopting the processes? Yin (2003) Inventory what questions, Who what where Questions
Explanatory Factual, focused on understanding a limited number of events	**Explanatory backward looking** What happened? Why did it happen? What is the current status? Yin (2003) How, why questions	**Explanatory current** What happened? Why did it happen? What is the current status? Yin (2003) How, why questions	**N.A.**

(Source: Fenema, 2002; Yin, 2003)

3.2.5 OBJECTIVES OF THE STUDY

The specific objectives of the research work are:

1. To understand and model the existing maintenance strategies & maintenance practices planning and execution in a large gas utility company in India.
    a. To describe the common and different maintenance strategies & practices in the business verticals such as Petrochemicals & NG Pipelines of gas utility company.
    b. To describe the extent of practices regarding reliability in maintenance of equipment/assets/processes.

2. To find the gaps between maintenance strategies & practices and benchmarks in maintenance.

3.3 OVERALL APPROACH AND RATIONALE

In the research process, researcher defines the problem in practice. Then, the researcher explores and understands the nature of problem completely through a systematic study (Maxwell, 1996). Research questions and research design are developed so as to methodically understand the problem in study. Next, existing theory related to the problem statement is explored and integrated using the theory development methodology. Based on the existing theory, "conceptual lens" is developed to study the problem.

Further, empirical research design and data analysis approach are developed with the basis of conceptual lens framework & research questions. Then, the researcher starts data collection as per defined design methodology in research study. The data collected is analysed based on conceptual lens framework and the outcomes of data analysis are the findings of the research study. These findings might lead to existing theory extension and helps to understand and specify recommendations to the problem. This overall research design is shown in the Figure 3.1.

This research study aims to understand the existing maintenance strategies and maintenance practices of Indian gas utility company to understand the processes of maintenance strategies formulation, selection, implementation and maintenance performance. Objective of this research approach is to provide rich description about processes of maintenance strategies & maintenance practices planning and execution including underlying factors contributing for maintenance strategy formulation in the operational and tactical level. Therefore, this research approach helps to understand how the formulation of maintenance strategies is carried out in the company and why the specific maintenance strategies are selected for particular operation/ equipment etc.

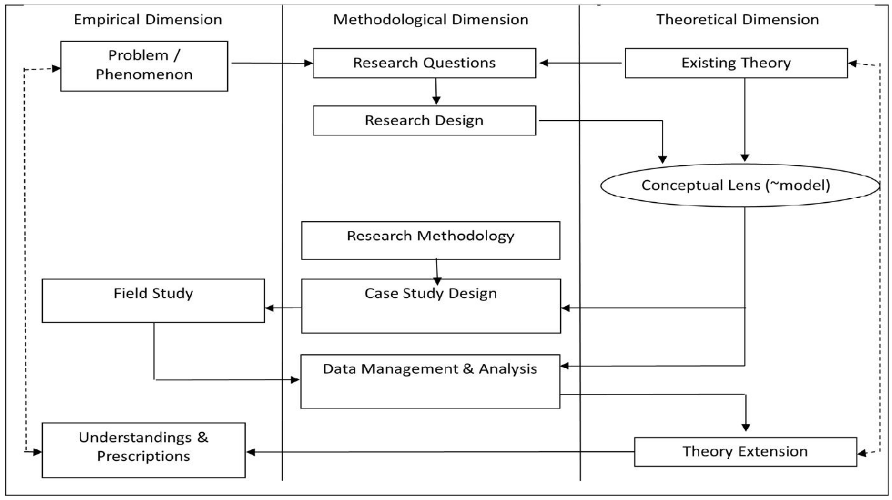


Figure 3.1 – Research Process (Maxwell, 1996)

Further, extensive literature are available in the area of maintenance strategies; but, there is a lack in study on how the maintenance managers/engineers are ensuring smooth operation of plant by effective use of maintenance strategies in planning & execution at an organisation level in an Indian context. Maintenance Strategy related frameworks cover the major elements related to maintenance strategy formulation to implementation of maintenance strategies (McAllister et al., 1999; Kelly, 2006; Salonen, 2011; Pintelon & Gelders, 2002; Eti et al., 2006; Muchiri et al., 2011; Pintelon & Parodi, 2008; Umar, 2011). However, these frameworks/models do not explain in-depth about maintenance strategy selection, outcomes of maintenance strategies based on maintenance practices being carried out at an organisation level.

In view of above background and research questions, it has been decided to undertake a study on maintenance strategies and maintenance practices at an organisation level in an Indian context (A large Indian gas utility company). Qualitative research method and Case-study method as research strategy have been used in this research study. The reasons for adopting these research methods are well explained in the subsequent sections. Next section discusses in detail about philosophical assumptions underlying this choice and reasons for adopting this approach.

3.3.1 Philosophical Assumptions

The appropriate research methods, constituents' of valid research, and assumptions about the nature of reality are few factors the research study depends on (Myers, 2013). These philosophical assumptions consist of a position toward the nature of the reality and how it should be constructed (ontology), how the researcher knows about the reality and what is the basis for his/her knowledge (epistemology), what are the values put into the research (axiology), how the researcher writes about it (rhetoric), and the methods used in the research process (methodology). These are explained by Creswell, 2007. The below given Table 3.2 summarises the above assumptions related to this research study and their implications on this research.

Table 3.2 Philosophical Assumptions along with implications for this Research Study

Assumptions	Question	Characteristics	Implication in this research study
Ontological	What is the nature of reality and how it should be constructed?	As described by participants in the research study, reality is subjective and multiple in nature. The nature of the world and what we can know about it.	Quotations & Concepts are described in words of participants and evidences have been provided to explain different perspectives.
Epistemological	What is the nature of knowledge and the relationship between the knower and the would-be known?	Researcher attempts to understand thoroughly and be in continuous touch with subjects being studied in this research work.	Researcher spent time of 30 days in various sites of gas utility company and observed the maintenance practices & implementation of maintenance strategies
Axiological	What values go in to research?	Researcher acknowledges the value addition in this research study	Inferences and interpretations of researcher are validated with the interpretations

			of interview participants
Rhetorical	How the researchers write about his/her research study?	The writing style adopted in this research study is of literary and informal style using the personal voice. It also uses qualitative terms and limited definitions.	First person pronoun is used in the research; Provided rich description of the problem
Methodological	What is the process of research? (or) How can the knower go about obtaining the desired knowledge & understandings?	To study the topic within its context inductive logic with good design is used.	Research has described the context of maintenance strategy and practices at an organisation level. Conceptual lens has been revisited based on the findings from case studies.

(Source: Creswell, 2007; Ritchie & Lewis, 2003; Guba & Lincoln, 2005)

These assumptions reflect a particular paradigm that researchers make when selecting qualitative research methods. A paradigm is “a broad view or perspective of something” (Taylor, Kermode & Roberts, 2007). Research could be affected and guided by a certain paradigm and it can be defined as “patterns of beliefs and practices that regulate inquiry within a discipline by providing lenses, frames and processes through which investigation is accomplished (Weaver & Olson’s, 2006)”. Therefore, to clarify the researcher’s structure of investigation and methodological choices, the paradigm adopted for this research study has to be discussed prior to any discussion about the specific methodologies utilized in this study. This study used interpretive paradigm (Orlikowski & Baroudi, 1991; Knowles & Cole, 2008), the details are provided in the subsequent section.

3.3.2 Scientific Paradigms

There are five underlying paradigms are available for qualitative research. They are positivism, post-positivism, critical theory, constructivism, and participatory (Guba & Lincoln, 2005). Another theory provides four paradigms such as post-positivism, constructivism, advocacy/participatory, and pragmatism (Creswell, 2003).

Positivism paradigm has more suitable options to conduct natural science research. Generally, positivists are having belief that reality can be described objectively with the measurable properties. Such properties are independent of researcher and the instruments being used (Myers, 1997). In this paradigm, theory has been tested based on hypothesis so that predictive understanding of the problem can be improved. A research can be categorised into positivist approach in case there is evidence of formal propositions, quantifiable measures of variables, testing of hypotheses and also inference about a problem can be drawn from the sample to a stated population (Orlikowski & Baroudi, 1991; Ritchie & Lewis, 2003). This research study is to explore the processes of maintenance strategies and maintenance practices at an organisation level in order to understand the tacit & implicit knowledge available with the maintenance managers; it is not possible to develop the hypothesis for testing and also to have a measurable list of variables. Therefore, positivist paradigm is not suitable for this study.

Social reality is historically constituted and people are responsible for production and reproduction of it. People can change their social and economic circumstances with their conscious act. The paradigm which is having such an assumption is named as Critical research paradigm. Accordingly, critical researchers begin from premise that there is an apprehension between control and resistance by various forms of social, cultural and political domination (Meyers, 1997). Estrange and restrictive conditions of the status quo are brought to reality by doing social critique which is the main task of critical researchers. Further, critical researchers should help to eliminate the causes of alienation and domination of society and their research should focus on conflicts and contradictions in present-day society. This research study does not search for alienation and domination conditions in the society. This research study would emphasize the social contractedness of reality and therefore an interpretive approach is selected for this research.

Hermeneutics and phenomenology is the philosophical base of interpretive approach (Myers, 1997). The basic assumption of interpretive research is that social reality can be accessed only through social constructions such as language, consciousness and shared meanings. Interpretive paradigm supports the view that there are many truths and multiple realities and focuses on holistic perspective of the person and environment. Interpretive studies usually attempt to understand problem through the meanings that people assign to them 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). The study adopts a social constructivist vision of reality that implies reality is socially constructed by the observer (Berger & Luckmann, 1967).

Table 3.3 Comparison between Scientific Paradigms

Characteristic	**Positivist View**	**Interpretive View**
Purpose	The researcher will predict and explain changes in phenomena of study	The researcher will interview the stakeholders and recognise the value and depth of the individual content
Beliefs	• One truth exists • Must be objective	• Many truths and realities • Different people have different perceptions, needs and experiences
Research Method	Quantitative	Qualitative
What Study Data is Based Upon	Measurable outcomes from questionnaire data	Descriptive, explanatory and contextual words of interview data
Study Sample	Clear and precise inclusion and exclusion data	Representatives who are able to provide expertise from different point of view

(Source: Ritchie & Lewis, 2003)

The holistic view of research problem and individual interpretive process for understanding of the problem are the characteristics of hermeneutics researcher. Researchers in this tradition are allowed to be subjective and devoted. Pre-understanding in the hermeneutic perspective is considered as a requirement as this will help the researcher to understand and interpret conditions (Patel & Davidson, 2003). Pre-understanding is an essential concept and also an indispensable prerequisite in the hermeneutic approach because, it gives direction to the research. In hermeneutics theory, interpretation and understanding of situation by studying the human nature, action and language can be carried out in well-structured manner (Bell & Bryman, 2007; Patel & Davidson, 2003).

Specifically, the study uses an adapted version of grounded theory (Glaser & Strauss, 1967). It can also be referred as constructivist grounded theory (Charmaz, 2006). Its two processes are ascertaining and emerging. These processes are carried out by a thorough interpretative process. The results of the interpretative process are concepts and development of theory. This approach does not seek the universal and lasting legitimacy. However, the research outcome will provide one interpretation among multiple interpretations of a shared or individual reality (Charmaz, 2006).

3.3.3 Scientific Approach

There are three different types of research approaches that are being used by researchers to relate the existing theories with empirical data. These research approaches are deductive, inductive, and abuctive. All these three research approaches are explained in detail in the subsequent paragraphs.
The deductive approach starts from the existing theories in the particular research area. These theories are tested with the help of hypotheses and the research questions formulated for the research study. The empirical data are collected based on these hypotheses and research questions so as to do comparison between existing theories and empirical data. The conclusion is

arrived through an analytical process. (Gummesson, 2000; Bell & Bryman, 2007).

The inductive approach is based on empirical facts. In this approach, empirical data collection is the first step. Based on the empirical data, researcher develops a concept. Further, the concepts are used to structure theories. The difference between inductive and deductive approaches is that deductive approach tests the existing theory and inductive approach generates new theory (Gummesson, 2000).

Inductive approach has been used in this research study. Empirical data are collected from maintenance managers of the gas utility company through semi-structured interview regarding their existing practices in the area of maintenance strategies in petrochemicals and NG Pipelines. Then, concepts have been developed through systematic analysis of data using qualitative software. Further, using these concepts process model has been developed for maintenance strategies & maintenance practices planning and execution.

The abductive approach is the iterative process among theoretical framework, empirical data and the analysis of case. The outcomes of creative iterative process are systematic combination of matching theory and extension of theory of previous research study (Spens & Kovacs, 2006). Therefore, new theory development is possible in this approach. The steps in abductive approach are development of theory through inductive approach, explanation of theory, testing of new theory through case study. This demands experience in the area of study therefore, this method cannot be applied schematically (Saunders, Lewis, & Thorhill, 2007). The abductive approach is not used in this research study since the new theory development is not the aim of this study.

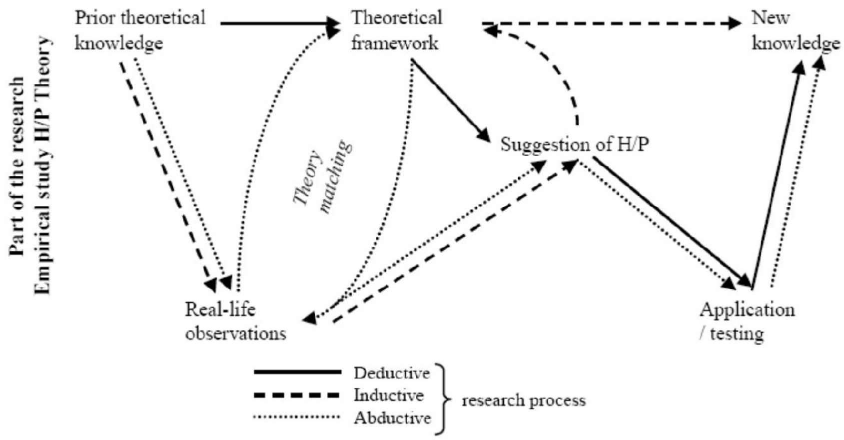


Fig. 3.2 – Three Different Research Approaches (Spens & Kovács, 2006)

3.3.4 Research Method

There are many ways to categorise research methods in social science research. The major research methods are *Quantitative* Research Method and *Qualitative* Research Method. Quantitative method starts with a test of theory then the researcher identifies the relationship among variables and finally poses this in terms of questions/hypotheses. This method uses instruments like surveys and experiments to understand natural phenomena in natural science research. To understand social and cultural phenomena in social sciences the *Qualitative* research method has been developed. Example of qualitative research methods are case study research, action research, and ethnography (Ritchie & Lewis, 2003).

Understanding the context of the research problem and setting of the participants are the requirements of Qualitative researchers. This helps researchers to gather information personally through visiting the problem context. So that, they can make interpretation based on their findings and the researchers experience and background help them to organise the interpretations (Denzin & Lincoln, 2005). Research questions are exploratory in nature (Maxwell, 1996; Yin, 2003), therefore the Qualitative research method has been chosen for this study. This method helps the researchers to study the problem in detail with respect to understanding of people and context (social/cultural) within which they exist (Myers, 1997). In Qualitative research method, research problem can be studied through understanding the patterns and relations in dialogue, archival documents, work place diagrams, etc. Inductive approach is the strength of the qualitative research method. This focuses on specific circumstances or people and emphasis on words rather than numbers (Maxwell, 1996). Rossman & Rallis (1998) offer eight characteristics of qualitative research and researcher as shown in Table 3.4

Table 3.4 Characteristics of Qualitative Research Method

Research Method	Characteristics
Qualitative Research	• Naturalistic – takes place in the natural world • Uses multiple methods that are interactive and humanistic • Is emergent rather than tightly prefigured • Is fundamentally interpretive • Views social worlds as holistic or seamless • Engage in systematic reflection on his own role in the research • Is sensitive to his personal biography and how it shapes the study • Uses complex reasoning that is multifaceted and iterative

(Source: Rossman & Rallis, 1998)

A comparison of Qualitative and Quantitative approaches is presented in Table 3.5 based on purpose, research methods, validity, conceptual framework etc. for understanding the qualitative research method.

Table 3.5 Comparison of Qualitative and Quantitative Elements in Design

	Quantitative	Qualitative
Purpose	• Precise measurement and comparison of variables • Establishing relationships between variables	• Meaning, Context & Process • Discovering unanticipated events, influences, and conditions • Understanding single cases Inductive development of theory

	• Inference from sample to population	
Conceptual framework	• Variance theories	• Process theories
Research questions	• Variance questions -Truth of proposition -Presence or absence -Degree or amount - Correlation • Hypothesis testing • Causality (factual)	• Process questions How and why • Meaning • Context (holistic) • Hypotheses as part of conceptual • framework • Causality (physical)
Research Methods		
Relationship	• Objectivity / reduction of influence (researcher as extraneous variable)	• Use of influence as tool for understanding (researcher as part of process)
Sampling	• Probability sampling • Establishing valid comparisons	• Purposeful sampling
Data collection	• Prior development of instruments • Standardisation • Measurement / testing – quantitative / • categorical	• Inductive development of strategies • Adapting to particular situation • Collection of textual or visual material
Data analysis	• Numerical descriptive analysis (statistics, correlation) • Estimation of population variables • Statistical hypothesis testing • Conversion of textual data into number of categories	• Textual analysis (memos, coding, connecting) • Grounded theory • Narrative approaches
Validity		
Internal	• Statistical conclusion	• Descriptive validity

validity	validity • Construct validity • Causal validity (control of extraneous variables)	• Interpretive validity • Construct validity • Causal validity (identification and assessment of alternative explanations)
Generalizability	• External validity (comparability)	• Transferability • Generalizing to theory

(Source: Maxwell & Loomis, 2003)

Qualitative research method was selected for this study for following reasons using above table as a guide. First, the nature of research questions suggests a qualitative approach. These are more of "how" and "what" types rather than "how many" or "how much" or "why" types. Second, the aim is to present a detailed understanding of maintenance strategies and maintenance practices at an organisation level (in a large gas utility company in India), requiring a focus on maintenance managers/engineers perspective and their meaning i.e. tacit & implicit knowledge available with the maintenance managers. Without getting involved, detailed understanding of these maintenance processes is difficult to understand and describe. Therefore, semi-structured interviews and secondary data were used for data collection. Participant observation has also been used as an additional technique for collecting data in this thesis. This helps to researcher to better understand tacit and implicit aspects of formulation of maintenance strategies and maintenance practices existing in the company. Third, maintenance strategy formulation and implementation aspects of this study needs to be studied in natural settings, rather than in controlled experimental settings.

3.3.5 Research Strategy– Case Study

Researcher can select a particular type of qualitative research method suitable to the research study since various qualitative research methods are available. Examples of qualitative methods are action research, case study research, and ethnography (Ritchie & Lewis, 2003). Based on the following conditions each method is having advantages and disadvantages: (a) type of research question,

(b) Investigator control over actual behavioural events, and (c) focus on contemporary phenomena instead of historical phenomena (Yin, 2003).

Solving actual problems with the active participation is the focus of action research method. This method is not suitable for this research study. Since the research objective is not to provide immediate solution to the problem of concerned people. Description and interpretations of a cultural and social group is the ethnography method. This method helps to understand the social world of people under study. The same can be done through engagement in the people community in order to produce people description in detail including their culture and beliefs.

Investigation of current phenomenon within its real-life context where the boundaries are not clearly evident between phenomenon and context is the main focus of case study method. Case study research uses multiple sources of evidence for data triangulation (Yin, 2003). In this research study, we need to understand existing maintenance strategies and practices at an organisation level. In a maintenance function of the organisation, the tacit and explicit knowledge available with maintenance managers & engineers working in the organisation needs to be captured for understanding existing approaches in maintenance strategies formulation. Therefore, there is a need to gather an in-depth understanding of this knowledge in formulation of maintenance strategy & practices at an organisation level. Qualitative research method is a suitable method in capturing and reusing such tacit and explicit knowledge in the field of best practices in maintenance management at the company.

For this research, case study method was chosen because it best matches with the requirements of the research and researcher's ability. Case study method is preferred when "how" or "why" questions are posed, when the investigator has little control over events, and when the focus is on contemporary as opposed to historical phenomenon within some real life context (Yin, 2003). Further, the case study method allows studying both the phenomenon of interest and context, producing a large number of potentially relevant variables

(Yin, 2003). Therefore, this method is selected. Case study method is the most commonly used qualitative method in such kind of study (Orlikowski & Baroudi, 1991; Alavi & Carlson, 1992; Myers, 1997; Palvia, Mao, Salam, & Soliman, 2003).

The purpose of this research work is to understand & describe the formulation of maintenance strategy at an organisation level (large gas utility company). Further, to understand why the particular maintenance strategy has been chosen and how these formulated strategies are being practiced in the organisation. A case study approach has been selected for this research study because, the definition of the case study method say that "the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result" (Yin, 2003).

The chosen design & methodology decisions which enclose the methods and techniques employed in designing this research study is summarised in the below shown Figure 3.3. Case Study Design and data collection strategies are described in the subsequent sections in detail.

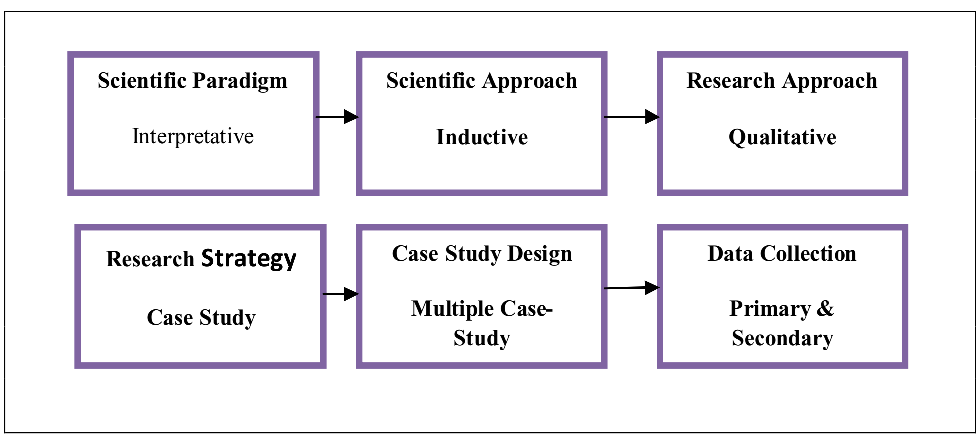


Figure 3.3 – Summary of Research Design & Methodology

3.4 Case Study Design

Design of case study includes the process of carrying out case study, selection of number of cases, unit of analysis, case selection criteria, etc. Figure 3.4 explains the case study design used in this research study.

Case Study method as research strategy encompasses all the aspects such data collection, data analysis, and data presentation which can be taken as an all-inclusive method (Yin, 2003). Therefore, such kind of study starts from existing literature discussion, data collection and a vigilant analysis of the evidences through an interpretive perspective (Yin, 2003). The same strategy has been used in this research study also.

GAIL (India) Limited, a large gas utility company has been chosen for the study on maintenance strategy & maintenance practices since it is having 70% market share in natural gas industry and it is a No. 1 gas utility company in India. GAIL (India) Limited, a Maharatna Public Sector Undertaking, is having 7 LPG processing plants, 1 Petrochemical processing plant & 3 Natural Gas Pipeline networks & 2 LPG pipeline networks. Further, researcher is having experience of 20 years in this company. In 20 years, the researcher worked in Petrochemicals plant maintenance for 10 years. The researcher is having almost 16 years of experience in maintenance of petrochemicals and gas processing plant. Selection of the large gas utility company helps researcher to interact with the maintenance managers in-depth & able to participate in the maintenance activities in order to observe the maintenance practices at site.

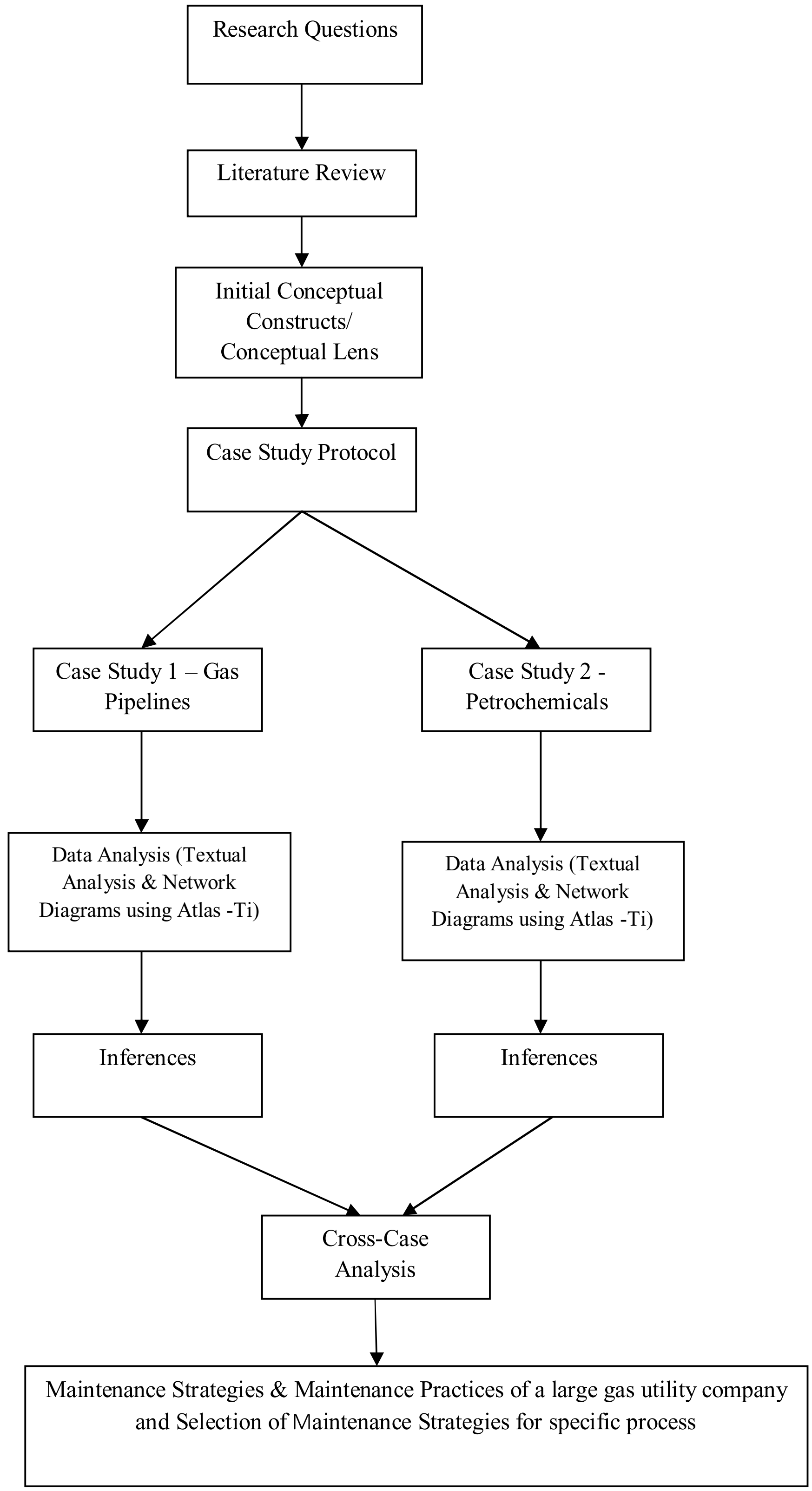


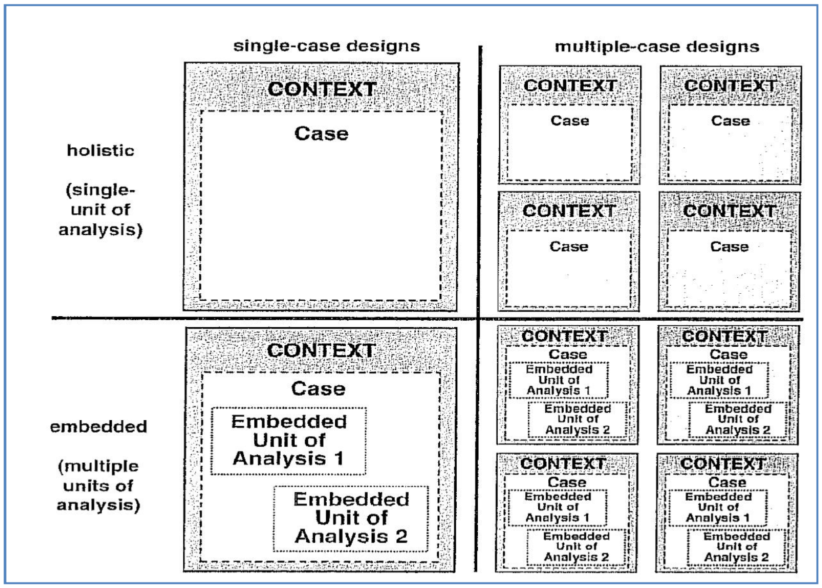
Figure 3.4 Case Study Design

3.4.1 Number & Type of Cases

Selection of case such as single case study design or multiple case study design is an important aspect in case study method. If the case is to test the well formulated theory, or an extreme or unique case or a revelatory case then the single case study design is a suitable method for the case study (Yin, 2003). Neither of these conditions is applicable to this research study. Therefore, a multiple case design was chosen. Then, the number of cases that was necessary or sufficient needed to be decided. In multiple case studies, each case serves an explicit purpose within the overall scope of examination (Yin, 2003). Replication logic is needed for multiple case analyses and further it increases the external validity of research (Eisenhardt, 1989; Yin, 2003)

GAIL's major business verticals are Natural Gas Transmission, Petrochemicals, Liquid Hydrocarbons (LPG Processing plant), LPG Transmission, City Gas Distribution, Exploration & Production, Tele communication & Power. The business verticals such as petrochemical process plant and natural gas pipeline networks are having unique operation processes in the gas utility company. Therefore, town case studies such as NG Pipelines and Petrochemicals are selected with the purpose of comparison of findings from multiple cases, the selection of case studies should follow "replication" logic. Replication logic suggests treating a series of cases as a series of experiments. Each case is helping to confirm or disconfirm the conceptual lens framed during the study. Replication logic aims to show or predict similar results, and explain contrasting results by giving anticipated reasons (Yin, 2003). Therefore, ***multi case holistic design*** *(Type 3; Yin 2003)* of case study research design has been selected for this research work.

Multiple-case design has been considered because, the evidence from multiple cases is often more compelling, and the overall study is therefore regarded as being more robust (Yin, 2003). Basic types of design of case studies suggested by Yin, 2003 is presented in the below given Figure 3.5 for reference.



Source: Yin (2003); COSMOS Corporation

Figure 3.5 Basics Types of Designs for Case Studies

3.4.2 Selection of Cases

The selection of two cases depended upon theoretical and pragmatic considerations. In the gas utility company, Natural Gas Transmission contributes 74% of the turnover of the company with the profit contribution of 58% of company's total PBT. Similarly, Petrochemicals contributes 8% of the turnover of the company with the profit contribution of 27% of company's total PBT. Approximately, 45% of man power has been deployed in these business verticals. Therefore, these two business verticals have been chosen for the study on Maintenance strategy & Maintenance practices.

3.4.3 Structure of Case Study Design

The structure of case design is as given under:-

Case 1: Maintenance strategy & practices for Petrochemical processing plant

Unit of Analysis: Plant

Level of Analysis:

1) Company level (at corporate)
2) Unit/Department level (Mechanical/Electrical/Instrumentation)
3) Individual (Sectional HODs/Supervisory level/Executing level)

Case2: Maintenance strategy & practices for Natural Gas Pipeline network

Unit of Analysis: Plant

Level of Analysis:

1) Company level (at corporate)
2) Unit/Department level (Compressor Stations/Gas Terminals/RR Stations/SV Stations)
3) Individual (Sectional HODs/Supervisory level/Executing level)

Above two cases have been done separately and then cross case analysis of maintenance strategies & practices in Petrochemical plant & Natural Gas Pipelines network are conducted. Three levels are selected to cover employee levels exists in the company i.e., junior level management (individual); middle level management (unit level/department level); senior level management (corporate level).

A common and different maintenance strategies & practices applicable are also identified for the above two business verticals of the large gas utility company in India. Based on the study of above cases Case 1 & Case 2, the process model of maintenance strategies & maintenance practices planning and execution for the selected gas utility company is developed.

3.4.4 Sampling

Theoretical sampling method was employed for this study. For data sample, Gail's petrochemical complex & compressor stations, Gas Terminals, Radio Repeater (RR) Stations and Sectionalising Valve (SV) Stations of NG pipeline network were considered. The plants/terminals/stations were identified using the data base available with the company in GAIL's Intranet/website. Among the maintenance and operation managers working in these plants/terminals/stations were interviewed based on their availability either at site location or Training institute.

The names & contact details of the maintenance/operation managers were obtained from the Telephone directory available in the GAIL's Intranet/ website. Among the managers identified, based on the unit of analysis & level of analysis, 25 managers/engineers related maintenance functions were chosen. Finally, interviews were conducted from 10 maintenance managers/engineers including both the case studies Case Study 1 & Case Study 2.

3.5 Data Collection Method

"Immersion in the details and specifies of the data to discover important categories, dimensions, and interrelationships; exploring genuinely open questions rather than testing theoretically derived hypotheses" (Patton, 1990). Accordingly, data gathered in this research has been analysed and interpreted inductively. Further, Qualitative data is "detailed, thick description, inquiry in depth, direct quotations capturing people's personal perspectives and experiences" (Patton, 1990).

The advantages of case study method are:- (i) case study method provides systematic collection & organisation of data, comprehensive data analysis methods in order to ensure in-depth information above each case under study, (ii) it allows to interviewees to share their experiences in their own language rather than the researchers', (iii) it involves collection of evidences for data collection from the various sources like documents, archival records, questionnaire, interviews, observations, and physical artefacts (Eisenhardt, 1989, Yin, 2003), (iv) this method ensures the validity of the research findings through triangulation of data collected from multiple sources.

Data collection activities primarily contain conducting site visits for the case studies, collection of data before and after a visit based on requirement. The empirical investigation in this research study included collecting data from the plants Petrochemicals and NG Pipeline units such as compressor stations, terminals etc. of gas utility company in India.

Data at the gas utility company was collected from four sources: participant observation, interviews, informal discussions and archival documents. The observations focused on the process elements of context, actors and actions (Pettigrew, 1997). The researcher also made detailed field notes and noted down the interactions taking place among the maintenance personnel at the company whenever possible.

The data was collected from the Maintenance Managers of GAIL using the **case study protocol.** A case study protocol is a document that contains the questionnaire (instrument) for data collection as well as the procedures and general rules to be followed in using the protocol. During data collection stage, Construct validity was checked using multiple sources of evidence (document analysis) and reliability has been ensured by using case study protocol (Yin, 2003). In section 3.8, Data Collection Protocol (DCP) used in this research study for interview is discussed in detail. The detailed case study protocol was developed before data collection and semi structured interviews with the maintenance personnel of the large gas utility company's petrochemical plant & NG Pipelines were conducted.

Before starting the interview, interviewee person was explained that the case study material and the interview data would be used in two ways: (i) To understand & model maintenance strategies & practices planning and execution for this research study and (ii) To use data for a case publication in thesis, conference, papers, and book. A brief introduction was also given to the interviewee person about this case study research based on the framework given above.

The interviews were conducted at three levels to collect the data for the study of maintenance strategy & practices in the gas utility company. The three levels are as given under.

1) Interview with Senior Management (Maintenance Heads in corporate level or unit level)
2) Interview with Middle Management (Departmental Heads at unit level)
3) Interview with Junior Management (Sectional Heads/ Engineers/ supervisors at unit level)

The above interviews lasted between 30 to 60 minutes. The interviews are recorded and fully transcribed. Typed interview scripts are also shown to the interviewees, along with follow-up questions. Table 3.6 summarises the main steps of data collection for all cases.

Table 3.6 Main Steps in Data Collection

Steps in data collection	**NG Pipelines (Case Study 1)**	**Petrochemicals (Case Study 2)**
Development of Case Study Protocol (CSP), Review and final CSP development	December, 2012 to April, 2013	
Initial Contact and Arrangements	May, 2013	June, 2013
Data Collection Interviews	July, 2013 to October, 2013	July, 2013 to August, 2013
Site visits for field observations	October, 2013 to November, 2013	September, 2013 to November, 2013
Review of case report for internal validity	November, 2013	November, 2013

Additional data collection	December, 2013	December, 2013
Total Number of interviews	6	6

3.6 Data Analysis Strategy

Systematic investigation and analysis of data so as to present the interpretation and presentation of findings is the main purpose of qualitative investigation. The challenges in data analysis are "make sense of massive amount of data, reduce the volume of information, identify significant patterns, and construct a framework for communicating the essence of what the data reveals" (Patton, 1990). The researcher's interpretations and description of phenomena is the basis for data analysis in this research. These interpretations are subjective based on actors' experiences in a context. Such kind approach is classified in modified form of ground theory (Locke, 2001; Charmaz, 2006).

Data analysis is aimed to identify (i) the nature of maintenance strategies & maintenance practices including benchmarking of maintenance practices and maintenance reliability of the large gas utility company, (ii) maintenance strategies selection process in the company, and (iii) the relationship between maintenance strategies selection process and the factors contributing to maintenance strategies & maintenance practices. Two major steps were adopted in data analysis for this research study: within case analysis and cross case analysis. Within case analysis approach is to understand the case individually and documenting it thoroughly. In cross case analysis, similarities and differences across cases were explored.

Within case analysis helps to organize individual case data for in-depth study and to manage the staggering volume of data (Eisenhardt, 1989). After completion of individual case's data collection and analysis, search for cross-case patterns are carried out from qualitative data. These patterns are such as categories, codes, dimensions, and theme/scheme classifications (Patton, 1990). The initial conceptual constructs identified for conceptual lens are the basis for categories to search for within-case similarities and between-case differences.

Data Analysis has been carried out with the Textual Analysis and cross case synthesis. Textual analysis has been done with the help of Atlas TI software; network diagrams have been formulated with the necessary quotation and frequency analysis.

3.6.1 Data Analysis using Grounded Theory

The data analysis using grounded theory is an iterative process involving several iterations between interview data, existing theory, and observation data (Charmaz, 2006).

Following three steps were used iteratively for conducting data analysis:

1. Open Coding
2. Focused Coding
3. Identifying patterns of relationship among conceptual categories

The first two steps help in exploring and understanding the nature of maintenance strategies and maintenance practices in the large gas utility company by developing codes, categories and concepts of maintenance strategies and practices being following in the company. The last step helps in identifying the factors contributing to the selection of maintenance strategies and their impact in maintenance practices. Details of these activities are as given under:-

Step I: Open Coding

Input data are selected, categorised and combined to understand main concepts by using open coding method. Further, it is used to identify the relevant constructs. Part of the text which are sentences or paragraphs (Strauss & Corbin, 1990) describing (i) the nature of maintenance strategies &

maintenance practices including benchmarking of maintenance practices and maintenance reliability of the large gas utility company, (ii) maintenance strategies selection process in the company, and (iii) the relationship between maintenance strategies selection process and the factors contributing to maintenance strategies & maintenance practices assigned with labels for easy retrieval and categorisation (Miles & Huberman, 1994) using open code technique (Strauss & Corbin, 1990; Charmaz, 2006).

'The investigator identifies potential themes by pulling together real examples from the text' is the process of open coding (Ryan & Bernard, 2000). Open coding implies that the codes are discovered from the empirical data. New codes are created as a new evidence (for example issues, themes) emerges from data. The open coding is used to investigate a new occurrence. The focus of research is on the outcomes of theoretical categories from empirical evidences (Strauss & Corbin, 1990; Charmaz, 2006).

Figure 3.6 below explains how the open coding was done from interview statement. In the example statement the words "Preventive Maintenance", "Predictive Maintenance", "Shutdown Maintenance" illustrates the maintenance methods (explains initial conceptual construct- Maintenance Tactics), therefore, in open coding step these were marked as codes. Similarly, phrases "maintenance of pipelines based on our previous experience", "Stand by equipment strategy" illustrate about maintenance strategy selection and therefore marked as codes. Phrase "pipeline availability of 99.9% on 24 X 7 basis" illustrates the maintenance objectives i.e., explains organisation's maintenance policy, and accordingly marked as code.

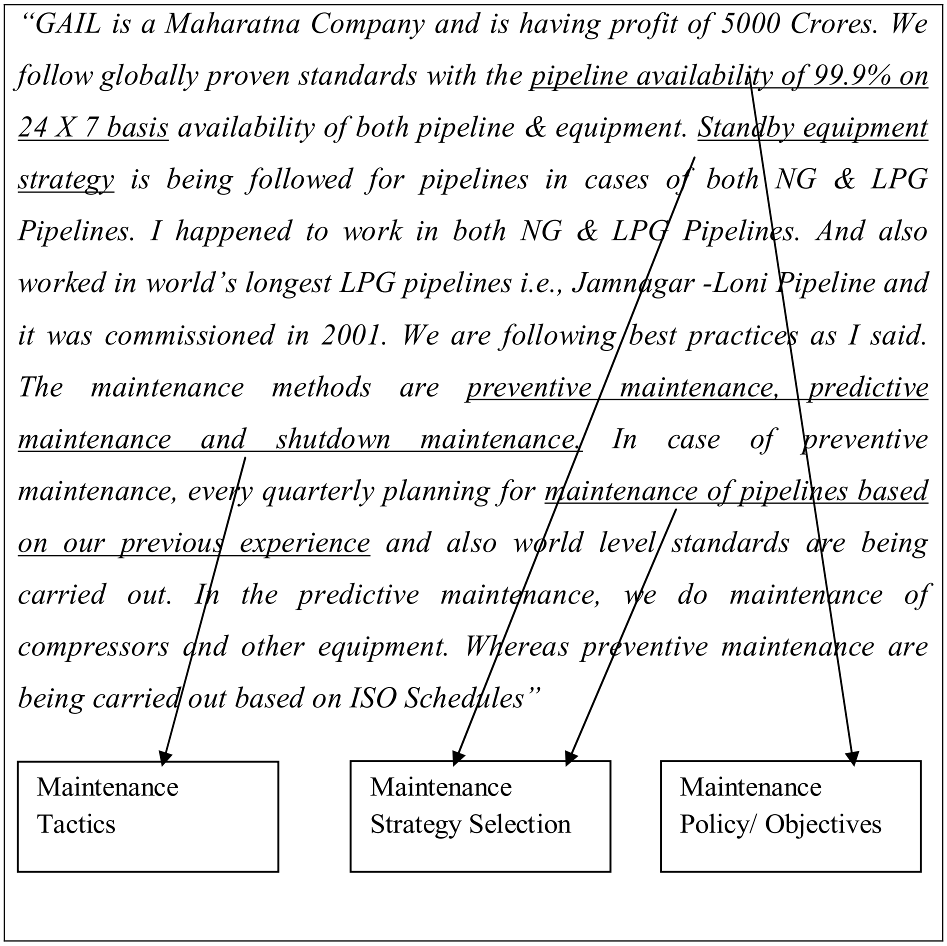


Figure 3.6 – Examples of Codes

Interview scripts coding was done through Qualitative Analysis software Atlas-Ti. This software enabled the data analysis process by helping with coding, linking codes, and text segments, creating memos, searching, editing and reorganising, and for visual display of data and findings (Miles & Huberman, 1994; Weitzman, 2000; Creswell, 2007).

Step II: Focused Coding

Codes with common attributes are merged to create conceptual categories and abstractions from the empirical data in focused coding. Such kind of consolidation helps to reduce the number of codes the researcher work with. It also helps to create the main themes which emerge from the empirical data

(Strauss & Corbin, 1990). Codes are grouped into categories using a bottom up approach as shown in the Figure 3.7 given below.

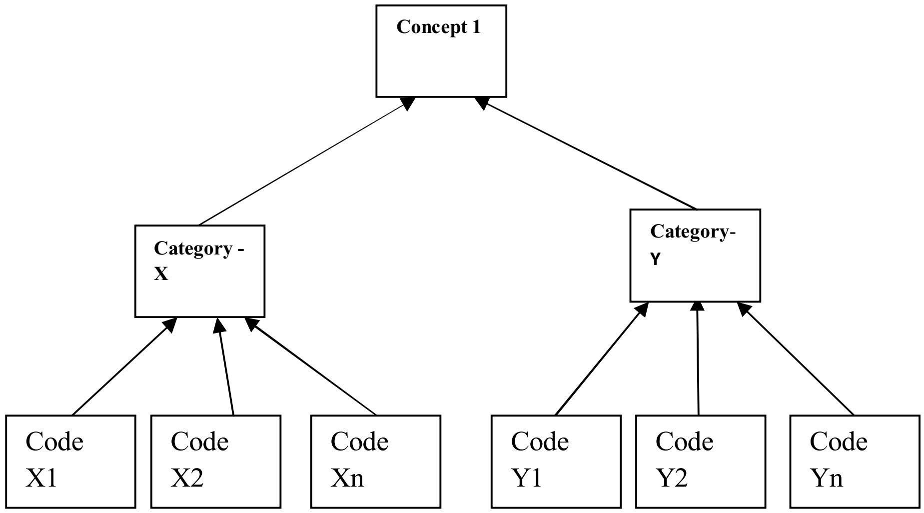


Figure 3.7 – Codes, Categories, and Concepts

During the open coding, codes illustrating (i) maintenance strategies and maintenance practices of the large gas utility company, (ii) selection of Maintenance Strategies, (iii) reliability of maintenance practices & strategies being used and (iv) benchmarking practices for maintenance processes, are discovered from the empirical data during the open coding. These codes are further consolidated into broader categories. Then, categories are classified into concepts/themes. Since it comes from conceptualisations of data, these are the basic units of analysis in grounded theory.

Initial Conceptual Constructs identified related to maintenance strategies from literature served as basis of identifying concepts. Statements illustrating these initial conceptual constructs are coded first. Then these codes are consolidated into categories: each category represented the factors which are related to maintenance strategies & maintenance practices of a large gas utility company. Finally, each category is linked to the categories of Initial Conceptual Constructs (ICC). In a category which could not be associated with the Initial Conceptual Constructs (ICC) is identified as new category (a new concept emerged). Figure 3.8 shows this categorisation and linking process in detail.

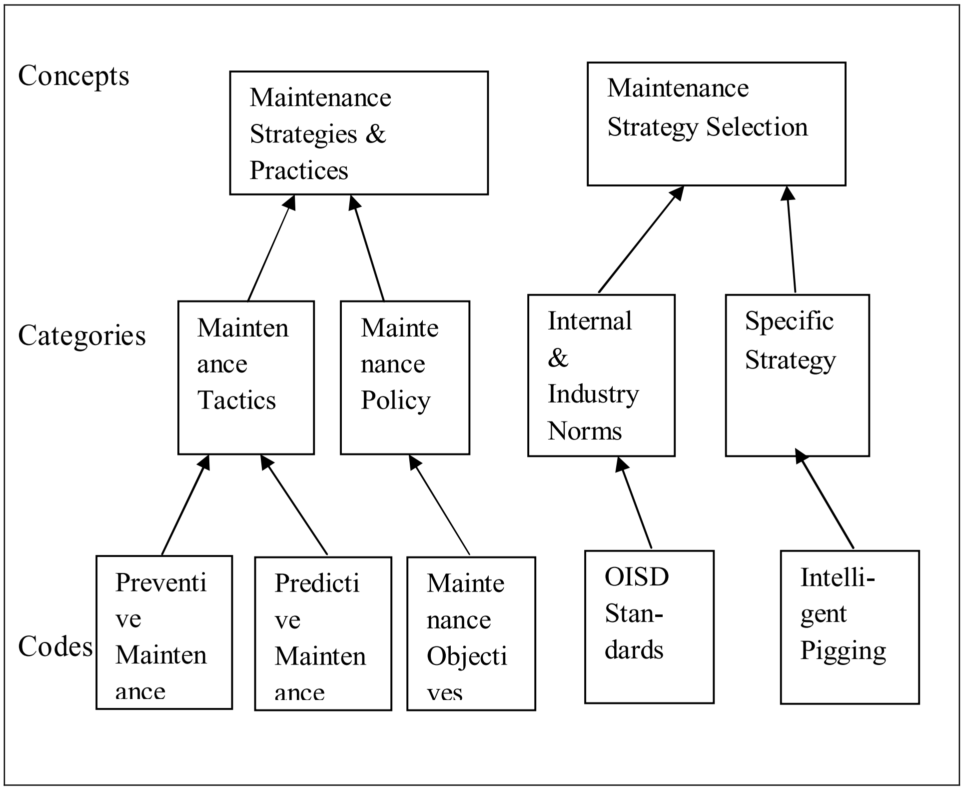


Figure 3.8 – Categorisation and linking of Codes, Categories & Concepts

Labelling of all interview data in to codes, categories and concepts are carried out using the methods such as open coding and focused coding as explained above. The relationships among codes and categories are compositional in nature. The relationships are generally of 'is part of', 'is a', 'is associated with'. The relationships between codes, categories and concepts are recognised using these causal relations. Then, the relationship is defined as the composition of a particular concept or category.

Step III: Identifying patterns of relationships among conceptual categories

This step supports to identify the underlying relationships between codes, categories and concepts. In data analysis, the relationships identified are causal ('is part of', 'is associated of') and associative in nature. Accomplishments mentioned by interviewees leading to the maintenance strategy processes are identified by creating appropriate codes in Atlas Ti software. Figure 3.9 below presents how causal relationships identified from the interpretation of interview statements.

"GAIL is a Maharatna Company and is having profit of 5000 Crores. We follow globally proven standards with the pipeline availability of 99.9% on 24 X 7 basis availability of both pipeline & equipment. Standby equipment strategy is being followed for pipelines in cases of both NG & LPG Pipelines. I happened to work in both NG & LPG Pipelines. And also worked in world's longest LPG pipelines i.e., Jamnagar -Loni Pipeline and it was commissioned in 2001. We are following best practices as I said. The maintenance methods are preventive maintenance, predictive maintenance and shutdown maintenance. In case of preventive maintenance, every quarterly planning for maintenance of pipelines based on our previous experience and also world level standards are being carried out. In the predictive maintenance, we do maintenance of compressors and other equipment. Whereas preventive maintenance are being carried out based on ISO Schedules"

Leads to   cause of

Figure 3.9 Casual Relationships identified from Interview Statements

As shown in the Figure 3.9, "Standby equipment strategy" is the specific maintenance strategy being adopted in gas pipelines that leads to "pipeline availability of 99.9% on 24 X 7 basis" in order to achieve the gas utility company's maintenance objective/policy. Similarly, "previous experience" of maintenance managers is the cause of "preventive maintenance plans" in the gas utility company. It implies that preventive maintenance planning is being done based on previous experience of maintenance engineers/managers in the organisation. Accordingly, these codes are linked through Atlas-Ti software by “leads to” and “is cause of” and “is part of” relations as shown in the above Figure.

Abstraction of these codes into categories and categories into concepts leads to inheritance of relationships between codes which are already identified from the data by the categories and codes. Continuing with the above example, code “pipeline availability of 99.9%” is associated with “maintenance policy”, which in turn is part of “maintenance strategies & maintenance practices” concept. Similarly standby “equipment strategy” code is associated with the category “Specific maintenance strategies for NG pipeline”, which is part of the concept “selection of specific maintenance strategy for a particular operation process/equipment”.

The casual relationships such as “leads to” and “cause of” between the codes are further classified in respective categories and codes as shown in Figure.3.10 below.

"GAIL is a Maharatna Company and is having profit of 5000 Crores. We follow globally proven standards with the pipeline availability of 99.9% on 24 X 7 basis availability of both pipeline & equipment. Standby equipment strategy is being followed for pipelines in cases of both NG & LPG Pipelines. I happened to work in both NG & LPG Pipelines. And also worked in world's longest LPG pipelines i.e., Jamnagar-Loni Pipeline and it was commissioned in 2001. We are following best practices as I said. The maintenance methods are preventive maintenance, predictive maintenance and shutdown maintenance. In case of preventive maintenance, every quarterly planning for maintenance of pipelines based on our previous experience and also world level standards are being carried out. In the predictive maintenance, we do maintenance of compressors and other equipment. Whereas preventive maintenance are being carried out based on ISO Schedules"

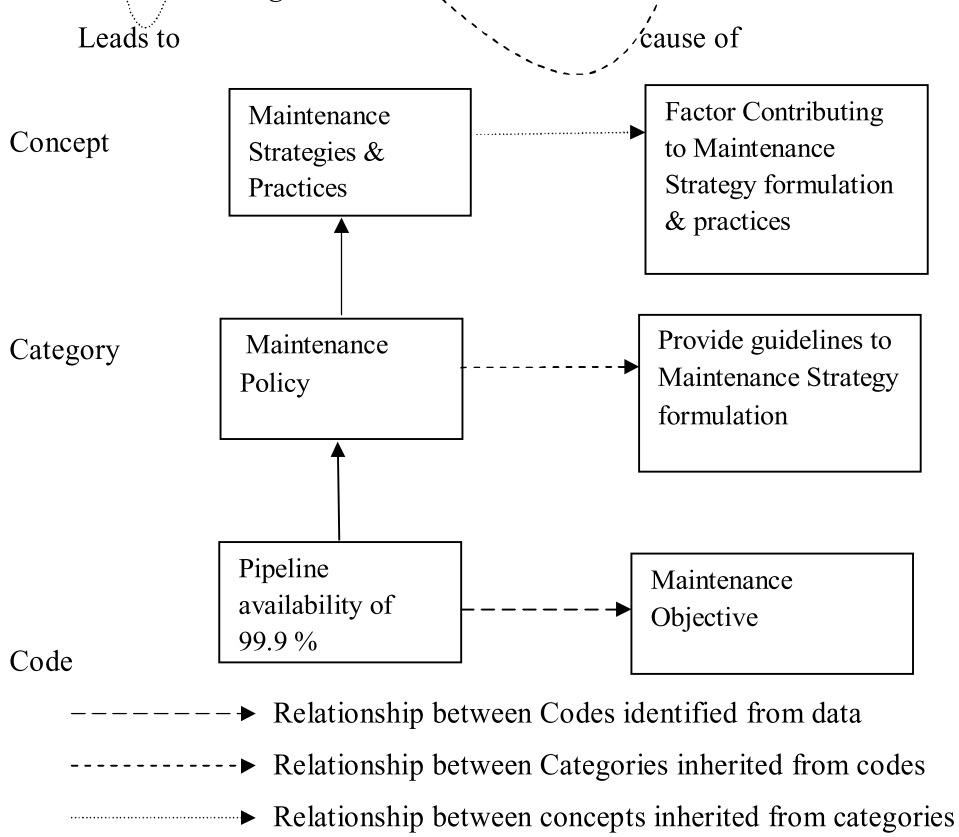


Figure 3.10- Relationships between Concepts/Categories inherited from Codes

3.6.2 Within Case Data Analysis

Within case data analysis is carried out based on interview data in terms of research questions: How the gas utility company is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?. This approach leads to the identification of various factors contributing to maintenance strategies and maintenance practices. These factors form the basis for maintenance strategies selection and maintenance practices in the large Indian gas utility company. Further, maintenance strategies selection process being adopted for a particular operation process/equipment in the organisation is also identified. Then, the relationship between the identified factors of maintenance strategies & maintenance practices and maintenance strategies selection process in the company are analysed thoroughly. Figure 3.11 below shows the phases within case analysis.

The data analysis is carried out in two levels, conceptual and detailed. Conceptual analysis findings are of descriptive nature. These findings describe about the nature of maintenance strategy formulation, selection, and maintenance practices. Detailed analysis findings are of perspective in nature (Tsang, 1997). Therefore, it describes the relationships among the factors contributing to maintenance strategies and practices & selection of specific maintenance strategy for a particular operation process/equipment. Two level data analysis provides better internal validity of the research study by triangulation of perspectives on the same data set. This is known as theory triangulation (Patton, 1990).

Phase 1 - Identification of factors contributing to maintenance strategies & practices in the large gas utility company

The basic aim of this phase is to identify the factors contributing to maintenance strategies formulation & maintenance practices which are being implemented in the large gas utility company. As described in the previous section, open coding and focused coding are used to identify categories and concepts from the data. Codes illustrating about maintenance strategies and maintenance practices are discovered from the empirical data during the open coding. Then, these codes are combined into broader categories. Further, the categories identified are classified into concepts. This phase resulted in description of various factors contributing to maintenance strategies selection & maintenance practices of the company. The categories and concepts identified in this phase are used in next two phases.

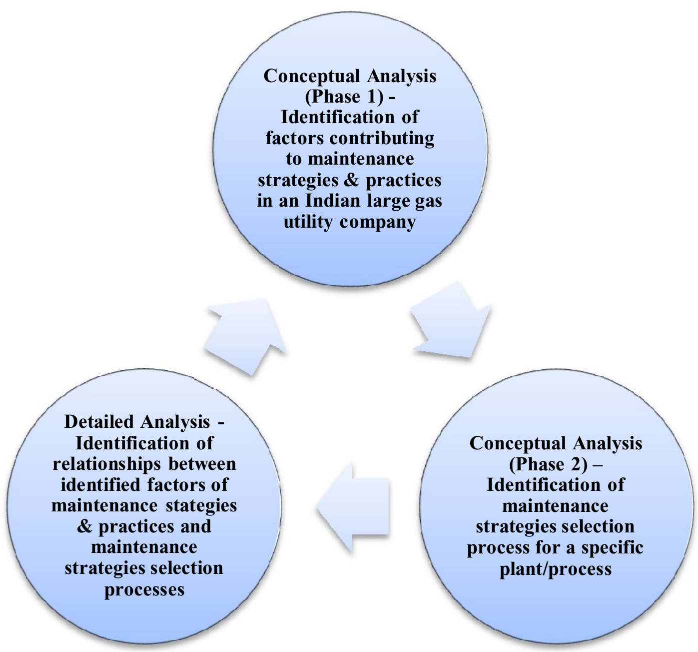


Figure 3.11 – Phases of within case analysis

Phase 2 -Identification of maintenance strategies selection processes for a specific plant/ process

In this phase, open coding and focused coding are used to identify the maintenance strategies selection processes for a specific plant/process. Codes illustrating activities for managing maintenance strategies selection are discovered from the empirical data during the open coding. These codes are combined into categories. Then these categories are further classified into concepts. The relationships among the identified factors are labelled in Atlas-Ti software with "is associated with" relations.

Phase 3 - Relationships among the factors identified in phase 1 & maintenance strategies selection processes identified in phase 2

In this phase, an attempt has been made to identify the relationships between factors contributing maintenance strategies and practices and selection of maintenance strategies. A detailed analysis of interview data is carried out to identify the basic patterns among these factors.

Each phase's results are compared with the exiting literature to identify emerging new ideas and concepts. This process is continued till no more concepts and categories are found. The results of within case analysis are presented in the form of "qualitative associative networks". Associative networks are having nodes linked to each other by association. These networks set aside for fuzzy, intuitive and, subconscious relations between concepts which are to be presented visually. The associative networks are displayed using boxes and arrows, with the boxes containing the concepts. The arrows are representing the relationships among the concepts. The arrows can be unidirectional and bi-directional. Relationships include causality, association, choices, and time (Ryan & Bernard, 2000). The qualitative associative networks developed for the case studies NG Pipelines & Petrochemicals of the gas utility company are discussed in details in the chapter 4 & 5.

3.6.3 Cross Data Analysis

Replication logic is used for cross data analysis. This analysis is to compare and explain similarities, dissimilarities and, complimentary findings in the study of maintenance strategies and maintenance practices of the large gas utility company. Case comparison can be done by listing similarities and dissimilarities between the cases. Such case comparison includes the relative findings and contextual factors across cases (Eisenhardt, 1989).

Cross case analysis results are exhibited in the form of a content analytic summary table. Such analytic table focuses on content primarily. It does not refer to which case it comes from (Miles & Huberman, 1994). In this study, a content analytic summary is presented in the form of qualitative associative networks. The findings across cases are integrated through these network diagrams. The cross case analysis is discussed in detail in Chapter 6.

3.7 Quality of Empirical Research

This study does not claim the objectivity in line with the view of socially constructed reality. However, it provides the argument that the evolving theory is one of numerous possible explanations of reality constructed with the researchers as active instruments. The theory replicates the observation as well as the observed. Therefore, all the explanations are not meant to be treated as equally relevant, credible, and acceptable. As a researcher, it is required to present the argument of the case for theory explanation as per the requirement of research study.

This research focuses on rich description of maintenance strategies selection and maintenance practices rather than on generality as encouraged by others (Yin, 2003). Such kind of approach may be criticised because it supports only generation of a local empirical theory. It may not be generalised. Hughes and Jones (2003) argued that the approach mentioned above is still useful and it can contribute to the existing body of knowledge. Early qualitative researchers are of the opinion that they are able to examine the case in more detail and thoroughly understand the interrelationships of data by limiting a study to a single organisation.

For evaluating quality of any research study following tests are used: Construct Validity, Internal Validity, External Validity, and Reliability (Yin, 2003) and the details of the same are discussed below.

3.7.1 Construct Validity

Ascertain the correct measures for the concepts being studied is referred as construct validity (Yin, 2003). This demands that the selected concepts are measured correctly. Data triangulation addresses the potential problems of construct validity when the evidences are collected from various sources. Few quotes from Yin, 2003 regarding data triangulation are, "it aimed at corroborating the same fact or phenomenon" and "when you have multiple sources that nevertheless address different factors". Gathering evidences from multiple sources essentially provide "multiple measures of the same phenomenon" (Yin, 2003) and ensures "stronger substantiation of constructs and hypotheses" (Eisenhardt, 1989).

A technique called triangulation which combines different sources of evidence in a single study is used to address construct validity (Rossman & Wilson, 1985). One of the major strength of the case study approach is the combination of different sources (Yin, 2003). This case study includes various sources for collecting relevant data like interviews, documents, company's website, intranet, observations and artefacts. The interviews and field observations are transcribed and used in the data analysis. This approach enhances the construct validity by providing multiple perspectives of the phenomena. Chain of evidence approach would allow an external observer to follow the source of evidence from initial research questions to case study conclusions.

As advocated by Yin (2003), the case study reports are reviewed by the key informants. Participants' feedback is also incorporated in the final case reports. Further, two level of analysis are carried out such as conceptual and detailed during data analysis. This analysis helps to improve the construct validity of the research by triangulation of perspectives on the same data set (theory triangulation) (Patton, 1990). The details of triangulations are presented in the below given Table 3.7.

Table 3.7 Data Evidences for Data Triangulation of Case Study 1 & 2 (NG Pipelines & Petrochemicals)

Concepts	**Categories**	**Evidence Type**	**Details of evidences**
Maintenance Strategies & Practices planning and execution	Maintenance Policies/ Budget	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interviews; company's maintenance policy/ budget is available on intranet; maintenance policy document; budget document; field notes
	Maintenance Tactics	Interviews; Company's Intranet; Documents; Participant Observation	Audio records & field notes of interviews; maintenance policy, objectives, mission are available in intranet; documents such as ISO documents, Department Quality Manuals (DQM), Preventive Maintenance Schedules, etc.; field notes
	Planning & Scheduling	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interviews; MOU parameters available on intranet; documents such as PM schedules, work orders etc.; SAP PM module data; field notes
	Material Management	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interview; Contract & Procurement (C & P) procedures available on intranet; SAP MM module data; field notes.

	Employee Empowerment	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interview; Contract & Procurement (C & P) procedures and O & M information available on intranet; field notes.
	Information Technology	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interview; SAP module data; SCADA system data; field notes.
	Organisation & Human Resources	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interview; training records & organisation structure available on intranet; field notes
	Maintenance Challenges	Interviews; Informal Discussion; Participant's Observations	Audio records & field notes of interview; field notes
Reliability Maintenance strategies & practices being used	Reliability Analysis	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interviews; no much document is available except Root Cause Analysis (RCA) reports & Incident Analysis (IA) reports; no data available on intranet; field notes.
Benchmarking practices for maintenance processes	Performance Measures & Benchmarking	Interviews; Company's Intranet; Documents; Informal Discussion	Audio records & field notes of interviews; MOU parameters & benchmark reports are available in intranet; documents such as MOU & IMOU data and standards such as OISD, PNGRB, AGA etc.; field notes.
Maintenance strategies selection processes for specific plant/process	Factors for maintenance strategy selection; Internal & Industry norms; specific maintenance strategies for NG Pipeline	Interviews; Company's Intranet; Documents; Informal Discussion; Participant Observation	Audio records & field notes of interviews; maintenance policy, objectives, mission are available in intranet; documents such as ISO documents, Department Quality Manuals (DQM), PM Schedules, etc.; field notes

3.7.2 Internal Validity

Establishing causal relationships among the conditions so as to one leads to another with the proper differentiation from the false relationships is implication of Internal Validity (Yin, 2003). There are two types of problems associated with internal validity. First one is making inferences from the case study i.e., researcher cannot directly observe the event every time. Second one is spurious effects i.e., there may be few additional constructive factors other than the factors identified in the research model.

In this research a number of methods are used to address the above mentioned problems in order to ensure internal validity. In this study, two of such methods are used. They are (i) Theory triangulation perspectives have been used on the same data set (Patton, 1990). Data have been analysed with different perspectives during with-in case analysis like conceptual and detailed level of analyses and, (ii) the key participants were requested to review and comment on case reports. The comments from review have been incorporated in the final case report.

The above two methods are used to focus on understanding and interpretation of the processes that can be characterised as casual relationships between concepts: (a 'cause') leads to another concept (an 'effect').

3.7.3 External Validity

Research study's findings can be generalized by establishing the domain of the study. This can be defined as External Validity (Yin, 2003). Multiple case study strategy helps to strengthen the generalisation of the research findings.

According to replication logic in case study, the design of multiple case studies and cross case analysis is a major step carried out in the research. This approach can be treated similar to use of experiments in which researcher generalise the theory using one experiment to another (Yin, 2003).

External validity can be addressed using replication logic in selecting case studies. Case study relies on analytical generalisation (Eisenhardt, 1989; Yin, 2003). Case study is not statistical generalisation as with experimental hypothesis-testing research. Research results can be accepted even after application of replication logic once. Multiple replications are not required to be performed (Yin, 2003).

3.7.4 Reliability

The errors and biases of the research study is basic objective of the reliability test. Operations of the study such as data collection procedures can be repeated to produce the same result using reliability test (Yin, 2003). This means that if another researcher applies the same data collection procedure as carried out by the previous researcher in case study, the researcher will arrive at same outcomes and conclusions.

To ensure consistency in applying procedures for data collection and analysis, number of methods is used in this research. First, the *Case Study Protocol (CSP)* has been used to guide the research process. The protocol is a major method in increasing the reliability of case study research. CSP guides the investigator in carrying out the case study research (Yin, 2003). The protocol includes interview questions as well as procedures and general rules that should be followed during interviews. This ensures consistency in the areas covered within cases and across cases.

Second, interviews are recorded and transcribed so as to capture all the data which permits independent data analysis by other researchers also. Third, use of Atlas-Ti software helps researcher to do systematic and consistent analysis of qualitative data (Weitzman, 2000) and increased the reliability of research because the procedures can be repeated (Yin, 2003). Fourth, the filed notes have been taken and the same are also transcribed for future reference. The Case Study Protocol is discussed in detail in the next section.

3.8 CASE STUDY PROTOCOL DEVELOPMENT

This section discusses the use of Case Study Protocol (CSP) and describes the process of developing one for this research. As discussed already, use of case study protocol enhances the reliability of case study research and serves as a guide for the researcher in carrying out the data collection from a single case study (Yin, 2003).

3.8.1 Process of Developing Case Study Protocol (CSP)

The case study protocol and survey questionnaire, both are directed at collecting data from a single data point, i.e. a single case study or from a single respondent. But the case study protocol differs from the survey questionnaire in a significant way. It is much more than a questionnaire or instrument, and contains the procedures and general rules to be followed in using the protocol (Yin, 2003). It is directed at the researcher rather than the subjects of the study and according to Yin (2003) having a case study protocol is essential for multiple case study research.

The case study protocol includes following main sections (Yin, 2003):-

i. Introduction to Case Study and Purpose of Protocol: This gives an overview of case study research including research objectives, issues, and related literature about the research.
ii. Data Collection Procedures: This section details the field procedures to be followed while conducting the research including presentation of credentials, access to the case study sites, and general sources of information.
iii. Outline of Case Study Report: This section details out the format for the case study report including the outline, format for data, use and presentation of other documentation, and bibliographic information.

iv. Case Study Questions: This section presents the case study objectives and questions the researcher must keep in mind while collecting data, formats for arranging data, and potential sources of information for answering each research question.

Based on the conceptual framework and guidelines given by Yin, a case study protocol was developed. The case study protocol is provided in full in the next section. The draft case study protocol was presented to the subject matter experts in maintenance in the large gas utility company i.e., GAIL (India) Limited. Further, a presentation was made on constructs of maintenance strategy selection and practices such as Maintenance Tactics, Reliability Analysis, Maintenance Performance/Benchmarking, Maintenance Policy/Budget, Material Management, Planning & Scheduling, Information Technology, etc. The feedback from the team members on these constructs was taken and duly incorporated in the finalisation of case study protocol.

3.8.2 CASE STUDY PROTOCOL- FORMAT

A. Introduction to Case Study and Purpose of Protocol

A1. Background

Production/Operation process is continuous in a gas utility company and any abrupt stop of whole production process cause delay and reduction in output. Although Organisation follows various maintenance strategies, the cost and impact (equipment safety, upstream supplier issues, and downstream customer issues) of sudden failure of equipment was found to be huge in the organisation. Therefore, this case study protocol has been prepared to study on this problem i.e., How the maintenance managers in a large gas utility company in India formulate the maintenance strategies for their gas transportation/processing operations and how they practice these formulated maintenance strategies to maintain the equipment healthy & operate the process/plant continuously without interruption?

To conduct the above case study, GAIL (India) Limited has been chosen to conduct the study. Approval of conducting this study has also been obtained from the organisation.

A2. Purpose of Case Study Protocol

A case study protocol is a document that contains the questionnaire (instrument) for data collection as well as the procedures and general rules to be followed in using the protocol. This purpose of this Case Study Protocol is using case study as research strategy to understand:

How the gas utility company (GAIL India Limited) is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as petrochemicals & pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment? The additional questions are,

a. What are the common and different maintenance strategies & practices to both the business verticals (and) how the maintenance strategy & practices differ with the specific assets available in one operation process/plant/pipeline network from others business verticals?
b. What are the benchmarks being used in petrochemicals/ NG pipelines? What is extent of achievement of benchmark parameters in practices?
c. How the reliability of the operation process/equipment/assets are ensured by the maintenance strategy used for the particular operation process/equipment/assets?

B. Data Collection Procedures

B1. Names of sites to be visited, including contact persons

Two case studies are considered in this case study protocol. First Case Study is on maintenance strategies & practices for Natural Gas Pipelines. Second case study is on maintenance strategies & practices of Petrochemicals Plant. For both of these case studies, data collection are done from the employees of GAIL (India) Limited. The proposed list of employees who will be contacted for interview along with the location & contact details is also prepared.

B2. Data Collection Plan

Data Collection from the employees of GAIL (India) Limited will be done in the calendar year 2013. The data collection will be done by semi-structured interview with an individual employee using the Case Study Protocol.

At least 60% of employees are visiting to GAIL Training Institute (GTI), Noida for attending training program based on data available with GTI, Noida. Therefore, it is proposed to conduct interview at GTI, Noida from those selected employees who are visiting for training program to this institute.

The site visit will be planned accordingly to cover the rest of the employees from the list of the selected employees who could not happen to visit GTI, Noida and also for participant observation.

Table 3.8 Data Collection Plan

Description	April, 2013	May, 2013	June, 2013	July, 2013	Aug, 2013	Sep, 2013	Oct, 2013	Nov, 2013
Data Collection for Case Study-1								
Data Collection for Case Study-2								
Site Visits for Case Study-1								
Site Visits for Case Study-2								

B3. Expected preparation prior to data collection

1. Intimate the employee regarding interview schedule & get his permission well in time.

2. Prepare with interview tool kit such as questionnaire, interview recording format, audio recorder etc.

C. Case Interview Guide (Natural Gas Pipelines & Petrochemicals)

This document serves as guideline specifying the type of questions in conducting interview for this case study “A study of Maintenance strategies & practices in a large gas utility company”. These constructs will be used for validation purpose during interview. Documentary evidences will be identified during interview & the same will be recorded.

C1. Description of the Case Study entity

C1.1 General

1. Company: GAIL (India) Limited
2. Name:
3. Designation:
4. Location:
5. Experience:
6. Date:

C1.2 Responsibilities & their Roles relevant to Maintenance function in NG Pipelines/Petrochemicals at GAIL:

C2. Planning & Execution of Maintenance Strategy & Practices

This section of interview will cover the primary research question of this case study which deals with the planning & execution of maintenance strategy and practices in Natural Gas Pipelines & Petrochemicals of GAIL (India) Limited.

C2.1.How the gas utility company (GAIL India Limited) is planning and executing its maintenance strategy for Natural Gas Pipelines/Petrochemicals?

How the company's policies/objectives influence the maintenance function in the company?

Describe the maintenance organisation/structure & its roles in maintenance in your company?

Describe about your maintenance mission & objectives?

Do you have maintenance policy for your organisation? If yes, please describe.

What are the factors influence maintenance strategy planning? How do you manage to prepare maintenance strategies for different business verticals?

What management approaches are being adopted in formulation of maintenance strategies for different business verticals of the company such as NG Pipelines, petrochemicals?

How has the maintenance strategies influenced the maintenance budget in your company? How do you prepare maintenance budget?

How do you manage to implement the maintenance strategies in your company?

What are the driving forces & challenges in maintenance practices?

How do you monitor the execution of maintenance strategies in your company?

Do you envisage employee empowerment becoming important for maintenance function?

Are you aware about Operator Based Maintenance/Autonomous Maintenance? If yes whether same is being practiced in your organisation?

How do you interact within your work teams/supervisors in maintenance function?

How do you manage modification works being carried out by the maintenance teams in your organisation?

How has the maintenance function influenced with external stake holders such key suppliers/contractors?

How do you envisage material management influence in maintenance management?

Do you foresee training will impact the execution of maintenance strategies & maintenance practices?

How IT has been leveraged in formulation and implementation of maintenance strategies?

C2.2.How the maintenance strategies are being practiced in the company to ensure smooth operation of natural gas pipelines/petrochemicals?

Describe about the maintenance strategies & practices in your plant (NG Pipelines or Petrochemicals)? How do you come up with such maintenance strategies?

How frequently your plant faces shutdown? How do you ensure smooth operation of plant?

How has the planning & scheduling influenced the maintenance practices in your plant?

How do you manage with long terms plans to forecast major maintenance works/ shutdowns in your plant?

How do you manage with short terms plans to comply with the preventive maintenance works/stoppages of plant?

How do you prioritise the day to day maintenance works/backlog maintenance works?

What are the management approaches to leverage Information Technology (IT) in maintenance function in your plant?

Do you foresee any material requirement for execution of particular maintenance strategy? If yes, how do you manage inventory of material in your plant?

How has the inventory control influenced the maintenance planning?

C3. Selection of Maintenance Strategy

This section of interview will cover the additional research question ('a' mentioned above in Section A2) which deal with the selection of maintenance strategy for particular operation/process/plant/equipment in Natural Gas Pipelines/petrochemicals.

C3.1.Why the specific maintenance strategy has been selected for a particular operation process/equipment in Natural Gas Pipelines/Petrochemicals at GAIL?

Describe the maintenance strategies adopted for a particular process/equipment within your plant? Are they same or differ with the type of process/equipment?

What decision processes are your company is applying in selection of particular maintenance strategies for a particular process/equipment? How they impact the overall maintenance practices in your plant maintenance?

How do you manage total maintenance man hours to the particular maintenance strategy (for e.g. Preventive Maintenance)?

How do you manage with compliance of maintenance strategy schedules (for e.g. Preventive Maintenance)?

How has the emergency/break down maintenance influenced the devotion of total man hours in your plant?

C3.2.What is the common and different maintenance strategies & practices to both Natural Gas Pipelines & Petrochemicals at GAIL?

Compare & describe the maintenance strategies & maintenance practices being adopted in both NG pipelines and Petrochemical plant operations?

How would you characterise maintenance strategies & practices between NG pipelines and Petrochemical plant operations?

C3.3.How the maintenance strategy & practices differ with the specific assets available in one operation process/plant/pipeline network from other business verticals within GAIL?

Describe the maintenance strategies & practices being adopted for the equipment/process available within the NG Pipeline/ Petrochemicals operations at GAIL?

How would you characterise maintenance strategies & practices of NG Pipelines/petrochemicals among other business verticals such as City Gas Distribution, LPG Pipelines etc., at GAIL?

C4. Benchmarking in Maintenance

This section of interview will cover an additional research question ('b' mentioned above in Section A2) which deals with benchmarking in maintenance.

C4.1.What is the benchmarks being used in maintenance Natural Gas pipelines at GAIL? What is extent of achievement of benchmark parameters in practices?

How the maintenance performance of "Best in Class" of NG pipeline/petrochemicals has been benchmarked at your company?

Describe the benchmark measures & targets in practices at your plant?

What initiatives & processes are being used to achieve the benchmark parameters of your plant in practices?

How do you manage with internal norms of the company & industry norms in maintenance performance measurement/benchmarking?

C5. Reliability in Maintenance

This section of interview will cover an additional research question ('c' mentioned above in Section A2) which deals with benchmarking in maintenance.

C5.1.How the reliability of the operation process/equipment/assets are ensured by the maintenance strategy used for the particular operation process/equipment/assets in Natural Gas Pipelines/Petrochemicals at GAIL?

How do plant operations cope with the reliability issues & What is the maintenance strategy being adopted to ensure reliability in plant operations, in specific to particular process/equipment/assets available in your plant?

How the reliability statistics of process/equipment/asset is maintained in your plant?

What initiatives & processes are being used to do incident/root cause analysis of plant shutdowns & equipment failures?

How do you manage with reliability based analysis of process/equipment/asset being maintained in your plant?

C6. Maintenance Strategies & Practices at GAIL's NG Pipeline/ Petrochemicals- Additional comments (other than above), if any

What is the great challenge in maintenance strategy formulation & maintenance practices in your company?

Anything to share more... (closing)

The above interview guide was used for all the levels of employees such as Top management, Middle management & Junior Management in Petrochemical plant & NG Pipelines at GAIL

3.9 CONCLUDING REMARKS

This chapter presented the research objectives and research questions formulated based on the problem statement for this research study. Overall approach and rationale for this research study is discussed in detail logically by explaining the philosophical assumptions, scientific paradigms, scientific approach, research method, and research study. The basis for this research study is based on interpretative paradigm, inductive based qualitative research approach, and multiple case design-case study research strategy.

Further, data collection method is discussed in detail in this chapter. Data collection was done majorly with the help of methods semi-structured interviews using Case study protocol, participant observation, site visits, and collection of documentary evidences. Interview data was transcribed and then analysed through Atlas- Ti software. The details of data analysis strategy such as within case analysis and cross case analysis are discussed in detail in this chapter. The methods used to ensure quality of research is described in detail explaining with help of four relevant tests such as construct validity, internal validity, external validity, and reliability. Case study protocol is presented in the last section.

Next chapter describes the case study-1 i.e., maintenance strategies and maintenance practices of Natural Gas Pipelines in large gas utility company.

CHAPTER 4

MAINTENANCE STRATEGIES & MAINTENANCE PRACTICES OF NATURAL GAS PIPELINES

4.1 INTRODUCTION

This chapter presents in detail the case study conducted at natural gas pipelines. Data collection details related to this case study-1 (NG Pipelines) is discussed in section 4.2. Then detailed data analysis findings are reported in the subsequent sections on maintenance strategies & practices in NG Pipelines (section 4.3), maintenance strategy selection processes in NG Pipelines (section 4.4), and relationship between maintenance strategy selection process and maintenance strategies & practices in NG Pipelines (section 4.5) of the large gas utility company in India. Further, detailed discussions on case findings are presented in section 4.6. Outcomes of the case study findings are summarised in concluding remarks. The sub-section of this section of this chapter discusses about Natural Gas Pipelines of a large gas utility company in India (GAIL India Limited) and its operation & maintenance systems at the company.

4.1.1 A LARGE INDIAN GAS UTILITY COMPANY

India's natural gas scenario is undergoing rapid changes and gas is poised to occupy a significant share in the energy mix. Natural Gas is a new age fuel. Natural Gas is the cleanest of fossil fuels. Natural Gas satisfies most of the requirements for fuel in a modern day industrial society, being efficient, non-polluting and relatively economical. Natural Gas requires a strong distribution network to not only support existing demand, but also fuel future demand. A big challenge lies in bridging the physical gap between demand and supply centres in an efficient, safe and eco-friendly manner. Pipeline transportation of gas offers a safe, economic and environmentally sound alternative to most other modes of energy transport. Meeting the emerging demand for gas requires transportation of gas across the length and breadth of India through creating gas transportation infrastructure of more than 2-3 times the present size. The Government and Regulator also recognize the need to augment the natural gas transmission infrastructure in the country. With the Petroleum and Natural Gas Regulatory Board in place, the conditions to support an expanded natural gas grid (NGG) and a fully functioning natural gas market are in place. The existing gas transportation infrastructure in India is presented in Table 4.1

Table 4.1 Existing Gas Transportation infrastructure in India (Source: CRISIL)

	Design Capacity (MMSCMD)	**Length (KM) including spur line**	**Average present flow (MMSCMD)**
GAIL	155	8000	120
GSPL Gujarat	40	2000	40
AGCL/OIL	08	500	
RGTIL EWPL	80	1400	50
TOTAL	**283**	**11,900**	166

Over the years, GAIL (India) Limited as a major pipeline operator has contributed to the growth and development of natural gas pipeline infrastructure and natural gas market and has existing 10,972 Kms. of robust gas pipeline infrastructure with a capacity of 210 MMSCMD. GAIL's existing natural gas pipeline network has Pan- India presence and covers 16 States (AP, Assam, Delhi, Goa, Gujarat, Haryana, Karnataka, Kerala, MP, Maharashtra, Punjab, Rajasthan, TN, Tripura, Uttarakhand, & U.P.) and 2 UT's (Puducherry & Dadra Nagar Haveli).

Figure 4.1 – Existing Natural Gas Pipeline Network in India

The existing pipeline network of GAIL is as shown in Figure 4.1. GAIL was also awarded Grant of Authorisation for Surat-Paradip P/L on 25.04.2012 by PNGRB which GAIL won under competitive bidding. The capacity of the P/L is 74.81 MMSCMD stretching over a Length of approx. 1990 Kms. With upcoming of Jagdishpur Haldia P/L and Surat Paradip P/L, GAIL shall cover 5 more new States such as Bihar, Chattisgarh, Jharkhand, Odisha and West Bengal. GAIL shall continue to meet the Noble objective of supply and transportation of natural gas through its state of art natural gas transmission pipeline system and shall contribute to the growth and industrialisation in India.

4.1.2 Natural Gas Pipelines – Operations & Maintenance

Operations and Maintenance of plant and equipment plays a vital role in the industry growth and development. Operations and Maintenance of pipelines and plants helps ensure a reliable and operationally safe system, providing not only uninterrupted supply of gas to consumers, but also maximising the throughput. GAIL's emphasis is not only on maximising production and sale of natural gas but also to achieve this with least energy consumption. Every effort is focused on energy-efficient operation of the plants, machinery and processes.

Availability of the best dedicated telecommunication/SCADA facilities in India has been fully utilised for online monitoring of machine/process parameters along the pipeline. Observe, Detect, Analyse, Compare and Improve are the watchwords for day-to-day operations. O&M covers various gas pipelines across the country, including the HVJ gas pipeline network and LPG recovery plants. In order to assess and monitor the health of pipelines, various condition monitoring tools and techniques are used which include continuous monitoring of pipe to check soil potential, corrosion sensing probes, post monsoon foot patrolling along pipeline, etc.

Some of the salient features of O & M activities in NG Pipelines are, (i) Round-the-clock supervision of the operation of the entire pipeline through National Gas Management Centre located at NOIDA and Regional Gas Management Centres located in each region with the help of SCADA and regular health monitoring; (ii) Surprise and periodic helicopter surveillance of the entire pipeline route, in addition to ground patrolling, for possible encroachment on ROU, soil erosion, line exposure etc.; (iii) As per National/International standard based on SOP maintenance of plant and equipment is being done. Maintenance schedule and records are generated in SAP; (iv) Gas scheduling, allocation and invoicing is being done through SAP based Gas Management System.

The objectives of GAIL's operations and maintenance policy include uninterrupted supply of gas and liquid hydrocarbon with quality, high reliability, high energy efficiency, inventory control, low operating cost and safety. *(Source: www.gailonline.co.in)*

An organisation chart for the large gas utility company's operation & maintenance team is as shown in Figure 4.2 below:-

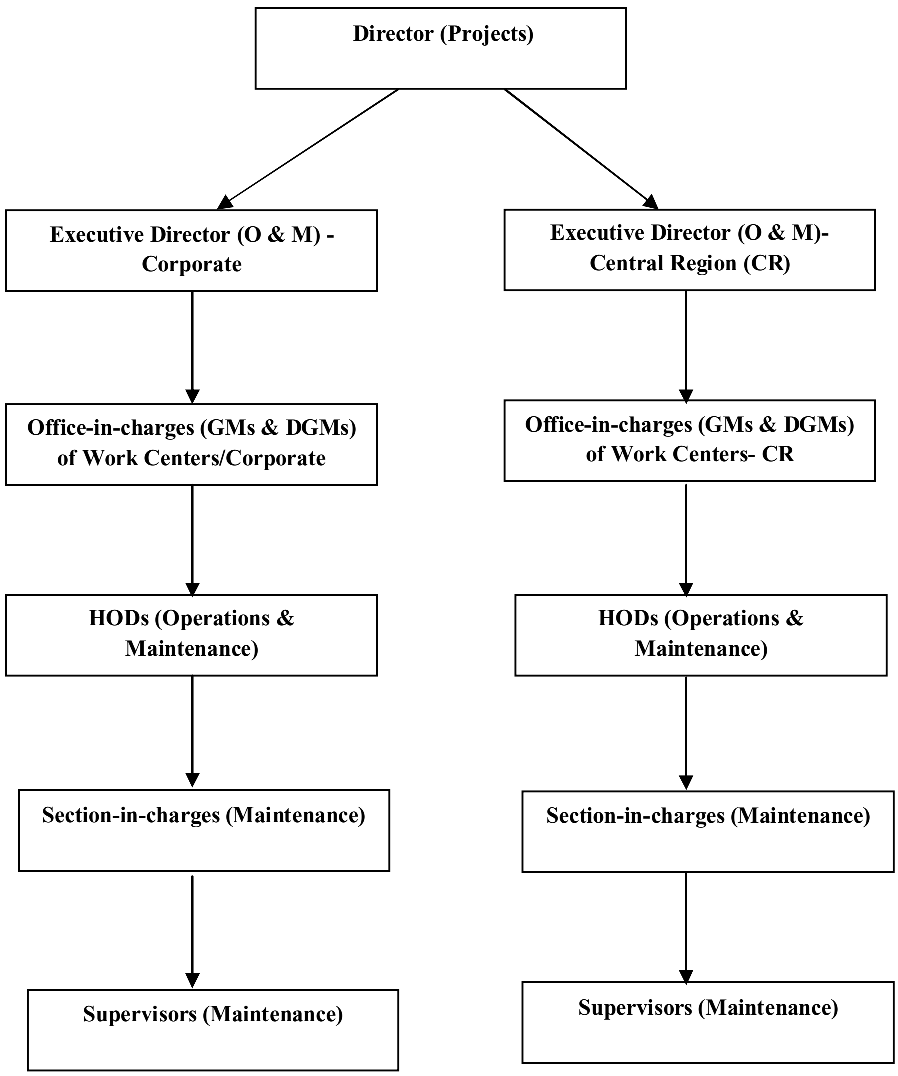


Figure 4.2 Organisation Chart for NG Pipelines Operations & Maintenance of Gas Utility Company

4.2 DATA COLLECTION

Semi structured interview was conducted from the following maintenance personnel in the area related to Natural Gas pipelines who are the employees of the large gas utility company using case study data protocol.

Table 4.2 - List of Interviewees of Case study-1 (NG Pipelines)

Level of Analysis	Designation	Date of Interview
Level 3 – Gas Terminal	Manager (NG- PL O & M)	16.07.2013
Level 2 – Pipelines	SM (Training) - Faculty	12.07.2013
Level 1 – Corporate	DGM (O & M)	10.08.2013
Level 1 – Compressor Station	CM (O & M)	10.08.2013
Level 2 – Pipelines	CM (LPG- PL O & M)	07.09.2013
Level 3 – Gas Terminal	DM (NG PL O & M)	07.10.2013

Note: The names of the participants are not given in the above table due to agreed confidentiality.

Data was collected from a variety of source: (i) Participant observation of team at NG Pipeline terminals located in Delhi NCR region for a month; (ii) Interviews; (iii) Company website, Intranet, and operation & maintenance related documents; and (iv) informal discussions with maintenance team leaders, maintenance mangers, maintenance engineers and maintenance technicians. As discussed in Section 3.5, the data collection was carried out at various sites in the Natural Gas Pipelines of the large gas utility company. The data collection phase lasted for almost six months. Initial one month was spent for initial contact and making arrangements for data collection (May, 2013). Then, four months were spent in conducting interviews based on the availability of maintenance mangers/engineers from various levels (July, 2013 to October, 2013). Thereafter, two months site visits were carried out in Delhi NCR region (October, 2013 & November, 2013).

The details of interview participants are shown in above Table 4.2. All interviews were recorded and then transcribed. After completion of the transcription of interviews, one month was spent to collect the interviewees' feedback on the transcripts (November, 2013). The draft of the case study report was shown to DGM (O &M), and his suggestions and feedback were incorporated. Follow-up over telephone was done for clarifications and additional information.

Based on the interview data, within case data analysis was undertaken keeping in mind the research questions: How the gas utility company is planning and executing its maintenance strategies & practices to ensure smooth operation process in the company's business vertical Petrochemicals and why the specific maintenance strategy has been selected for a particular operation process/equipment?. This lead to the identification of various factors forms the basis for maintenance strategies selection and maintenance practices in NG Pipelines of the large gas utility company. Further, maintenance strategies selection processes being practiced in NG Pipelines and specific maintenance strategies for a particular operation process/equipment were identified. Then, the relationship between maintenance strategies selection processes and the identified factors for maintenance strategies & maintenance practices in NG pipelines was analysed. Next Section describes about the detailed data analysis and findings of NG Pipelines case study.

4.3 MAINTENANCE STRATEGIES & PRACTICES IN NG PIPELINES

Data collected from NG Pipelines of the large gas utility company were analysed as per the data analysis strategy described in the Section 3.6. This section describes about the factors contributing to the maintenance strategies and maintenance practices in NG Pipelines of the large gas utility company. The detailed data analysis based on initial conceptual constructs and sub-constructs identified & conceptualised from the literature review (Section 2.6) such as Performance Measures, Maintenance Tactics, Planning & Scheduling, Materials Management, Organisation/Human Resources, Employee

Empowerment, Information Technologies, and Maintenance Polices/ Budget is presented below.

4.3.1 Performance Measures

The interviewee data shows that the sub-constructs such as breakdown records, key performance indicators, training man hours of maintenance staff, maintenance performance measures, and internal & industry norms identified from literature for maintenance performance measures are being practiced in the company. A few of the representative quotations from the interviews are:-

“GAIL is having so much long proven track records in maintenance. GAIL person is involving in drafting standards such as OISD etc. Reliability records are being maintained such as PLT availability, breakdown records, stand-by pump maintenance records” – Manager (Pipeline O & M).

Breakdown records are part of the maintenance records being maintained by NG Pipeline O & M group in their plant. These maintenance records are also being used as part of the reliability records of equipment/systems in NG Pipeline networks.

“Objective of maintenance is based on MOU targets. These targets are such as production targets, equipment availability targets etc. Since the production targets are high & stringent, we need to make available the equipment & plant through better maintenance practices. These targets are performance indicators of maintenance” – Senior Manager (Mechanical).

“NG pipelines benchmarking is much related to enforcement of law. The bench mark for NG pipeline is availability of pipeline must be 99.9 %. Bench marks may be taken as parameters which come from MOU targets” – Senior Manager (Mechanical).

"As far as bench marking is concerned, we have bench marked the maintenance cost. This is being monitored on monthly basis. The down time of plant is being monitored by GAIL. But, there is no linkage with bench marking. Maintenance targets are based on MOU targets signed with petroleum ministry. GAIL is achieving every year its targets in the category of excellent. I can proudly share this with you" – Deputy General Manager (NG Pipeline O & M).

It is clearly evident from the above quotations that the MOU (Memorandum of Understanding) targets which are agreed upon with Petroleum ministry are only used for the purpose of benchmarking of Operation & Maintenance practices in NG Pipelines of the company as conceived by the maintenance managers/engineers. There are no separate parameters for measuring maintenance performance which are not part of the operation/production targets.

"We are having regular training program for outsourced manpower. Both safety & technical training are being provided to the contract manpower before assigning the job then they are being imparted every quarter. These trainings are being video recorded and well documented" – Manager (NG Pipeline O & M).

"Training is a very important factor in performing maintenance function. Own engineers should have specialised knowledge on the equipment gaining from their own experience. But, we have the constraint that even after training, we require expert manpower from OEM for specialised jobs such as engine overhauling, compressor overhauling etc."- DGM (NG Pipeline O & M).

"Training is very important for maintenance function. Training helps also to share our experience among maintenance managers" – Chief Manager (NG Pipeline O & M)

As described above by the maintenance managers in gas utility company, training function is being given importance by maintenance managers. From the company's intranet, further as explained by the maintenance managers, there is a structured process to allot training to the maintenance personnel in the company. However, a gap between training & application in job exists in the company. As quoted by one of the O & M manager, even after training, maintenance team still depends on OEM expertise in many of the jobs being carried out in plant.

"We are following OISD standards in case of industry norms. We are also following ISO, OHSAS, metering standards such as AGA/API etc." – Manager (NG Pipeline O &M)

"Internal norms are based on MOU & IMOU targets which are defined by ministry & corporate management. GAIL is a market leader in gas industry therefore, GAIL's operating parameters itself can be taken as benchmarks which are comparable to global benchmarks" – Senior Manager (Mechanical).

From the above quotations, it is evident that the company is following certain internal norms such as guidelines from corporate management based on targets assigned by petroleum ministry and industry norms such as standards & industrial compliance requirements.

"The maintenance systems are being audited such as ISO Audit (Half yearly), Internal Audit (Yearly) which is being done by multi-functional experts from C.O. to ensure proper O & M systems and follow the uniformity across all the work centres. Further, we also have IUSA (Intra unit safety Audit) consists of cross- functional experts, external audits like OISD Audits. We cannot miss any small maintenance activities. These audits provide reports with the observations. This helps to implement at unit level the industry practices being adopted and also to incorporate improvements in maintenance systems. This is due to maintenance methods are being evaluated based on industry standards and auditors are experts in their field. Internal & external audits provide lot of scope for improvement in maintenance practices. Though we are hard pressed during audits, audits benefits are excellent" – Manager (NG Pipeline O &M).

"We have different audits such as ISO audits, OISD Audits (5 years), PNGRB Audits, IUSA Audits (2 years) etc. for maintenance methods and performance monitoring"- Senior Manager (NG Pipeline O & M).

As described by maintenance mangers, maintenance performance measures are majorly done using methodology of audits. These audits are being conducted internally by company's employees like Inter-unit audit and Intra-unit audit and further external audit experts from statutory bodies, third party vendors, etc. These audits provide audit reports with suggestions. These audit points are implemented to improve the maintenance performance as told by the maintenance managers.

"We have unit wise benchmarking system. Each unit are assigned with the set of maintenance parameters or targets to achieve. This is the responsibility of the unit to accomplish these targets on yearly basis. The same is being monitored by the corporate O & M"- Senior Manager (NG Pipeline O &M)

"As far as bench marking is concerned, we have bench marked the maintenance cost. This is being monitored on monthly basis. The down time of plant is being monitored by GAIL. But, there is no linkage with bench marking. Maintenance targets are based on MOU targets signed with petroleum ministry. GAIL is achieving every year its targets in the category of excellent. I can proudly share this with you"- DGM (NG Pipeline O & M).

Maintenance managers of the company are of the opinion that the targets in Operation & Maintenance of NG Pipelines are based on MOU & Internal MOU targets. Further, these targets are considered as benchmarks in operation & maintenance because the company is market leader in this business segment and also NG Pipeline availability is being maintained at 99.9%.

There is no clear evidences could be collected from interview data related to labour cost and material cost relation with the maintenance performance measures or no indicators are available for benchmarking the cost of labour and material. However, one maintenance manager told about maintenance cost is benchmarked. Further, he has also confirmed that this not being practiced in targets, benchmarking, etc.

The findings from the case data related to these sub-constructs are also shown in Table 4.3.

Table 4.3 Performance Measures sub-constructs and empirical findings

Initial Conceptual Constructs	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Performance Measures/ Benchmarking	Downtime Records	Performance Measures/ Benchmarking	Breakdown Records	Records are being maintained by the company for measuring maintenance performance
	Key Performance Indicators		Key Performance Indicators	KPIs are available. Basically, these are derived from MOU Targets which are drawn from MOU with Petroleum Ministry
	Training man hours of maintenance staff		Training man hours of maintenance staff	Structured Training Process is available in the company
	Maintenance Performance Measures		Maintenance Performance Measures	Maintenance Performance is largely based on Internal & External Audit Process.
	Internal Norms & Industry Norms		Internal Norms & Industry Norms	Company is following relevant Internal & Industry Norms as per applicable standards & statutory requirements.

	Benchmarking measures & targets		Benchmarking measures & targets	No International Benchmarks are being followed. But, MOU targets are treated as benchmarks since the company is market leader.
	Labour and material cost		Nil	No evidence could be collected from maintenance managers which support importance being given to labour and material cost in maintenance function.

The qualitative associative network associated with the initial conceptual construct "Performance Measures" is as shown in Figure 4.3.

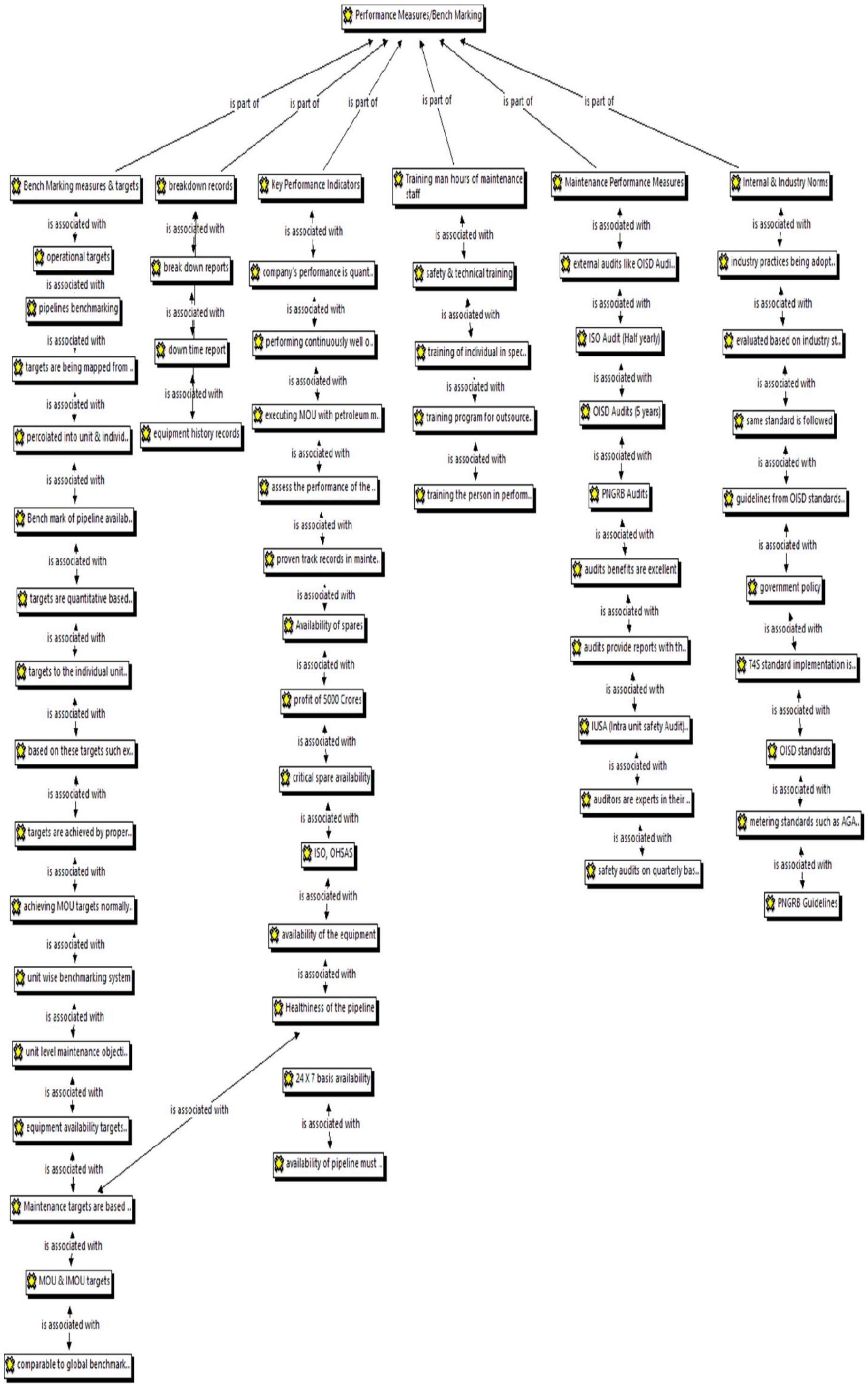


Figure 4.3 QAN for Performance Measures & Benchmarking

4.3.2 Planning & Scheduling

Interviewees indicated that the planning & scheduling is an important factor which plays crucial even at the stage of maintenance strategies formulation. A qualitative network associated with planning & scheduling is shown in Figure 4.4. The categories emerged out from this qualitative associative network are explained next with the help of evidences and descriptions from the case study.

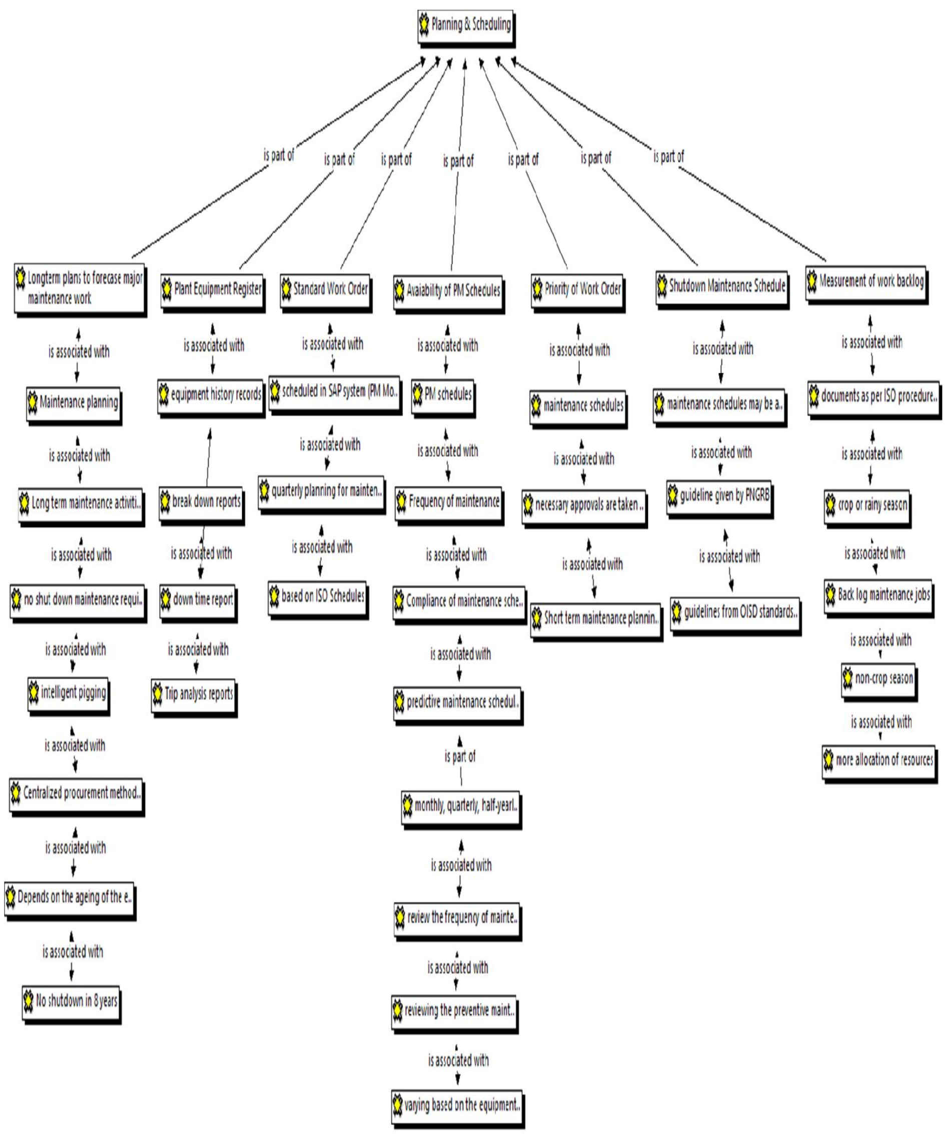


Figure 4.4 QAN for Planning & Scheduling

“Maintenance monitoring is also based on preventive maintenance schedules and the same is available in SAP maintenance PM Module. Further, through SAP maintenance planning, job requests, permits are being maintained” – Sr. Manager (NG Pipeline O & M).

“....scheduling & planning of maintenance is completely is being done through SAP -PM module” – Sr. Manager (NG Pipeline O & M).

“All the maintenance scheduling & planning are being done through SAP- PM Module all across GAIL. We get reminders of maintenance schedules also from SAP” – DGM (NG Pipeline O & M).

As explained by the maintenance managers above, the maintenance records used for planning & scheduling such as plant equipment register, standard written work order, availability of PM schedules, priorities of work order, shut down maintenance schedule, and backlog maintenance jobs are being maintained in SAP-PM Module in SAP system installed in the company.

“When break down occurs, we are going into root cause analysis. Trip analysis reports and break down reports provide inputs to maintenance schedules. Accordingly, tuning of schedules is done in maintenance schedules & planning” – DGM (NG Pipeline O &M).

“...further leveraging of this module is done ...by maintaining equipment history records etc...” – SM (NG Pipeline O & M).

From the above it is clearly evident that trip analysis reports and break down reports are being maintained as part of the plant equipment register in SAP PM Module.

“....maintenance activities are being scheduled in SAP system (PM Module) as per frequency.... quarterly planning for maintenance of pipelines... based on ISO Schedules”- Manager (NG Pipeline O & M).

“Short term maintenance planning is based on PM schedules. This includes cathodic protection (CP). In CP, PSP potential measurement is to be done on monthly basis. The same is to be recorded in ISO formats & sent for approval of WICs” – SM (NG Pipeline O & M).

“The preventive maintenance schedules & frequency of maintenance are decided based on OEM recommendations and experiences of maintenance personnel” – DGM (NG Pipeline O & M).

“We have schedules for maintenance like monthly, quarterly, half-yearly and annually... varying based on the equipment/instruments type” – Manager (NG Pipeline O &M).

The quotations shown above explain that the PM schedules are being maintained in NG Pipelines of the company and the same are being maintained in SAP PM Module. These schedules are based on frequency of maintenance, types of maintenance such as predictive, preventive etc., and schedules are prepared based on OEM recommendations and vary based on equipment types.

“...depends on the ageing of the equipment and history of the equipment maintenance schedules are being prepared...” – Manager (NG Pipeline O & M).

“...during this period, maintenance schedules may be affected... deviations are informed to in-charge of plant and necessary approvals are taken...” – DGM (NG Pipeline O &M).

According to the maintenance schedules priorities of work orders are being assigned based on equipment ageing and equipment history. In case of equipment is not able to release for maintenance due to operational constraint, priorities may be shifted with the due approval from the competent authority of the plant in NG Pipelines of the company.

“...shut down maintenance is the major maintenance activity. This is not in case of NG Pipelines...” – CM (NG Pipeline O & M).

“...guidelines given by PNGRB come out with the standard called T4S. It clearly defines the maintenance activities, frequencies, etc. for NG Pipelines” – SM (NG Pipeline O & M).

There is no evidence of maintaining shutdown schedules in SAP -PM Module from the above quotations. Further, during case study review with the interviewee, it is confirmed that shut down maintenance job schedules are being maintained by maintenance managers separately. The same is guided by standards such as T4S from PNGRB (Petroleum and Natural Gas Regulatory Board) and other standards from OISD (Oil Industry Safety Directorate).

“...in case of deviation in maintenance schedules and the same is to be brought to the knowledge of OIC of the unit and necessary approval to be taken and to be documents as per ISO procedure” – Manager (NG pipeline O & M).

“During crop or rainy season, we may not be taken up maintenance activities. Normally, we plan maintenance activities accordingly. Backlog of maintenance may be there due to the reasons I told like crop season, we complete those jobs during non-crop season. Accordingly, we ensure completion of maintenance schedules” – CM (NG Pipeline O & M).

“Back log maintenance jobs are completed with the more allocation of resources such as manpower, man hours etc.” – DGM (NG Pipeline O &M).

From the above representative quotations, it is evident that during crop or rainy season maintenance activities related to maintenance schedules cannot be carried out so that the same are being taken up during non-crop season. It is ensured by the company that such kind backlog maintenance jobs are completed at next available opportunity with the allocation of more resources such as man power, material, etc.

"Maintenance planning varies based on types of equipment & processes within our Vijaipur plant. For example, NG pipeline compressors, schedules are different due to stand by strategy. But, in case of processing plant LPG, the maintenance are varies due to continuous running nature of process"- DGM (NG Pipeline O & M).

"Long term maintenance activities are being planned based on intelligent pigging. Suppose, one portion of pipeline is corroded, we need to plan for material, manpower, necessary approvals from local authorities, farmers, consumers etc. These all involves long term planning. Short term maintenance planning is based on PM schedules. This includes Cathodic protection (CP). In CP, PSP potential measurement is to be done on monthly basis. The same is to be recorded in ISO formats & sent for approval...."- SM (NG Pipeline O & M).

"In NG/LPG pipelines, there is no shut down maintenance requirement... We do not have any records of shut down of pipelines in last 8 years in VSPL LPG/NG Pipeline.... Centralised procurement method is being adopted in VSPL pipeline."- Manager (NG Pipeline O &M)"- Manager (NG Pipeline O & M).

From the above quotations from the interviews of maintenance managers clearly explains about long term plans of the company to forecast activities in NG Pipelines. First, there is no major shutdown planning activities associated with NG Pipelines. Second, long term maintenance planning is based on the type of equipment such as compressors, turbines etc. and requirement of process plants. Outcomes of Intelligent Pigging activity will be the inputs to long term maintenance planning in NG pipeline; it involves replacement of pipe segments, statutory approvals, permission from supplier/customers etc.

Centralised procurement methods helps for better planning for long term maintenance activities.

The findings from the case data related to these sub-constructs are also shown in Table 4.4.

Table 4.4 – Planning & Scheduling sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Planning & Scheduling	Plant Equipment Register	Planning & Scheduling	Plant Equipment Register	Equipment details are being maintained in SAP PM module; As part of plant equipment register breakdown records & reports and trip analysis reports are also being maintained in SAP system.
	Standard written work order		Standard written work order	Work orders are being maintained in SAP PM module based on ISO Schedules with the frequency of PM jobs planned. Automatic work orders are being generated based on schedule incorporated in the system.
	Availability PM schedules		Availability PM schedules	PM Schedules are available & the same are being maintained in SAP PM Module. PM Schedules are based on frequency & types of maintenance. These schedules are prepared based on OEM recommendations and are equipment specific.
	Priorities of work order		Priorities of work order	Work orders priorities are assigned and being maintained in SAP PM module. The same is based

				equipment history & criticality of the equipment. Approval is taken for any change in priorities of work order from Competent Authority.
	Availability of work schedule for a week ahead			Work schedules are being maintained in SAP PM module and can be accessed any point of time based schedule.
	Shutdown Maintenance Schedule		Shutdown Maintenance Schedule	Shutdown jobs schedules are being maintained by maintenance managers separately. The shutdown jobs schedules are being prepared based on standards provided by PNGRB & OISD.
	Measurement of work backlog		Measurement of work backlog	Backlog maintenance jobs are maintained in SAP PM module. The same is completed in the next available opportunity. Completion of backlog jobs is ensured with proper allocation of resources.
	Long Term Plans to forecast major shutdown/ maintenance work		Long Term Plans to forecast major shutdown/ maintenance work	In NG Pipelines, shutdown maintenance is not part of the long term maintenance planning. Intelligent pigging is the primary activity from which long term planning is being done in the company. Long term planning is based on types of equipment, processes in plant and centralised procurement facilitates such planning in NG Pipelines' compressor stations.

4.3.3 Materials Management

Materials Management is a critical part in maintenance strategy formulation stage itself. The effective materials management will facilitate efficient implementation of maintenance strategies. A qualitative associative network which is the outcome of data analysis of interviews taken for NG Pipelines case study is presented below in Figure 4.5.

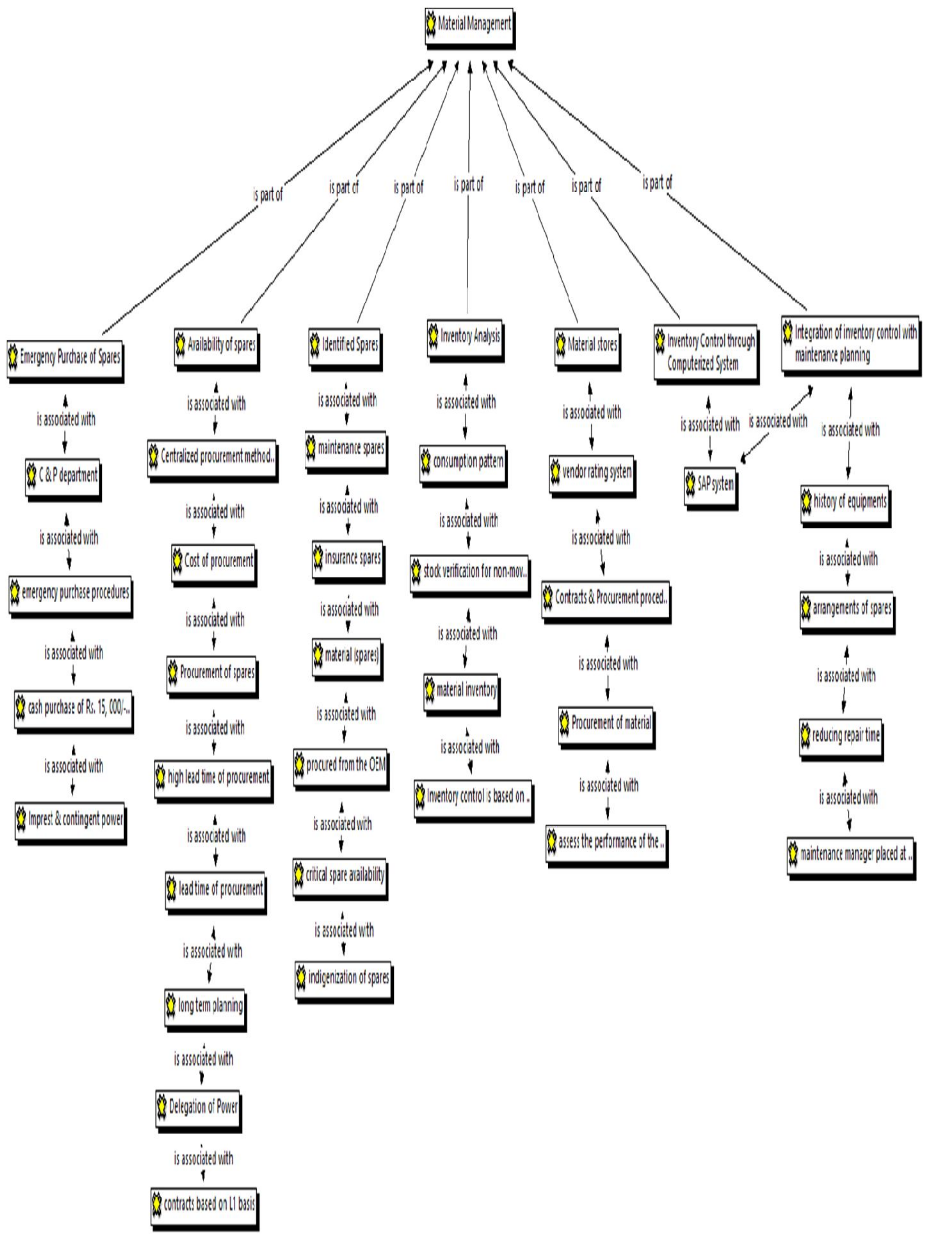


Figure 4.5 QAN for Materials Management

“....there are emergency purchase procedures. Maintenance managers can go for nomination based purchase also...” – DGM (NG Pipeline O & M).

“Imprest & contingent power are used for cash purchase of Rs. 15, 000/- at the level of Chief Manager level i.e., WIC level” – Manager (NG Pipeline O & M).

Inferences related to sub-construct i.e., focused code “Emergency purchase of Spares” could be derived from the above representative quotations. Emergency purchase procedures are available in the company as per maintenance mangers. The same is also verified with the documentary evidence “C& P Procedures” document of the company. This procedure includes imprest & contingent advances and the nomination based procurement etc. which helps maintenance managers to keep provisions for emergency situations while formulating the maintenance strategy.

“Centralised procurement method is being adopted in VSPL pipeline. Similar practice is being used in other locations also. Cost of procurement & long term planning are the basis of centralised procurement method”- Manager (NG Pipeline O & M).

“...spares are having high lead time of procurement. Managing these spares is very critical in maintenance function. Procurement of spares depends on types, criticality, consumption pattern, lead time of procurement etc...”- DGM (NG Pipeline O & M).

The above quotations show the evidences for the focused code “available of spares” from the data analysis. Spares availability are being ensured by the company using economical method i.e., centralised procurement. The centralised procurement method facilitates optimum cost of procurement and able to plan for long time maintenance activities. The spares procures are basically depends on types, criticality, consumption pattern, lead time of procurement, etc.

“In GAIL we have both maintenance spares (less lead time procurement materials) as well as insurance spares. Insurance spares are rarely required spares. But without these spares, we may face larger down time of the equipment/plant”- DGM (NG Pipeline O & M).

“...need to maintain the equipment/machines as good as new one. To maintain in such a condition there is no concept of indigenization of spares/retrofitting of the particular machine. All the spares required for the particular machines are being procured from the OEM only....”- SM (NG Pipeline O & M).

“Availability of system is more in pipeline is due to 1) highly skilled manpower 2) training of individual in special areas 3) Availability of spares (top management monitors the critical spare availability through quarterly reports)...” – Manager (NG Pipeline O & M).

Spares have been identified as maintenance spares (consumable, less lead time spares & less cost spares are grouped in this category) and insurance spares (critical spares, high lead time spares, and high cost spares are grouped in this category). Critical spares can be insurance spares. Therefore, it is evident from the above quotations that there is a clear identification/demarcation of spares is available in the company C & P procedures as stores procedures.

“...Managing these spares is very critical in maintenance function. Procurement of spares depends on types, criticality, consumption pattern, lead time of procurement etc.”- DGM (NG Pipeline O & M).

“Based on the history of equipment, material inventory is reviewed and controlled. Further, stores have a procedure of stock verification for non-moving items on annual basis. Based on this procedure, non-moving items are identified and necessary action is taken for the control of inventory” – SM (NG Pipeline O & M).

"Inventory control is based on critical spares availability. The same is being maintained through SAP system..." – Manager (NG Pipeline O & M).

Inventory analysis is being done based on equipment history, spare stock position and stock verification for non-moving items on annual basis. Based on analysis outcomes, inventory control is being done through SAP system majorly for all identified critical spares and other spares also.

"...Material stores are available in Rajamundhry, Vijayawada & Cheralapalli" – Manager (NG Pipeline O & M).

"Inventory control is being monitored and controlled in SAP PM & MM modules by C & P Department and stores and we received intimation regarding spare inventory & purchase orders through SAP...: - CM (NG Pipeline O & M).

The findings from the case data related to the above sub-constructs are also shown in Table 4.5.

Table 4.5 – Materials Management sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Materials Management	Spare parts availability	Materials Management	Availability of Spares	Availability of spares are being ensured by maintenance department using Centralised procurement method in NG pipelines for optimum cost of procurement & long term planning.
	Reordering of consumable		Identified Spares	All the spares have been identified as routine maintenance spares,

	s/identified spares			insurance spares, and critical spares and the same is being maintained by C & P Department at Stores.
	Inventory Analysis		Inventory Analysis	Inventory analysis is being done based on equipment history, spares stock position and identification of non-moving items on annual basis and being maintained in SAP system.
	Emergency purchase of spares		Emergency purchase of spares	Emergency purchase procedures are available with C & P department such procedures are imprest, contingent, and nomination purchase. The same is being done by maintenance department in coordination with C & P Department as per procedures.
	Average Inventory Turnover		Nil	No evidence of following “Average Inventory Turnover” concept in the company
	Inventory control through computerise d system		Inventory control through computerised system	Inventory control is being monitored through SAP system by Stores & concerned maintenance department.
	Availability of stores		Material Stores	Material Stores is available in all the major work centres/compressor stations in NG Pipelines of the company.
	Integration of inventory		Integration of inventory	Inventory control with maintenance planning is

	control with maintenance planning		control with maintenance planning	being integrated through SAP-MM Module and SAP- PM Module in SAP system. The same is being monitored by C & P department and Stores. On regular basis notification are being sent to concerned maintenance managers/ Engineer-in-charges regarding inventory of spares.

4.3.4 Human Resources

Human Resources (HR) function is a critical function in any company. In maintenance function also HR plays a vital role. The data analysis outcomes is shown in the below given Figure 4.6 qualitative associative network. The network components such as focused codes and categories are discussed in detail below by presenting representative quotations from the interview data collected. Further the same is also summarised in Table 4.6.

"Maintenance organisation level is varying in the company among the business verticals such as petrochemicals, NG pipelines, LPG pipelines etc. In case of NG pipeline, taking the case of KG Basin, 850 Km. of pipeline n/w, taking the gas supply from ONGC & Cairn energy and supplying gas to around 45 consumers including major (>1 mmscmd), medium consumers & small consumers... Maintenance personnel are working in 24 X 7 Shift" - Manager (NG Pipeline O & M)

"GAIL's maintenance organisation in such a way operating that 2 Executive Directors is there to take care of maintenance function. One Executive Director (ED) is looking after Corporate Function and another ED is looking after central region. These 2 EDs are looking after Natural Gas O &M. Another ED is looking after Petrochemicals. Below ED, work centres are there all over central region" – DGM (NG Pipeline O & M)

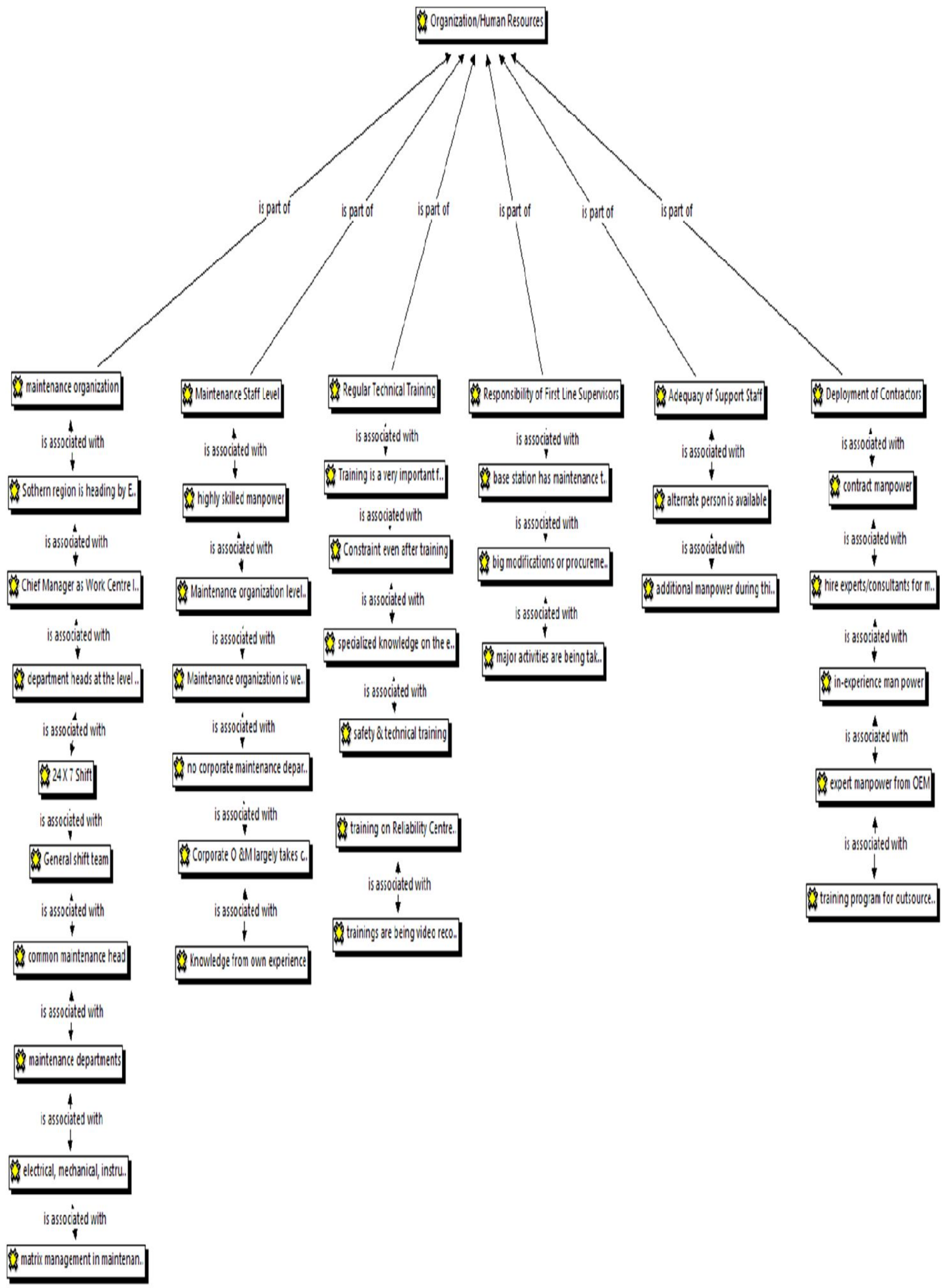


Figure 4.6 QAN for Human Resources/Organisation

"Maintenance organisation is well structured. The maintenance organisation is divided into several maintenance departments such as electrical, mechanical, instrumentation, civil, etc. These departments are working under one common maintenance head in the level of GM. There is no corporate maintenance department per say. Individual units are completely taking care of maintenance related jobs" – SM (NG Pipeline O & M).

"...availability of system is more in pipeline is due to:- 1) highly skilled manpower; 2) training of individual in special areas ... Manpower standby is also kept for reliability improvement. We are using matrix management in maintenance. Always alternate person is available to perform the particular maintenance job." – Manager (NG Pipeline O & M)

The above representative quotations show that there is a well-structured maintenance organisation structure existing in the company. Maintenance personnel are coming in general shift as well in shifts in order to ensure 24 X 7 manpower availability in gas terminals & compressor stations of NG Pipeline network.

Further, maintenance staff level exists in the company. The maintenance personnel are highly skilled and trained in specific equipment/processes.

"Maintenance structure of KG Basin consists of total 1000 km pipe line network with 5 O & M base stations. Each base station has maintenance team which includes mechanical, electrical, instrumentation engineers. Day-to-day activities are being managed by this team. In case of major maintenance, main station at Rajahmundry will coordinate & help"- CM (NG Pipeline O & M)

"...first line supervisors of concerned maintenance departments such as electrical, instrument, mechanical are responsible for keeping their maintenance activities updated. These maintenance activities are being scheduled in SAP system (PM Module) as per frequency..."- Manager (NG Pipeline O & M)

From the above representative quotations from interview data show that the first line supervisors of concerned department such electrical, mechanical, instrumentation, etc. are responsible for execution of day to day jobs and update the job status in SAP system. They are placed in base stations in the NG Pipeline network. They will report to main station to which they have attached based on pipeline network regions.

“....Manpower standby is also kept for reliability improvement. We are using matrix management in maintenance. Always alternate person is available to perform the particular maintenance job.... we need additional manpower during this shutdown of NG Pipelines” – Manager (NG Pipeline O & M).

“Training is a very important factor in performing maintenance function. Own engineers should have specialised knowledge on the equipment gaining from their own experience. But, we have the constraint that even after training, we require expert manpower from OEM for much specialised jobs such as engine overhauling, compressor overhauling etc.”- DGM (NG Pipeline O & M).

“We are having regular training program for outsourced manpower. Both safety & technical training are being provided to the contract manpower before assigning the job then they are being imparted every quarter. Remote stations (which have section valves) are manned with security personnel. These security personnel are being called to the work centres and provided with the security sensitization training on quarterly basis. These trainings are being video recorded and well documented.”- Manager (NG Pipeline O & M).

“Maintenance department is empowered to manage the maintenance problem to hire experts/consultants for maintenance jobs”- SM (NG Pipeline O &M).

It is evident from above quotations that company is having well- structured training process and documenting training programs. However, as highlighted by one senior maintenance manager, dependency on OEM for execution of maintenance jobs in major equipment needs to be reduced.

Further, deployment of contractors is required to execute the major maintenance jobs like overhauling of major equipment. Manpower assistance for execution of day-to-day maintenance jobs also is taken from service contractors. Deployment of such contracts is being done by maintenance department through C & P departments. Engineer – in-charge of contracts are from maintenance department. Therefore, for contractor job execution, maintenance department is responsible. The findings from the case data related to the above sub-constructs are also shown in Table 4.6.

Table 4.6 Human Resources sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Organisation/ Human Resources	Maintenance Staff Level	Organisation/ Human Resources	Maintenance Staff Level	Maintenance Staff level exists in the company.
	Maintenance Organisation		Maintenance Organisation	Well Structured maintenance organisation existing in the company. Maintenance personnel are deployed on 24 X 7 basis in NG pipeline installations such as compressor stations, gas terminals etc.
	Responsibility of first line supervisors		Responsibility of first line supervisors	Supervisor responsibilities are well defined & they are responsible for execution of day- to-day jobs of their concerned departments and update the job status in SAP system. They are placed in base stations of NG Pipeline network and reports to main station in-charge.
	Adequacy of Support staff		Adequacy of Support staff	Support staff is adequate and maintenance

				personnel are coming in shifts to ensure 24 X 7 basis monitoring & maintenance and for emergency handling manpower is also kept in standby.
	Regular Technical Training		Regular Technical Training	Technical training is being imparted to the employees in the structured manner including fire & safety training. *As highlighted by one senior maintenance manager, OEM dependency needs to be reduced by more advanced trainings on equipment.*
	Apprenticeship program		Nil	No evidences from interview data. However, from company secondary data Apprentice program is available as per statutory requirements.
	Deployment of Contractors		Deployment of Contractors	The company is regularly deploying contract manpower including expert manpower from OEMs etc. as per requirement. The same is being managed by maintenance department in coordination with C & P Department.

4.3.5 Information Technology

Maintenance strategy formulation leverages the information technology for effective formulation of maintenance strategies. All the sub-constructs related to information technology identified through literature reviews have been emerged out from our case study. The same is displayed in the qualitative associative network Figure 4.7 which is developed through Atlas-Ti software.

“In pipelines operation, we have vibration monitoring system which provides input to maintenance schedules. Integration of this system is under progress” – DGM (NG Pipeline O &M)

“IT has been leveraged through SAP System. SCADA & centralised SCADA are used to monitor the pipeline parameters & inform the alarming condition to the concerned sites”- Manager (NG Pipeline O &M).

“...In NG pipelines, satellite based monitoring & GIS monitoring may be followed...” – SM (NG Pipeline O &M).

In the company, expert systems such as vibration systems, intelligent pigging, SCADA system, satellite monitoring etc. are used for NG pipeline operations monitoring & for giving early diagnostics of failures in NG pipelines so that preventive action can be initiated in well-advance.

“Information Technology is leveraged through SAP in maintenance. Scheduling & planning of maintenance is completely is being done through SAP PM Module... preventive maintenance schedules and the same is available in SAP maintenance PM Module. Further, through SAP maintenance planning, job requests, permits are being maintained”- SM (NG Pipeline O & M).

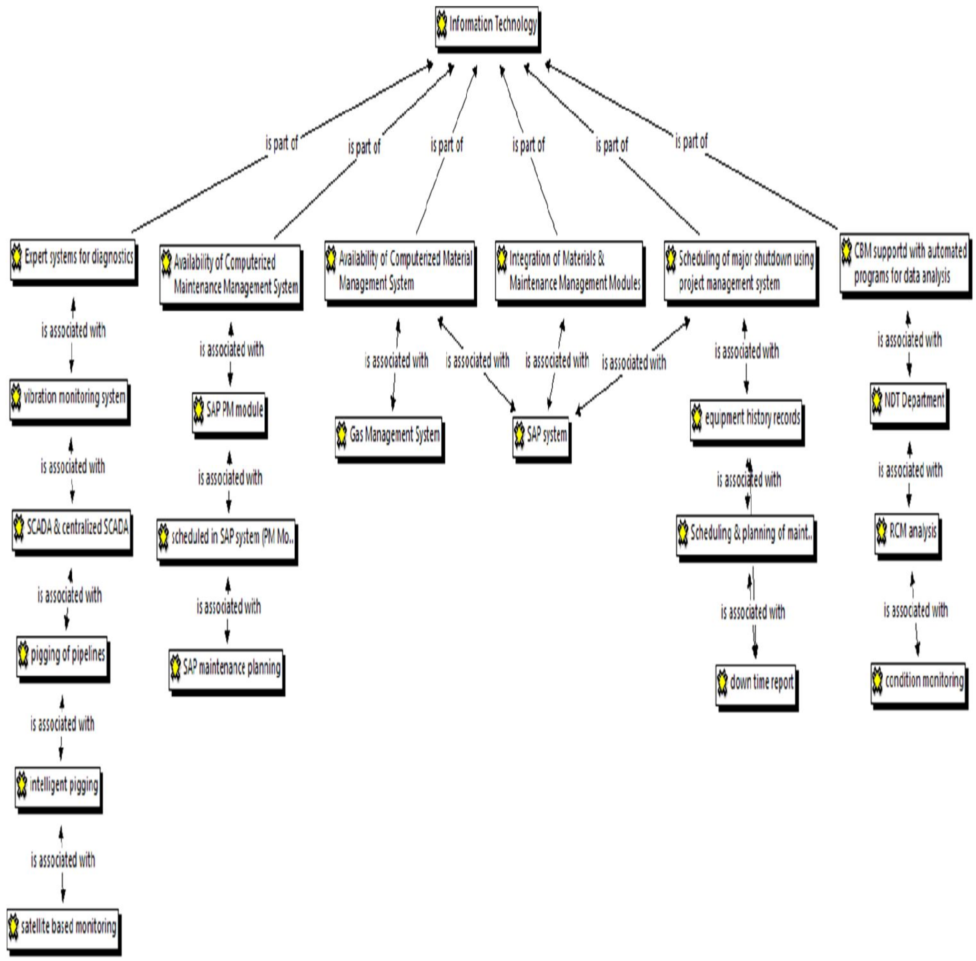


Figure 4.7 QAN for Information Technology

"All the maintenance scheduling & planning are being done through SAP- PM Module all across GAIL. We get reminders of maintenance schedules also from SAP"- DGM (NG Pipeline O &M)

"...maintenance activities are being scheduled in SAP system (PM Module) as per frequency..."- Manager (NG Pipeline O & M)

"Information Technology has been leveraged through SAP system & SCADA system in maintenance function. Entire pipeline networks are connected through SCADA system and monitoring is being done centrally. Gas billing is being done through SAP, GMS (Gas Management System) module..." – CM (NG Pipeline O &M).

“NDT Department is looking after the predictive maintenance of rotating equipment such as compressors, turbines etc. The vibration levels/monitoring are being done by this inspection department. In NG pipelines we have predictive maintenance such as pipeline thickness measurement, intelligent pigging etc.”- DGM (NG Pipeline O & M).

The empirical findings related to sub-construct information technology based on above representative quotations from interview data collected from NG Pipelines maintenance managers of a large gas utility company in India are summarised in the below given Table 4.7.

Table 4.7 Information Technology sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Information Technology	Availability of computerised system for maintenance management	Information Technology	Availability of computerised system for maintenance management	Maintenance planning & scheduling and execution of maintenance work orders are being done through SAP PM Module in SAP system for NG Pipelines O & M in the company.
	Availability of computerised system for materials management		Availability of computerised system for materials management	NG Pipelines O & M team is using SAP- MM module for material procurement, spares management, stores management and inventory analysis & control.

	Integration of maintenance & materials management modules scheduling of major shutdown using project management system		Integration of maintenance & materials management modules Scheduling of major shutdowns using project management system	In NG Pipelines of the company SAP- MM & SAP-PM Modules have been integrated for effective implementation of maintenance strategies. Further, SAP-GMS Module is being used for gas management & gas balancing.
	CBM supported with automated programs for data analysis		CBM supported with automated programs for data analysis	Real Time condition monitoring systems such as vibration monitoring systems, leak detection systems are available in NG Pipeline systems.
	Expert Systems for diagnostics		Expert Systems for diagnostics	Vibration monitoring, SCADA system, Intelligent Pigging & Satellite based monitoring are available in NG Pipelines to monitor & prevent major failures by taking preventive actions through early warning of such advanced diagnostics systems.

4.3.6 Employee Empowerment

The qualitative associative network developed through Atlas-Ti software for construct employee empowerment is shown in the below given Figure 4.8

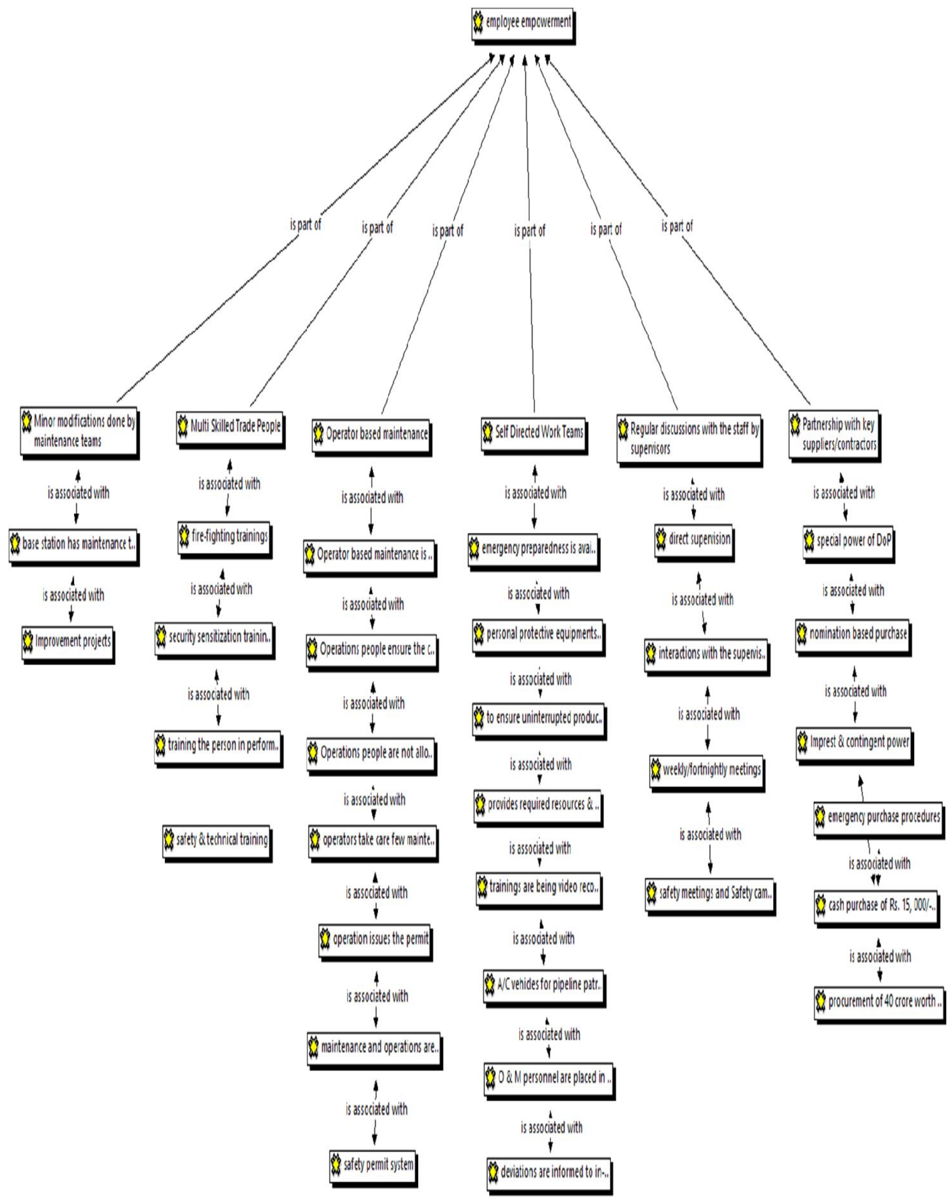


Figure 4.8 QAN for Employee Empowerment

"Operator based maintenance is not being followed in GAIL. In GAIL, maintenance personnel is taking cares all jobs related to maintenance. In NG pipelines, maintenance and operations are merged together. When pipeline personnel goes for pipeline walk and found one valve requires greasing. He needs to do immediately without calling specialised manpower from maintenance" – SM (NG Pipeline O & M).

“Operator based maintenance is followed in our base stations. Because, the operation personnel are required to perform few maintenance activities as and when required…” – CM (NG Pipelines O & M).

“Operations people are not allowed to do maintenance. Therefore, operator based maintenance is not being followed in GAIL. We follow safety permit system like cold work, hot work & work at height permits. Operations people ensure the clearance of giving such permits in order to ensure uninterrupted production. There is clear cut roles are there in O & M at GAIL. For example, electrical lock out permit, electrical department requests the permits, operation issues the permit, safety persons countersign the permit and after work clearance from electrical, then operations takes over. Best maintenance practice in GAIL, using of personal protective equipment, non-sparking tools” – Manager (NG Pipelines O & M).

It is evident from the above representative quotations from interview data reveals that in small gas terminals there is no demarcation like operations and maintenance team. The team working gas terminal is fully responsible for all the jobs. Therefore, they are required to complete the jobs as per requirement irrespective of their disciplines. In compressor stations/pumping stations, there is separated teams for operations and maintenance. In this case, job responsibility of operation personnel is to issue work permits ensuring all clearances so that the maintenance team can perform the jobs as per requirement. Hence, company does not have any job role/responsibility based on operator based maintenance concepts exist in other industries.

“Interaction with supervisors are done face to face basis, direct supervision etc. In bigger installation, weekly/fortnightly meetings are being conducted by in-charges of the plant. There we discuss incident analysis report, down time report etc.”- DGM (NG Pipeline O &M).

“As an in-charge of gas terminals, interactions with the supervisors are being done through weekly meeting by reviewing the preventive maintenance schedules and resource requirements for the NG pipeline section within the limits of my gas terminal. Visit different terminals and observe the customer complaints. Those complaints are discussed with supervisors. NG pipelines, spare materials are being taken along with the maintenance personnel" – SM (NG Pipeline O & M)

"….security personnel are being called to the work centres and provided with the security sensitization training on quarterly basis. They are also being provided with fire-fighting trainings. These are the interactions with the supervisors/technicians" – Manager (NG Pipeline O &M).

"Interactions with maintenance team are being done with the ways such as direct interaction during on the job, O & M meeting on monthly basis and weekly basis visits to sites for interaction & discussion based on daily progress reports. Further, we have safety meetings and Safety campaigns at sites/terminals. Therefore, regular interaction is there with maintenance team" – CM (NG Pipeline O & M).

As described above by maintenance managers/engineers, it is clear that there are regular discussions are being done by staff with supervisors through planned interventions like weekly/fortnightly meetings, safety & technical trainings for supervisors, etc. Further, informal discussions with individuals are also being practiced by the maintenance managers in the company.

"…emergency preparedness is available for NG pipelines such as Emergency Response Vehicle, Emergency tool box, emergency phone numbers, man power etc."- SM (NG Pipeline O &M)

"…best maintenance practices are being followed in GAIL such as using of personal protective equipment, non-sparking tools… provides required resources & manpower… O & M personnel are placed in shifts…" – Manager (NG Pipeline O & M).

"….deviation is being informed to in-charge of plant and necessary approvals are taken…" – DGM (NG Pipeline O & M).

It is evident from the above quotations that the company is having well-structured maintenance process so that the team is self- directed. For example, maintenance personnel can work on self-direction during emergencies. Because, emergency preparedness procedure provides clear directions for individuals concerned in plant operations & maintenance. There is a procedure for taking approval from competent authority in case of any deviation in any procedures.

"With employee empowerment, the maintenance jobs cannot be performed in an efficient manner. Our company (GAIL) provides A/C vehicles for pipeline patrolling and provides required resources & manpower. We have been given special power of DoP. DoP was revised in last year. More empowerment has been given to the employees.   Imprest & contingent power are used for cash purchase of Rs. 15, 000/- at the level of Chief Manager i.e., WIC level" – Manager (NG Pipeline O & M).

"Employee empowerment is enough in GAIL as per is maintenance is concerned. There are emergency purchase procedures. Maintenance managers can go for nomination based purchase also" – DGM (NG Pipeline O &M)

"Employee empowerment is enough at GAIL. For example, when I was in-charge of gas terminal, I can go for procurement of 40 crore worth material within the budgeted amount at the level of senior manager. Delegation of Power (DoP) i.e., financial power of the employees below board level is well documented and available" – SM (NG Pipeline O &M).

From the above quotations from interview, maintenance managers have confirmed that the overall employee empowerment is much satisfied in the company. Partnership key suppliers/ contractors are facilitated with the well-defined & documented "Delegation of Powers (DoP)" and Contracts & Procurement Procedures exists in the company.

"…both safety & technical training are being provided to the contract manpower before assigning the job then they are being imparted every quarter. Remote stations (which have sectional valves) are manned with security personnel. These security personnel are being called to the work centres and provided with the security sensitization training on quarterly basis. They are also being provided with fire-fighting trainings. In absence of safety officer another officer will take care of these activities. Concept of everyone is safety officer is inculcated in pipeline installations at GAIL." – Manager (NG Pipeline O &M).

The above quotation explains about the company's policy of developing multi skilled people. In case of emergency the person available in shift must able to attend the emergency situation. Hence, all maintenance staff is being provided with fire & safety training. Even security personnel are also being covered in fire & safety training.

"We have Quality Circle systems in GAIL. Improvement projects are being taken care by Quality Circles" – Manager (NG Pipeline O & M).

"Modification in NG pipelines ensures no interruption to consumers. We follow Change management system. Based on this system, the necessary approvals are taken from Competent Authority" – CM (NG Pipeline O & M).

"For modification, we have structured process. We need to go through change management process. It will go to technical cell personnel. HAZOP study will be done and then necessary approval will be taken from competent authority. Finally, technical cell hand over the job to maintenance personnel. Maintenance personnel then arrange for material, manpower etc. for execution…" – DGM (NG Pipeline O &M).

In the company to do modifications there is a well-structured & documented change management system procedure available. Accordingly, modifications are being done by maintenance personnel. Few improvement projects are also being done through Quality Circles. These are established from the above representative quotations. The findings from the case data related to these sub-constructs are also shown in Table 4.8.

Table 4.8 Employee Empowerment related sub constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Employee Empowerment	Multi skilled trade people	Employee Empowerment	Multi skilled trade people	Multi skilled people are being developed in NG pipelines in the company. They are being given training in various skills such as fire & safety, security to handle the emergency situation in NG pipelines.
	Operators based maintenance		Operators based maintenance	Team working gas terminals/remote gas stations are required to all the activities irrespective of their function. Compressor stations are having separate teams for operations & maintenance. Interview data is emerging with contra arguments among the interviewees. This shows that concepts of OBM are not being practiced uniformly in the company.

	Regular discussions with the staff by supervisors		Regular discussions with the staff by supervisors	Formal interventions such as scheduled meetings, safety and technical trainings etc. with the supervisors & informal interactions with individuals as and when required are being practiced by maintenance managers in the company.
	Self-directed work teams		Self-directed work teams	Maintenance teams are self-directed. Evidences are there such as adopting safety norms, ready with emergency work plan, etc.
	Minor modifications done by maintenance teams		Minor modifications done by maintenance teams	Minor modifications are being taken care by maintenance through structured process of “Change Management System”. Few improvement projects are also being done through Quality Circles.
	Partnership with key suppliers/cont ractors		Partnership with key suppliers/cont ractors	Well defined & documented Delegation of Powers and Contracts & Procurement procedures are facilitating the partnership with key suppliers/contractors.

4.3.7 Maintenance Tactics

Interview data has been analysed through Atlas-Ti software. Maintenance Tactics has been emerged out as a category and data analysis outcome is qualitative associative network as shown in Figure 4.9

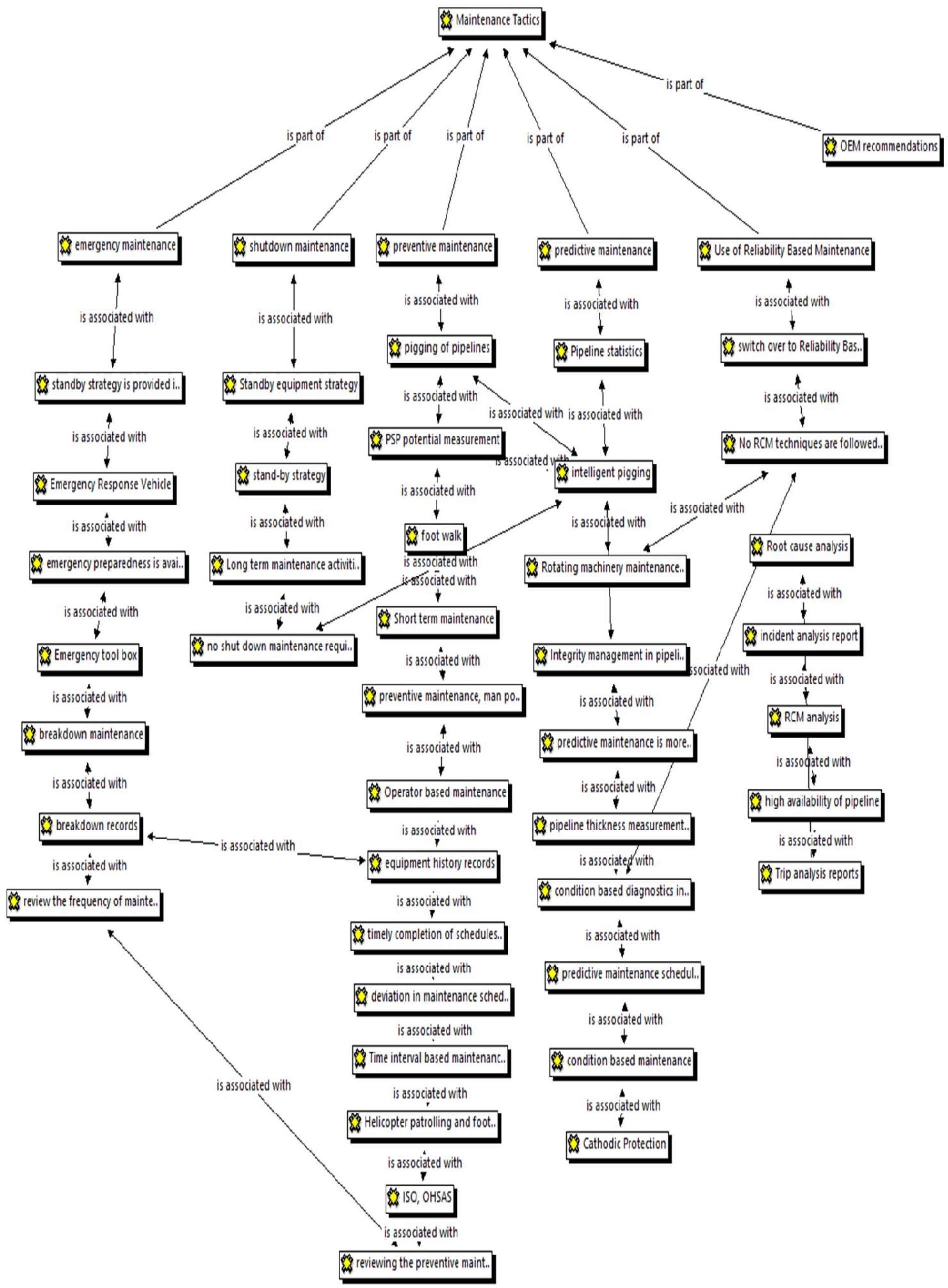


Figure 4.9 QAN for Maintenance Tactics

"The maintenance methods are preventive maintenance, predictive maintenance and shutdown maintenance. In case of preventive maintenance, every quarterly planning for maintenance of pipelines based on our previous experience and also world level standards are being carried out. In the predictive maintenance, we do maintenance of compressors and other equipment. Whereas preventive maintenance are being carried out based on

ISO Schedules…preventive maintenance schedules are varying based on the equipment/ instruments types…" – Manager (NG Pipeline O & M)

"We review the frequency of maintenance schedules every year. If break down maintenances are more for the particular equipment then preventive maintenance schedules will be reviewed accordingly. Due to the ageing of NG/LPG pipelines, maintenance problem increases. so, the preventive maintenance schedules are reviewed accordingly"- Manager (NG Pipeline O & M)

"GAIL's major maintenance strategies are preventive maintenance and predictive maintenance or condition based maintenance. Sometimes we face shutdown maintenance also…In NG pipelines, preventive maintenance methods are line walk/foot walk to see encroachment, helicopter patrolling, cleaning pigging. Predictive maintenance methods are intelligent pigging, cathodic protection, etc… preventive maintenance, man power requirement is much more… preventive maintenance scheduling is based on OISD standards and guideline given by PNGRB. PNGRB comes out with the standard called T4S. It clearly defines the maintenance activities, frequencies, etc. for NG pipeline maintenance" – SM (NG Pipeline O &M)

"Maintenance strategy planning: Major maintenance strategies are preventive maintenance, predictive maintenance /condition monitoring, breakdown maintenance used in NG pipelines. The preventive maintenance schedules & frequency of maintenance are decided based on OEM recommendations and experiences of maintenance personnel. Few methods are CP system, foot walk, survey etc." – DGM (NG Pipeline O &M)

As described by maintenance managers with reference to above quotations, *preventive maintenance is used in NG pipelines maintenance*. The key observations are,

- Preventive maintenance schedules along with frequency of maintenance are prepared based on OEM recommendations, OEM manuals, OISD standards, PNGRB standards like T4S, equipment types & history records of equipment and previous experience of maintenance managers.

- Preventive maintenance methods specific to NG Pipelines are line walk/foot walk to see encroachment, helicopter patrolling, pigging for pipeline cleaning, etc.
- For execution of preventive maintenance schedules, more man power is required compare to other maintenance methods.
- Preventive maintenance schedules are being reviewed on annual basis by the company based on ageing of equipment & pipelines and no. of breakdowns/failures occurred in particular equipment/system.
- Preventive maintenance schedules are included in ISO procedure and ISO system. Completion of PM schedules ensured through ISO internal audits & external audits.

"…predictive maintenance schedules also again OEM recommendations are available for types of test, periodicity etc. NDT Department is looking after the predictive maintenance of rotating equipment such as compressors, turbines etc. The vibration levels/monitoring are being done by this inspection department. In NG pipelines we have predictive maintenance such as pipeline thickness measurement, intelligent pigging etc…" – DGM (NG Pipeline O & M).

"Reliability of the equipment is very high at GAIL. Rotating machinery maintenance group has been formed across GAIL compressor stations. No RCM techniques are followed at GAIL… When break down occurs, we are going into root cause analysis. Trip analysis reports and break down reports provide inputs to maintenance schedules. Accordingly, tuning of schedules is done in maintenance schedules & planning."- DGM (NG Pipeline O & M).

"Reliability is important in case of metering systems, equipment etc. We go for root cause analysis in case of failures of NG Pipelines"- CM (NG Pipeline O & M).

"…predictive maintenance is more in NG pipelines such as intelligent pigging. Integrity management in pipelines are new maintenance strategy but it is not implemented so far…"- SM (NG Pipeline O & M).

"To ensure reliability, we follow only preventive maintenance & predictive maintenance. Pipeline statistics are available and failure analysis has not been carried out due to very high availability of pipeline" – Manager (NG Pipeline O & M).

As described by maintenance managers with reference to all above quotations, majorly *predictive maintenance is used in NG pipelines maintenance*. The key observations are,

- Predictive maintenance procedures are prepared based on OEM recommendations, OEM manuals, methods prescribed in standards issued by OISD, PNGRD, etc., and previous experience of maintenance managers.
- Predictive maintenance specific to NG Pipelines are intelligent pigging, cathodic protection, vibration monitoring & analysis, thickness measurements of pipelines, etc.
- Predictive maintenance is integrated with computerised analysis software systems & Human Machine Interface (HMI). Such kind of system provides early warnings about equipment or system failures. Based on these warnings, maintenance is being carried out in NG pipelines systems.

"Compressor station shut downs are more in NG pipelines at Vijaipur. This is being managed by stand-by strategy. This may be due to aero derivative compressors. We have margin time due to pipeline pack availability"- DGM (NG Pipeline O & M).

"…standby strategy is provided in the NG pipeline systems. Suppose compressor A trips/on maintenance and Compressor B comes on line and ensures the NG supply to such critical plant like petrochemicals so that ensures gas supply availability of 99.9%... in NG/LPG pipelines, there is no shut down maintenance requirement. In pipeline shut down means it is only leakages of pipeline & sabotage to pipelines…. Reliability records are being maintained such as PLT availability, breakdown records, and standby pump maintenance records."- Manager (NG Pipeline O & M).

"We keep provisions for emergency maintenance pipelines. Complete emergency preparedness is available for NG pipelines such as Emergency Response Vehicle, Emergency tool box, emergency phone numbers, man power etc. Safety aspects are very important in NG pipelines maintenance. All safety precautions/procedures are available"- Manager (NG Pipeline O & M).

The key findings on emergency maintenance and shutdown maintenance in NG Pipelines from the above quotations of interview data are appended in the below shown Table 4.9.

Table 4.9 Maintenance Tactics sub constructs and empirical findings

Initial Conceptual Constructs	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Data Analysis**
Maintenance Tactics	Use of Condition Based Maintenance (CBM)	Maintenance Tactics	Predictive Maintenance (CBM)	Predictive Maintenance methods are being used in NG Pipelines. Predictive maintenance procedures have been developed based on OEM recommendations, OEM manuals, standard, and previous experience of maintenance managers.
	CBM is favoured over Time Based		Nil	Predictive Maintenance (CBM) methods are used more in NG Pipelines than

	Maintenance (TBM)			preventive maintenance (TBM) methods.
	Total maintenance man hours devoted to Preventive/Predictive maintenance (PM)		Preventive Maintenance (TBM)	Preventive Maintenance method is being used in NG Pipelines of the company. Preventive Maintenance procedures/schedules are prepared based on OEM recommendation, OEM manual, equipment types & history, recommended standards for the system, and previous experience by maintenance managers.
	Compliance of PM Schedules		Nil	PM Schedules are included in ISO Schedules/ ISO Procedures. Timely completion of PM schedules is being ensured through ISO internal/external audits. PM Schedules are also being reviewed by the company on annual basis.
	OEM recommendations for an equipment regarding PM		OEM Recommendations	OEM recommendations are used to prepare preventive maintenance schedules and predictive maintenance systems & procedures for NG Pipeline systems.
	Use of Total Productive Maintenance (TPM)		Nil	No evidence of following TPM by NG pipelines of the company is found.
	Use of formal Reliability Based Maintenance (RBM)		Use of Reliability Based Maintenance	No RCM is being followed in the company. Few basic metrics used such as Incident Analysis Reports, Root Cause Analysis, PLT Availability records etc. However, maintenance managers are interested to implement Reliability

				Centred Maintenance in NG Pipelines.
	Total maintenance man hours devoted to emergencies/break down maintenance		Emergency Maintenance/ Breakdown Maintenance	Emergency maintenance is very less in NG pipelines due to standby equipment strategy is being followed & availability of pipeline packs. However, emergency preparedness is kept ready in NG pipelines of the company.
			Shutdown Maintenance	Shutdown maintenance is the method in which pipelines system become totally shutdown. Such kind of requirements is well planned based on data available through intelligent pigging and necessary approvals will be taken from all concerned. One such example of shutdown maintenance is attending leakage of pipeline by replacing the pipeline segments. There is no shutdown maintenance requirement in NG pipelines equipment, because standby equipment strategy is followed in the company.

4.3.8 Reliability Analysis

Reliability Analysis is one among the category emerged out from the data analysis. The qualitative associative network related to Reliability Analysis is presented below in Figure 4.10. The same is prepared through Atlas- Ti software based on interview data from maintenance managers of a large gas utility company in India.

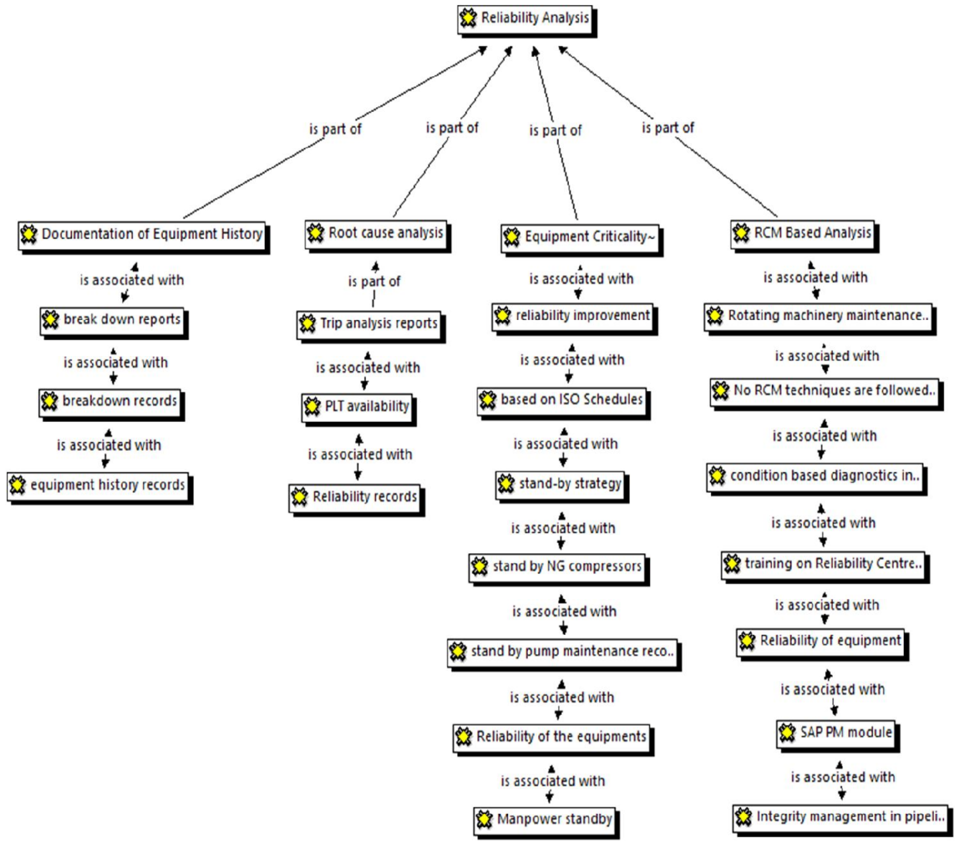


Figure 4.10 QAN for Reliability Analysis

"…When break down occurs, we are going into root cause analysis. Trip analysis reports and break down reports provide inputs to maintenance schedules. Accordingly, tuning of schedules is done in maintenance schedules & planning…Reliability records are being maintained such as PLT availability, breakdown records, stand by pump maintenance records…Manpower standby is also kept for reliability improvement" – Manager (NG Pipeline O & M).

"Scheduling & planning of maintenance is completely is being done through SAP PM Module. But, further leveraging of this module is to be done for RCM analysis, equipment history records etc." – SM (NG Pipeline O & M)

"Reliability of the equipment is very high at GAIL. Rotating machinery maintenance group has been formed across GAIL compressor station. No RCM techniques are followed at GAIL… Compressor station shut downs are more in NG pipelines at Vijaipur. This is being managed by stand-by strategy. This may be due to aero derivative compressors. We have margin time due to pipeline pack availability" – DGM (NG Pipeline O & M).

"There should be training on Reliability Centred Maintenance for maintenance managers. These types of quantitative methods related to RCM analysis is must. History of equipment failures are to be documented & should be given to new recruits" – SM (NG Pipeline O & M).

Empirical findings related to Reliability Analysis from the above representative quotations as described by maintenance managers are summarised in the below given Table 4.10.

Table 4.10 Reliability Analysis sub constructs and empirical findings

Initial Conceptual Constructs	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Data Analysis**
Reliability Analysis	Documentation of Equipment History	Reliability Analysis	Documentation of Equipment History	Equipment History Records are being maintained in NG Pipelines. Such records are available in the form of break down records and break down reports.
	Root Cause Analysis/Incident Analysis		Root Cause Analysis	Root Cause Analysis (RCA) reports are being prepared by maintenance managers in NG Pipelines and the same is available.
	Mean Time Between Failures		Nil	No evidence found in using such metrics in maintenance practice.

	(MTBF)			
	Value Risk Study of maintenance program		Nil	No evidence found in using such study in maintenance practice.
	Equipment Criticality		Equipment Criticality	Equipment Criticality is based on types of equipment, OEM recommendations and process requirement. Maintenance schedules are being prepared based on equipment criticality.
	Reliability Statistics of equipment/assets		Nil	Basic metrics are being used such equipment availability, plant availability etc. Advanced metrics based on RCM are not being practiced in NG pipelines of the company.
	Reliability Centred Maintenance based analysis		Nil	RCM Analysis is not being used in NG Pipelines of the large gas utility company.

4.3.9 Maintenance Polices/Maintenance Budget

Maintenance Policy and Maintenance Budget is another category emerged out from the data analysis. The qualitative associative network related to Maintenance Policy/Maintenance Budget is presented below in Figure 4.11 & Figure 4.12. The same has been developed through Atlas- Ti software based on interview data from maintenance managers of a large gas utility company in India. Few representative quotations from interview data are presented below:

"In the Maintenance Policy of GAIL, we have defined maintenance objectives. The major objectives are to ensure high level of availability, reliability and safety. To operate the equipment/pipelines in order to ensure trouble free operation, keep the maintenance cost optimum, achieve the good performances. Overall Company's mission and vision is available. Maintenance policy is the backbone of the mission of the company. For example, in case of deviation in maintenance schedules and the same is to be brought to the knowledge of OIC of the unit and necessary approval to be taken and to be documents as per ISO procedure..." – Manager (NG Pipeline O &M).

"...As for as GAIL is concern, we have maintenance policy in force. The maintenance policy is available in GAIL's intranet. This policy provides guidelines to maintenance function for NG pipelines as well as petrochemicals processing plants. These are broader guidelines, and based on these guidelines each unit formulates its maintenance strategy. Management approach to formulating strategy is provided in maintenance policy... Driving forces of maintenance are from maintenance vision & mission which ensures the smooth operations of pipelines."- SM (NG Pipeline O & M).

"...Presently, I am working in Natural gas pipelines. Our company is having maintenance policy. The basic maintenance methods used are preventive maintenance, predictive maintenance and shut down maintenance... Basic mission of the pipelines system is that pipeline availability should be kept at 100%. Healthiness of the pipeline needs to be maintained in excellent condition by adopting preventive and predictive maintenance activities. This is the main objective of maintenance in pipe line O & M... Objective of maintenance is based on MOU targets." – CM (NG Pipeline O & M).

"Maintenance policies and objectives of the company are derived from the "Maintenance Policy" document. Company's mission is to be the dominant player in natural gas industry. Accordingly, maintenance policy has been prepared. The purpose of the maintenance is to keep the assets/ infrastructure in healthy condition" – DGM (NG Pipeline O & M).

“Budget is function of preventive, predictive & shut down maintenances...we have budget preparation activity every year (BE & RE estimates) based on the actual expenditures of last year by the concerned department. GAIL management’s support & commitment is there for such budgeting activity in maintenance. We do the exercise of evaluating the present availability spares & future requirement and similar we also consider the new improvements/modification requirement for the unit. The same will be considered as revenue budget & capital budget respectively. We also take OEM expert service for major maintenance/ overhauling of equipment on man day basis, the same will also be included in the budget based on the requirement of the unit... Based on the job requirement, the budget allocation/resource requirement can be reviewed. In past, based on my experience budget allocation was never being a constraint for performing maintenance jobs.” – Manager (NG Pipeline O & M).

“We know that what are the maintenance activities to be taken for next year? Based on this we do our budgeting. Budget provisions are kept for capital expenditures & also revenue expenditures” – CM (NG Pipeline O & M).

“Maintenance budget is based on the ratio of maintenance used between preventive & predictive maintenance. If we add more methods condition based diagnostics in predictive maintenance, obviously maintenance budget will increase” – SM (NG Pipeline O & M).

The findings from the case data related to these sub-constructs are also shown in Table 4.11.

Figure 4.11 QAN for Maintenance Policy

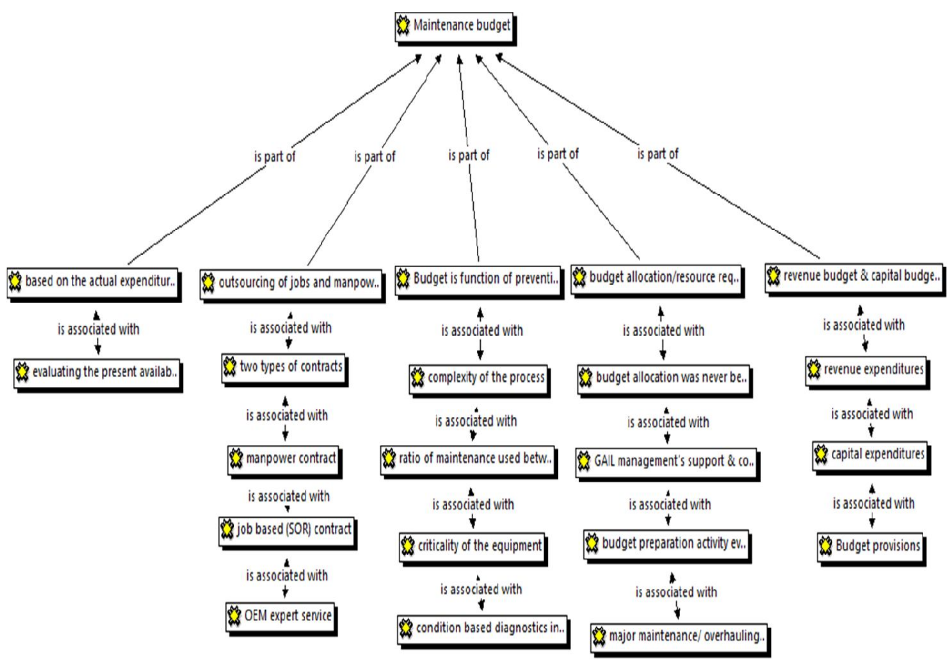


Figure 4.12 QAN for Maintenance Budget

Table 4.11 Maintenance Policy/Maintenance Budget related sub-constructs and empirical findings

Initial Conceptual Constructs	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Data Analysis**
Maintenance policies/ budget	Maintenance mission & objectives	Maintenance Policies/ Budget	Maintenance mission & objectives	Clear maintenance mission & objectives are available in the company as per Maintenance Policy & MOU targets. The targets have been further divided into objectives of individual units/ maintenance departments.
	Long term plans for maintenance function integrated with corporate plans		Long term plans for maintenance function integrated with corporate plans	Company's mission & vision is integrated with the maintenance policy & objectives.
	Maintenance Policies		Company's maintenance policy	Maintenance Policy is documented & available in company's Intranet in the company.
	Maintenance budget		Maintenance budget	Well defined budgeting system is available in the company. Maintenance Budget is function of Preventive maintenance, predictive maintenance, and shutdown maintenance job requirements/ plan; Budget allocation/resource requirement is being reviewed by the company every six months

4.3.10 Maintenance Challenges

A new category has been emerged from the interview data which is collected from maintenance managers of the large gas utility company in India. Maintenance managers are of the opinion that the maintenance challenges are actually helping in formulating maintenance strategies for the company. The data analysis outcomes shows that the new category maintenance challenges contributing to maintenance strategy formulation, selection, and implementation of maintenance strategies. Qualitative Associative Network developed for this category is presented in the Figure 4.13 and few representative quotations from maintenance managers are also discussed below.

"Due to the ageing of NG/LPG pipelines, maintenance problem increases so, the preventive maintenance schedules are reviewed accordingly...in our KG Basin, we have very old pipelines network which was taken over from ONGC. These pipelines do not have pigging facility. We do not know the actual condition of the pipeline. Therefore, we may take operating decisions on such pipeline. This is another challenge in KG Basin pipelines... Major maintenance challenge is condensate from ONGC gas supply and to avoid condensate filtering systems are being used." –Manager (NG Pipeline O & M).

"We have challenges in the pipeline. Manpower placed in pipelines is the executives from GAIL role. But, the jobs are being executed by the contract manpower. Contract work force changes every two year once the new contract has been awarded. Sometimes, new contractors deploy same manpower from previous contract. In case of new contractor brings the new manpower, then training the person in performing the maintenance job is the challenge. Our managers are experts so that the outsourced manpower can be trained during the maintenance" –Manager (NG Pipeline O & M).

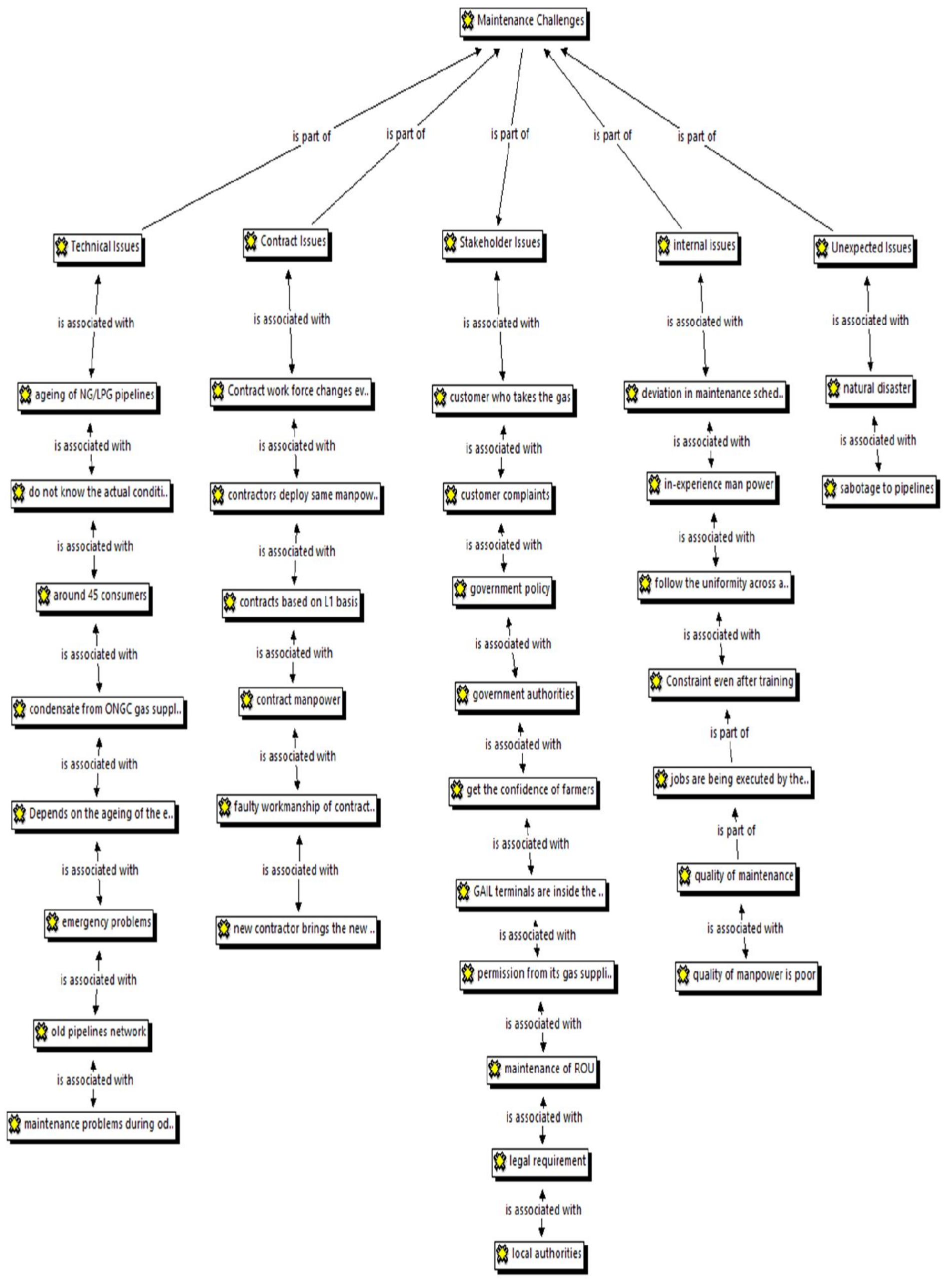


Figure 4.13 QAN for Maintenance Challenges

“The challenges are government policy, procurement procedures, outsourcing of maintenance manpower (GAIL’s policy). Since we are hiring the contracts based on L1 basis, due to this quality of manpower is poor and that leads to maintenance problem” – SM (NG Pipeline O & M).

"In pipeline maintenance, external stake holder influence/involvement is very high. When I compare with petrochemicals, there stake holder influence/involvement is very low. Petrochemicals can analogue to gated community. Where, we can control whole lot of activities. But, in NG pipelines, pipelines are passing through the lands of farmers who farming the land, customer who takes the gas, government authorities and local authorities. All of these external stake holders are coming into the picture... for some maintenance reasons such as pipeline leakages etc., you need to get the confidence of farmers and necessary approvals from local government authorities. Your pipeline territory is highly controlled by external stake holders" - Manager (NG Pipeline O & M).

"At times, due to organisation's lean & thin manpower, quality of maintenance gets affected due to in-experience man power" – DGM (NG Pipeline O &M).

"...we have the constraint that even after training, we require expert manpower from OEM for much specialised jobs such as engine overhauling, compressor overhauling etc." – DGM (NG Pipeline O &M).

"...we have challenges in the pipeline. Manpower placed in pipelines is the executives from company's role. But, the jobs are being executed by the contract manpower" – Manager (NG Pipeline O &M).

"...pipelines are passing through the lands of farmers who farming the land, customer who takes the gas, government authorities and local authorities. All of these external stake holders are coming into the picture. If we want to take shut down of the pipelines for maintenance, GAIL needs to get permission from its gas supplier ONGC and its downstream consumers. Even after approval from the external stake holders, we need to complete the maintenance activity as per schedule and restore back the operation as early as possible... Since we are hiring the contracts based on L1 basis, due to this quality of manpower is poor and that leads to maintenance problem."- SM (NG Pipeline O & M).

“Shutdown of pipeline is mainly due to leakage of pipeline, sabotage of pipeline and natural disaster. Sometimes, in SV stations if one valve failures, we may use bypass valve/bypass line temporarily to ensure smooth operation of the NG pipeline” – Manager (NG Pipeline O & M). The findings from the case data related to these sub-constructs are also shown in Table 4.12.

Table 4.12 Maintenance Challenges factors and empirical findings

Categories from empirical data	**Focused codes from empirical data**	**Data Analysis**
Maintenance Challenges *(newly emerged out)*	Technical Issues	Few technical issues have been identified from data analysis. They are ageing of pipelines, condensate carry over along with NG through supplier gas pipelines, etc.
	Contact Issues	Few contract related issues have been identified from data analysis. They are deployment of contractor manpower, contract selection based on lowest bid (L1) basis, training of newly deployed contract manpower, etc.
	Stakeholder Issues	Few stakeholders related issues identified from data analysis are changes in government policy, fulfilment of procedures laid down by local authorities, customer & supplier related issues, issues by farmers etc.
	Internal Issues	The issues related to the company’s internal functions are in-experienced manpower, even after training engineers are not able to perform like OEM experts, Poor quality of contract manpower, etc.
	Unexpected Issues	Few issues which are natural and unexpected are Sabotage to pipeline systems & natural disaster like earthquake, flood etc.

4.4 MAINTENANCE STRATEGIES SELECTION PROCESS IN NG PIPELINES

This section describes about maintenance strategies selection related activities in the large gas utility company. Data collected from the maintenance managers/engineers of the company were analysed as per the data analysis strategy described in Section 3.6. After phase I, the conceptual analysis of the case study was undertaken in order to identify various activities carried out by the maintenance managers for maintenance strategies selection and their practices in NG Pipelines. Then, these activities were combined into categories/concepts based on processes related to maintenance strategies & maintenance practices. The detailed data analysis based on literature review Section 2.5.3 (selection of maintenance strategies) and Section 2.5.5 (maintenance decision support system).

Interview data has also been analysed in terms of selection of formulated maintenance strategies. A Qualitative Associative Network has been developed to understand the existing methods available in the gas utility company for maintenance strategy selection. QAN for maintenance strategy selection is shown in Figure 4.14 and the same is supported with the representative quotations as described by the maintenance managers of the gas utility company.

"...frequency of maintenance is depending on the critically of the equipment/instrument. Further, criticality is based on the previous experience and process requirement... maintenance strategy selection is being affected with the factors such as process severity and criticality of the system. Standby equipment strategy is being followed for pipelines in cases of both NG & LPG Pipelines." – Manager (NG Pipeline O & M).

"...these requirements are decided at unit level based on criticality of the equipment and complexity of the process... maintenance policy provides guidelines to maintenance function for NG pipelines...these are broader guidelines, and based on these guidelines each unit formulates its maintenance strategy...factors of maintenance strategy planning are complexity of the equipment, maintenance requirement and required availability of the equipment."- SM (NG Pipeline O & M).

"Selection of maintenance like preventive or predictive is based on two factors as I told earlier also. They are experience of maintenance personnel and OEM recommendations" – DGM (NG Pipeline O &M).

"...predictive maintenance is more in NG pipelines such as intelligent pigging. Integrity management in pipelines are new maintenance strategy but it is not implemented so far... Short term maintenance planning is based on PM schedules. This includes cathodic protection (CP). In CP, PSP potential measurement is to be done on monthly basis"- SM (NG Pipeline O & M).

"In pipelines operation, we have vibration monitoring system which provides input to maintenance schedules. Integration of this system is under progress" – DGM (NG Pipeline O & M).

"In my view, we should switch over to Reliability Based Maintenance. In NG pipelines, satellite based monitoring & GIS monitoring may be followed in future...in NG pipelines, preventive maintenance methods are line walk/foot walk to see encroachment, helicopter patrolling, cleaning pigging. Predictive maintenance methods are intelligent pigging, cathodic protection, etc. – SM (NG Pipeline O & M).

"...problem faced by the individual unit are shared with other units of similar nature. So that, the preventive actions can be initiated by the other units in order to avoid similar maintenance problems. This is the maintenance policy being followed among the GAIL units"- Manager (NG Pipeline O & M).

"PNGRB comes out with the standard called T4S. It clearly defines the maintenance activities, frequencies, etc. for NG pipeline maintenance. These activities must have to be followed since T4S standard implementation is statutory... Maintenance modification such as re-routing pipelines is being done with guidelines from OISD standards"– SM (NG Pipeline O & M).

The findings from the case data related to maintenance strategies selection process are shown in Table 4.13.

Table 4.13 Maintenance Strategy Selection Process empirical findings

Categories from empirical data	**Focused codes from empirical data**	**Data Analysis**
Selection of Maintenance Strategy for particular operation process/equipment	Factors Contributing to maintenance strategy selection	Few factors which are contributing to the selection of maintenance strategy have been identified from the data analysis. Such factors are previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, Maintenance Policy, equipment complexity, equipment availability, process severity, complexity of the process
	Specific maintenance strategy for NG pipeline	Specific maintenance strategies being used in NG Pipelines are intelligent pigging, integrity management system, Cathodic Protection, Vibration monitoring system, Stand-by equipment strategy, Helicopter Patrolling, Line walk, Cleaning Pigging.
	Internal & Industry Norms	Gas utility company is following industry norms such as standards of OISD, PNGRB, etc. and internal norms are such as sharing maintenance problems among work centres and maintain SAP system so that all data can be accessed by all work centres across the country. These norms help the company to implement uniform maintenance strategy selection process across the work centres in the country.

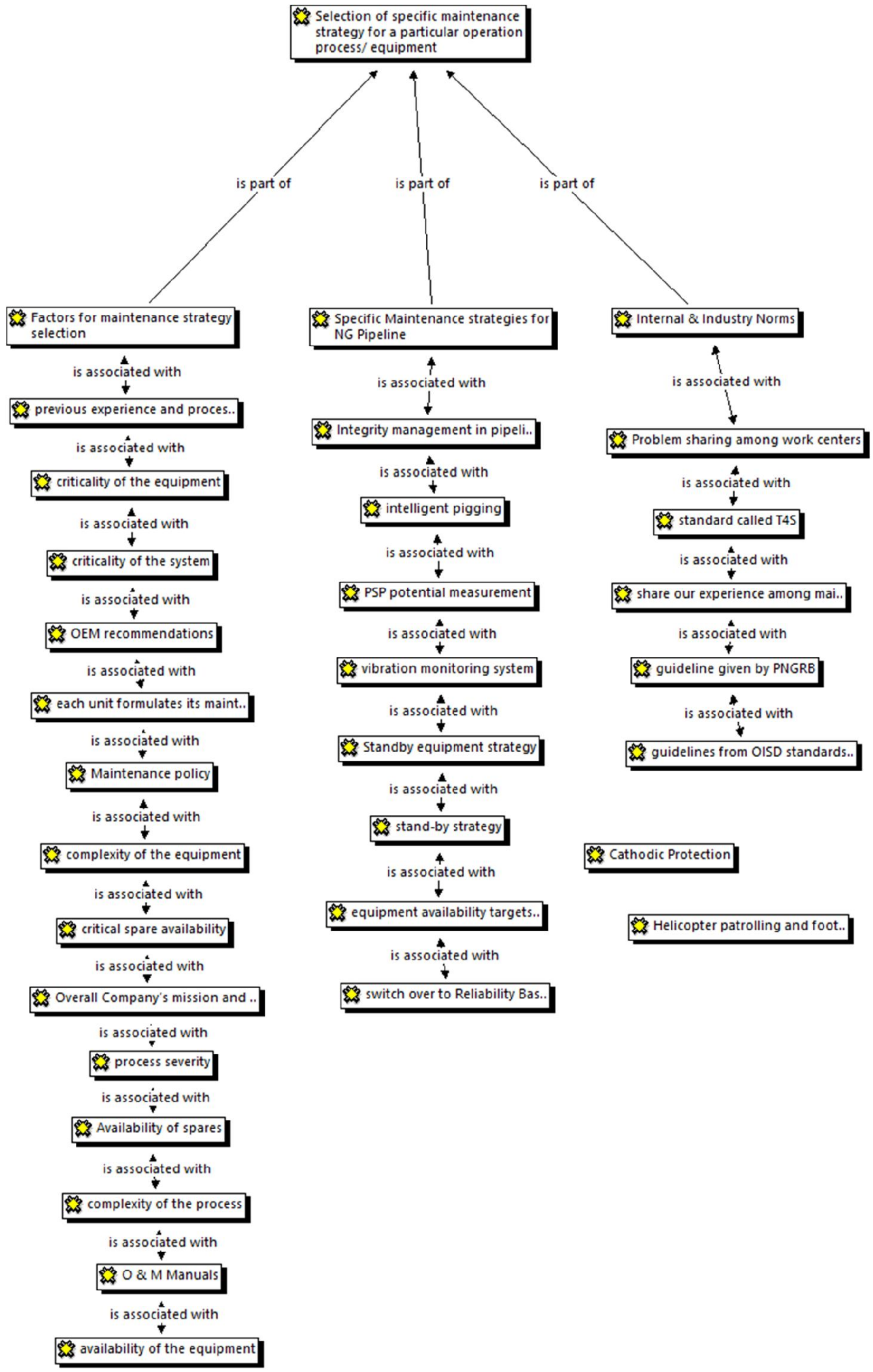


Figure 4.14 QAN for Maintenance strategy selection process in NG Pipelines

4.5 RELATIONSHIP BETWEEN MAINTENANCE STRATEGY SELECTION PROCESS AND MAINTENANCE STRATEGIES & PRACTICES

This section describes the relationship between factors contributing to maintenance strategies and maintenance practices and maintenance strategy selection processes in NG Pipelines of the gas utility company.

As shown below in Figure 4.15, maintenance strategies & maintenance practices planning and execution in NG Pipelines of the gas utility company depends on the factors contributing to maintenance strategies & maintenance practices including benchmarking practices and reliability maintenance practices in the company. Maintenance strategies selection process identified in section 4.4 play a crucial role in maintenance strategies & practices.

The key findings regarding relationship between maintenance strategy selection process and maintenance strategies & practices are as follows:- Total Productive Maintenance (TPM) technique is not being practiced in the gas utility company NG Pipelines; planned shutdown maintenance is one among the maintenance tactics is being used for the equipment/systems where standby is not available. This is the new tactics emerged out from this study; Predictive Maintenance is preferred more in NG Pipelines over Preventive Maintenance; Reliability Cantered Maintenance (RCM) technique is not being practiced in the gas utility company NG Pipelines. Therefore, the RCM metrics such as MTBF, Value Risk Study are not being used in maintenance; no International Benchmarks are being followed. But, MOU targets are treated as benchmarks. From the documentary evidence, it is found that maintenance cost is benchmarked i.e., 0.83 % of Gross Block (Inflation Adjusted); Maintenance managers are referring MOU targets/ operational targets as Key Performance Indicators (KPI) for maintenance also. This shows that there is no specific KPIs are identified for measuring maintenance performance.

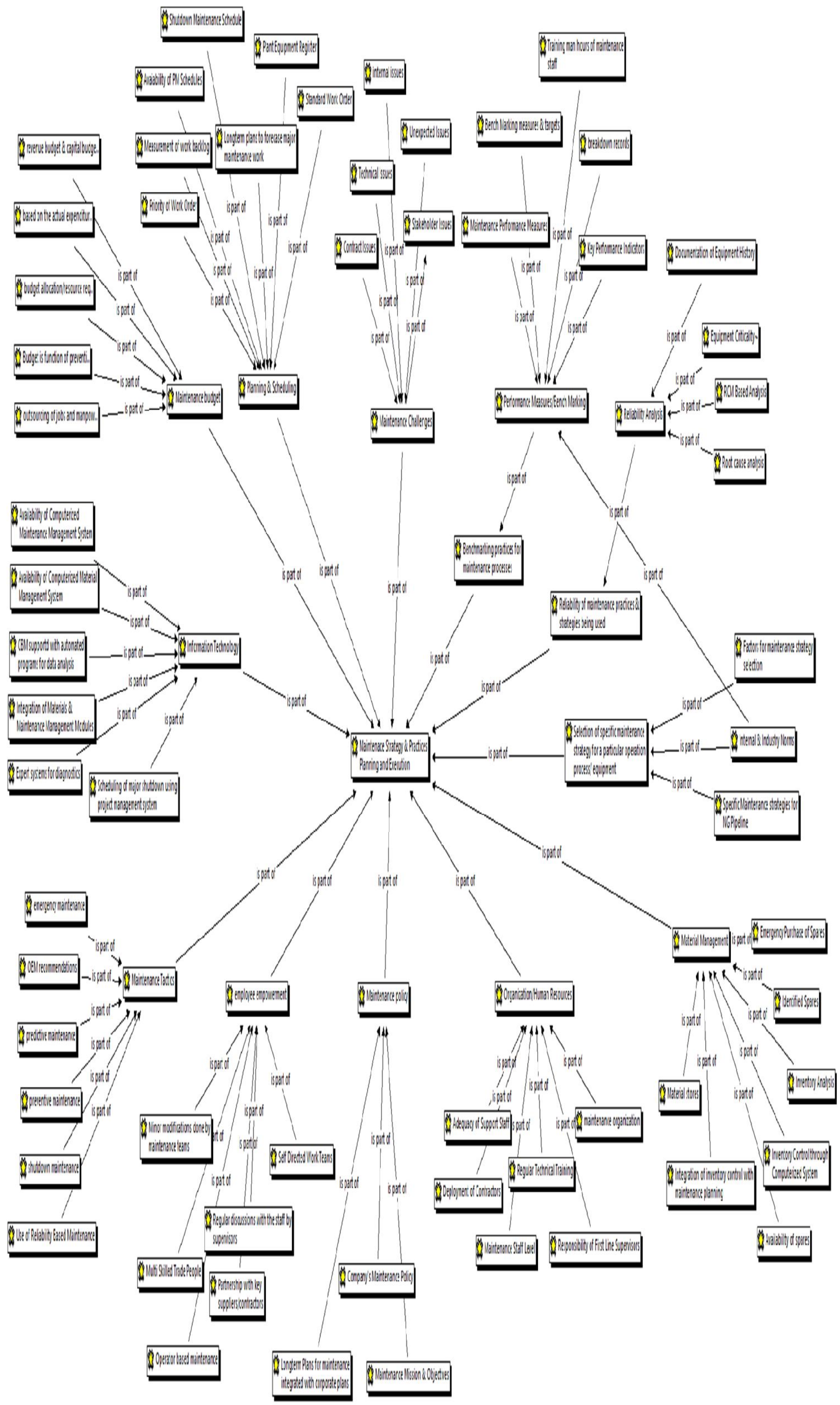


Figure 4.15 Maintenance Strategies & Maintenance Practices in NG Pipelines

Further, maintenance performance is assessed through Internal Audits & External Audits. Since, these audits are being conducted based on some standards such as OISD, PNGRB guidelines etc., these audit recommendations & their implementations are guiding the maintenance performance in the large gas utility company; there is no evidence of awareness or usage of metric related to labour cost/material cost from the interview data. However, maintenance cost is benchmarked by the company as given above; no evidence of following "Average Inventory Turnover" concept in the company; during interview, maintenance managers were not telling about Apprentice program. However, from company secondary data Apprentice program is available as per statutory requirements; maintenance challenges is the new category of maintenance strategies emerged out from this study. This includes the major issues being faced by maintenance managers in their day-to-day jobs. These are grouped in to technical issues, contract issues, stake holder issues, internal issues & unexpected issues. These factors will play crucial role in development of maintenance strategies & maintenance practices. Presently, these challenges are managed by individual/team as and when required. The same has to be formalised & documented for better maintenance practice; key maintenance challenges which are need to be considered before formulating maintenance strategy & while implementing maintenance practices are ageing of assets, NG Pipelines issues such as condition, no. of consumers, gas source problems etc., deployment of contract manpower & workmanship of contract employees, award of contracts, legal & statutory requirements, customer/supplier plant issues, quality of maintenance & inexperience maintenance personnel, dependency on OEM support, and natural disasters.

4.6 FINDINGS AND DISCUSSIONS

This section discusses the findings from empirical data analysis on maintenance strategies & maintenance practices of the large gas utility company business vertical NG Pipelines, maintenance strategy selection processes specific to NG Pipelines equipment/process and further relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in the company.

4.6.1 Maintenance Strategies & Maintenance Practices

The above detailed data analysis results with the following categories which contributes to maintenance strategies selection and maintenance practices.

1. Performance Measures/Benchmarking
2. Planning & Scheduling
3. Materials Management
4. Organisation/ Human Resources
5. Employee Empowerment
6. Information Technology
7. Maintenance Policies/Budget
8. Maintenance Tactics
9. Reliability Analysis
10. Maintenance Challenges

Earlier literature on maintenance strategies & maintenance practices has identified nine categories of factors contributing to maintenance strategies selection & practices as discussed in the literature review chapter section 2.6. This research study could find evidence for all these nine contributing factors. There is one new category emerged out from this study is maintenance challenges.

Earlier literature on performance measures as discussed in section 2.6.3 has identified sub-constructs such as labour and material cost, breakdown records, maintenance performance measures, key performance indicators, downtime records, training man hours of maintenance staff, internal norms/industry norms, benchmarking measures & targets. From the data analysis, there is evidence of all these construct except labour/material cost. Even though, maintenance cost is the only benchmarked parameter in the gas utility company's document, no evidence is found from interview data. i.e., maintenance managers/engineers are practically not using this measure. The interviewees indicated that the key performance measures and benchmarking parameters are based on MoU (Memorandum of Understanding) with concerned ministry of Government of India. It is observed that the most of the parameters are related operational targets and they are not measuring the maintenance performance. Benchmarking exercise was carried out by the gas utility company during 2002 only. Benchmarking is majorly related to operational/financial aspects of the business. There is no separate maintenance benchmarking parameters available.

Earlier literature identified the construct planning & execution to cover the sub-constructs (Refer section 2.6.4) such as plant equipment register, standard written work order, availability of PM schedules, priorities of work order, availability of work schedule for a week ahead, shutdown maintenance schedule, measurement of work backlog, long term plans to forecast major shutdown/maintenance work. This case study has found the evidences for all these elements. Planning & execution activities in NG Pipelines are being executed, maintained, and documented in the SAP system as indicated by the interviewees.

Earlier literature on material management as discussed in section 2.6.5 has identified with sub-constructs such as spares availability, identified spares, inventory analysis, emergency purchase of spares, average inventory turnover, availability of stores, inventory control through computerised system, and integration of inventory control with maintenance planning. This case study has found the evidences for the all these elements except average inventory turnover. This concept has not been used by the gas utility company. As per interview data analysis, the material management activities in NG Pipelines of the company are being managed through SAP MM Module in SAP system. Further, material management module is also integrated with SAP PM Module which is used for maintenance planning & execution. Therefore, practice of proper planning, organising, and controlling of the spare procurement in alignment with the maintenance planning process exists in NG Pipelines of the company.

Earlier literature identified the construct organisation/human resources to cover the sub-constructs (Refer section 2.6.6) such as maintenance staff level, maintenance organisation, responsibility of first line supervisors and adequacy of support staff, regular technical training, apprenticeship program, and deployment of contractors. Evidences are found for all these elements of organisation/human resources from interview data except apprenticeship program. However, interaction during site visits and documentary evidences show that the company is following apprentice program and this is statutory also. Especially, training systems are well structured in the company as indicated by interviewees. This facilitates technical training in maintenance in order to ensure smooth operation and quick restoration of equipment/processes after breakdown.

Earlier literature on employee empowerment as discussed in section 2.6.7 has identified the sub-constructs such as multi-skilled trade people, operators based maintenance, regular discussion with the staff by supervisors, self-directed work teams, minor modifications done by maintenance teams, and partnership with key suppliers/contractors. This case study could find evidences for all these elements. There are contra arguments among interviewees regarding operators based maintenance practice. Because, in gas pipeline terminals, such practice is existing and it is not the case with compressor stations in NG Pipelines. Modifications are managed through change management systems and the modifications are carried out only by main stations not by base stations.

Earlier literature identified the construct information technology to cover the sub-constructs (Refer section 2.6.8) such as availability of computerised system for maintenance management, availability of computerised system for materials management, integration of maintenance management & materials management modules, scheduling of major Shutdown using project management system, CBM supported with automated programs for data analysis, and Expert systems for diagnosis. This case study could find evidences for all these elements of activities related leveraging information technology in NG pipelines of the gas utility company. Expert systems for maintenance diagnostics used in NG Pipelines are SCADA, intelligent pigging, and satellite based pipeline survey/monitoring.

Earlier literature on maintenance polices and maintenance budget has identified the sub-constructs as discussed in section 2.6.9 such as maintenance mission & objectives, long term maintenance plans integrated with business plans, maintenance policies, and maintenance budget. Interview data analysis provides evidences for all these elements related to maintenance policies and maintenance budget. Interviewees indicated that clearly defined maintenance mission and maintenance objectives are available in the maintenance policy document. Further, they also explained about budget system and its role in maintenance function in NG Pipelines of the large gas utility company.

Earlier literature on maintenance tactics has identified the sub-constructs as discussed in section 2.6.1 such as use of Condition Based Maintenance/ Predictive Maintenance, Condition Based Maintenance is favoured over Time Based Maintenance (TBM), total maintenance hours devoted to Predictive Maintenance/ Preventive Maintenance, compliance of PM Schedules, OEM (Original Equipment Manufacturer) Recommendations for an equipment regarding PM, use of formal Reliability Based Maintenance (RBM), and use of Total Productive Maintenance (TPM). This case study could found evidences for all these elements of maintenance tactics in NG Pipelines of the gas utility company except use of Reliability Based Maintenance and Total Productive Maintenance. *Shutdown maintenance is the maintenance method is emerged out from this case study*. The maintenance jobs which could not be carried out during NG pipelines are under operational condition will be planned during pipelines shutdown (shutdown is the period in which NG Pipelines are not under operation due to non-requirement of gas by customer).

During this period, maintenance jobs are carried out. This type of maintenance is called as shutdown maintenance.

Earlier literature identified on reliability analysis to cover documentation of equipment history, equipment criticality, Root Cause Analysis (RCA)/Incident Analysis (IA), Mean Time Between Failures (MTBF), Value Risk Study of maintenance program, reliability statistics of equipment/assets, and Reliability Centred Maintenance (RCM) based analysis. This case study could not find any evidences for most of the elements except RCA/IA from interview data analysis. Interviewees has indicated that the reliability based maintenance or reliability centred maintenance is not being practiced in the company. However, few reliability measures like RCA/IA and equipment history are being practiced in NG pipelines of the company as indicated by maintenance managers/engineers of the company.

This case study could find evidences for “Maintenance Challenges” as a new category of factor contributes to maintenance strategies planning and execution in the company. This includes the major issues being faced by maintenance managers in their day-to-day jobs. These are grouped in to technical issues, contract issues, stake holder issues, internal issues & unexpected issues. These factors play crucial role in maintenance strategies & maintenance practices. Presently, these challenges are managed by individual/team as and when required. These maintenance challenges factors are to be formalised and documented for better maintenance practices in the company as indicated by the interviewees. The major maintenance challenge in NG Pipelines is sabotage to pipelines and natural disasters.

4.6.2 Maintenance Strategies Selection Process in NG Pipelines

As discussed in Chapter 2, section 2.5.3, literature indicated that the maintenance strategies selection process is being carried out using mathematical modelling. In the organisations, selection of maintenance strategies for particular equipment/process is treated as Multiple Criteria

Decision Making (MCDM) Problem. This type of problem can be solved using techniques like AHP, Fuzzy AHP, VIKOR model etc. This case study could not find any evidences of using such techniques in NG pipelines of the gas utility company for maintenance strategies selection process.

Further, as discussed in section 2.5.5, literature indicated that Decision Support System (DSS) models have been used for optimizing the maintenance strategies mix use in the organisations in order to ensure better implementation of maintenance strategies and improving maintenance. No evidences are found in this case study regarding implementation DSS models in NG pipelines of the gas utility company.

As detailed above in section 4.4, NG pipelines maintenance strategies selection process includes the following elements such as previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process in selecting a particular maintenance strategy for a specific equipment/process. However, there are specific maintenance techniques are applicable in NG Pipelines in performing maintenance strategies such as preventive maintenance and predictive maintenance like intelligent pigging, integrity management system, cathodic protection, vibration monitoring system, stand-by equipment strategy, helicopter patrolling, line walk, cleaning pigging, internal norms, and industry norms.

4.6.3 Relationship between Maintenance Strategies Selection Processes and Maintenance Strategies & Practices in NG Pipelines

Earlier literature identified with various maintenance strategies related models to explain the processes related to maintenance strategies selection and maintenance practices and contributing factors as discussed in chapter 2, section 2.6 & section 2.7. Such processes are deliberated like formulation of maintenance strategies (McAlister, 1999; Waeyenbergh & Pintelon, 2002;

Kelly, 2006), maintenance strategy selection (Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy, Atrens & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Lin et al., 2009), and implementation of maintenance strategies (Campbell & Picknell, 2006; Eti M.C., 2006; Crespco, 2005; Pinjala, Pintelon & Vereecke, 2006; Veldman, Klingenberg & Wortmann, 2011), e-maintenance and its impact (Liptrot, David & Palarchio, Gino, 2000; Muller, Alexander; Crespo, Marquez, Adolfo & Lung, Benoit, 2007; Swanson,2003; Elliot & Tobias, 2005). Maintenance performance provides key inputs to maintenance strategies selection and maintenance practices as indicated by various literatures (Albert et al., 1999; Tsang, 1999; Sherwin,, 2000; Swanson, 2001; Kutucuoglu et al., 2001; Visser & Pretorious, 2003; Weber & Thomas, 2006; Parida & Chattopadhyay, 2007; Parida & Uday, 2009; Muchiri et al., 2011; Simoes et al., 2011).

This case study could find evidences of relationship among the processes related to maintenance strategies & maintenance practices such as formulation of maintenance strategies, maintenance strategy selection, and implementation of maintenance strategies. E-maintenance implementation in NG pipelines is majorly based on the implementation of SAP system and other intelligent diagnostic systems. There is an evidence of using maintenance performance assessment in framing maintenance strategies and improvement in maintenance practices.

This case study could find evidences showing maintenance processes in the gas utility company such as maintenance strategies formulation, maintenance strategy selection, implementation of maintenance strategies and practices in the company. Further, this case study could come out with the factors contributing to those maintenance strategy related processes.

4.6.4 Case Study Findings in terms of Research Questions

The constructs and sub-constructs identified through literature review have been verified in data analysis of empirical data collected from maintenance managers/engineers of the large gas utility company in India. The detailed discussions, observations and findings have been presented above in section 4.3 & section 4.4. Further, the relationships among these factors emerged from data analysis and holistic picture for answering the central research question, a Qualitative Associative Network has been developed and the same is shown in section 4.5. The case study findings are summarised in terms of research questions and presented below.

- *Findings related to CRQ (Maintenance strategies & practices planning and Execution & specific maintenance strategies of gas utility company)*
    - NG pipelines of gas utility company is planning & executing its maintenance strategies majorly based on: overall company's maintenance policy guidelines, MOU/ IMOU targets, maintenance challenges faced by maintenance managers/engineers such as ageing of assets, dependency on OEM, contract issues, etc.
    - Specific maintenance strategies are selected in NG pipelines majorly based on: OEM (Original Equipment Manufacturer) recommendations, standard industry practices and past experience of maintenance managers.
- *Findings related to ARQ1- Common & different maintenance strategies between petrochemicals & NG Pipelines*
    - Predictive Maintenance is more used compare to preventive maintenance in NG Pipelines than petrochemicals
    - Emergency maintenance is very rare in NG Pipeline where in Petrochemicals the same is minimized by various maintenance tactics
    - Maintenance Techniques used are also very specific to systems in NG Pipelines such as cathodic protection, intelligent pigging, etc.

  - Maintenance challenges play a crucial role in deciding on maintenance strategies & impact the maintenance practices in NG Pipelines.
- *Findings related to ARQ2- Benchmarking in Maintenance of NG pipelines*
  - Benchmark report (2002) is available but it is not being practiced fully in NG Pipelines of the gas utility company.
  - From the documentary evidence, it is found that one parameter maintenance cost is benchmarked i.e., 0.83 % of Gross Block (Inflation Adjusted).
  - MOU targets are being treated as benchmarks by the maintenance managers since the company is market leader in NG pipelines transmission and availability of pipeline is 99%.
  - Maintenance performance is assessed through Internal Audits & External Audits by OISD, PNGRB, etc.
- *Findings related to ARQ3- Reliability in maintenance*
  - Reliability Centered Maintenance (RCM) technique is not being practiced in NG Pipelines of the gas utility company.
  - RCM metrics such as MTBF, Value Risk Study are not being used in NG pipelines maintenance practices.
  - However, Root Cause Analysis (RCA) of maintenance failure & Incident Analysis Report (IAR) are being used to identify root cause failure of equipment and report failure incident respectively.

4.7 CONCLUDING REMARKS

This chapter presented and discussed the analysis and results of NG Pipelines case study of Indian gas utility company. Categories of factors contributing to maintenance strategies & maintenance practices and maintenance strategy selector process in NG Pipelines of the gas utility company have been presented and discussed. One new type of category maintenance challenges and one new type of maintenance tactic/method shutdown maintenance emerged out from the data.

The relationship between maintenance strategies selection process in NG Pipelines and categories of factor contributing to maintenance strategies & maintenance practices have been presented and discussed. The findings of the case study illustrate that interviewees considered the following categories such as performance measures, planning & Scheduling, materials management, human resources, information technology, employee empowerment, maintenance tactics, reliability analysis, maintenance policies/maintenance budget, and maintenance challenges are important in deciding on maintenance strategies selection process & maintenance practices in NG Pipelines of the gas utility company.

Further, interviewees indicated that the maintenance strategies selection process is not based on mathematical modelling using quantitative techniques & tools and it is based on previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity/complexity, internal norms and industry norms.

This chapter presented and discussed NG Pipelines Case study. Next chapter presents and discusses the Petrochemicals Case Study.

CHAPTER 5

MAINTENANCE STRATEGIES & MAINTENANCE PRACTICES OF PETROCHEMICALS PLANT

5.1 INTRODUCTION

This chapter presents in detail the case study conducted at petrochemicals plant. Data collection details related to this case study-1 (Petrochemicals) is discussed in section 5.2. Then detailed data analysis findings are reported in the subsequent sections on maintenance strategies & practices in Petrochemicals (section 4.3), maintenance strategy selection processes in Petrochemicals (section 4.4), and relationship between maintenance strategy selection process and maintenance strategies & practices in Petrochemicals (section 4.5) of the large gas utility company in India. Further, detailed discussions on case findings are presented in section 4.6. Outcomes of the case study findings are summarised in concluding remarks. The sub-section of this section of this chapter discusses about Petrochemicals of the large gas utility company in India and its operation & maintenance systems at the company.

5.1.1. Petrochemicals Industry – An Overview

Petrochemicals are the derivatives of crude oil and natural gas. Olefins (ethylene, propylene & butadiene) and Aromatics (benzene, toluene & xylenes) are the major building blocks from which most chemicals and petrochemicals are produced. They are used in dyes, synthetic fibres, rubbers, plastics, pharmaceutical bulk drugs, industrial appliances, packaging industry, detergents (surfactants).

Petrochemicals production process consists of primarily two stages. In the first stage naphtha, produced by refining, crude oil or natural gas is used as a feedstock and is cracked. Cracking (breaking of long chain of hydrocarbon molecule) produces olefins and aromatics. In stage two, these building blocks are polymerized (made to undergo chemical processes) to produce downstream petrochemical products (polymers, polyesters, fibre intermediaries and other industrial chemicals. The upstream integrated naphtha / gas cracker complexes are technology intensive and enjoy economy of scales. However, downstream plastic processing industry is quite fragmented across the country and operates at lower than optimum capacity.

Olefins are the key building blocks of the petrochemical industry. Of the main, while India has sufficient capacities for ethylene and propylene, styrene continues to be in deficit. Ethylene capacity grew in the five year plan due to partial de bottlenecking of capacity by GAIL, HPCL and the start-up of IOC complex at Panipat. Propylene production boosted due to extraction of Propylene by RIL at its Refinery Complex. For Butadiene, RIL and Haldia are the only two domestic producers.

The industry suffers from high capital and energy costs, shortage of natural gas, lack of skilled manpower, low focus on value added exports of end products, cyclical nature of business, zero import duty differentials between polymers and feed stocks. The key demand drivers of this industry are GDP growth, improvement in disposable income, aspirations of young India, urbanization, etc. These mega trends get translated to increase demand for healthcare, packaging, white goods, automobiles, agriculture produce, retail, etc. The margins in the industry are cyclical and typically follow a 6-8 year period of troughs and peaks.

Availability and high duty on feedstock (natural gas), high cyclicality in the business, low import duties on polymers, poor margins due to nil duty differential between feed-stock and Products, large capex needed to set petrochemical projects (Petrochemical feed stocks face 5%customs duty) are some of the issues that the industry faces. (*Source:* www.equitymaster.com)

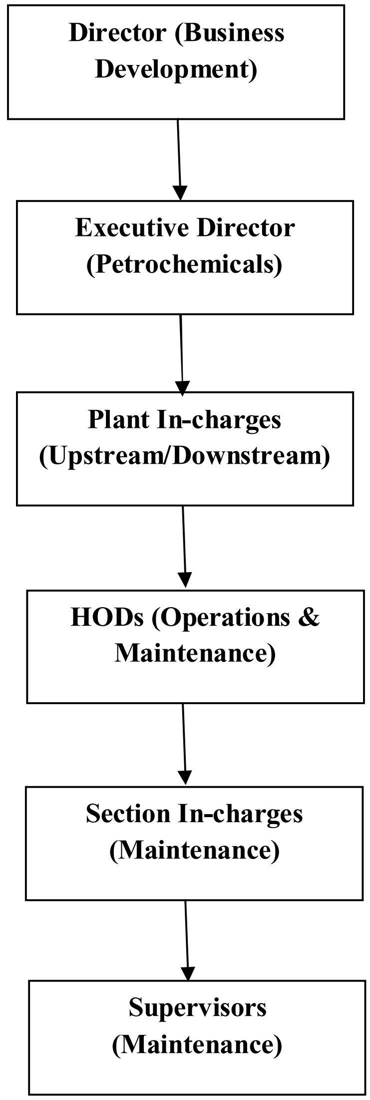
5.1.2. Petrochemicals Operations & Maintenance

The large gas utility company owns and operates a gas based Petrochemical Complex at PATA, District-Auraiya in UP (around 380 km from Delhi). GAIL has world class “Sclairtech” solution polymerization process licensed from M/s Nova Chemicals, Canada to produce LLDPE and HDPE, with nameplate capacity of 210 KTA and has two slurry based polymerization process licensed from M/s Mitsui Chemicals, Japan, to produce HDPE, each with nameplate capacity of 100 KTA. A new world class gas phase Unipol PE Process of M/s Univation Technology, USA, to produce HDPE/LLDPE with a nameplate capacity of 400 KTA is expected to be commissioned shortly.

GAIL has 70% equity in joint venture company Brahmaputra Cracker & Polymer Limited (BCPL) in Dibrugarh, Assam with a nameplate capacity of 220 KTA of HDPE & LLDPE and 60 KTA of PP. GAIL has acquired equity in OPaL’s greenfield petrochemical project at Dahej to produce 1060 KTA of HDPE & LLDPE and 360 KTA of PP. With ISO 9000, ISO 14000 and ISO 18001 accreditations, GAIL is committed towards producing a quality product with creating, maintaining and ensuring a safe and clean environment. GAIL’s polymer products are environment-friendly and fully recyclable. GAIL provides a wide choice of grades with consistent and reliable quality to its customers. Its manufacturing process and quality systems ensure that the products conform to the technical specifications, backed by high quality services to provide complete solution to the customers. The company’s marketing network is designed to ensure regular supply of material through multiple delivery modes, from both our Production Site as well as Stock Points.

GAIL Polymer Technology Centre (GPTC) is the technical support division of the GAIL Petrochemical Marketing group. It functions as the interface between the valued customers and plant. The centre is situated at Noida. The centre is equipped with state of the art plastic testing facilities for raw materials, additives and end products. It is NABL accredited Laboratory. With the support of laboratory equipment, it guides the customer for usage of GAIL's material. GPTC endeavours to bring customer delight by providing the total technical solutions to fulfil customer's needs.

GAIL petrochemical complex is called as Uttar Pradesh Petrochemical Complex (UPPC), PATA which is located 100 KMs. Away from Kanpur, Uttar Pradesh, India. It is producing 4.5 Lakh Tons of Polymer in its complex. Approx. 900 employees are working in this petrochemical complex. The petrochemical complex is producing polymer from natural gas. From natural gas, Ethane (C2) is extracted through gas processing plant and then C2 is cracked in Gas Cracker unit furnaces to convert Ethane to Ethylene. Then, Ethylene is transported to downstream plants to convert to Polyethylene grades High Density Poly Ethylene (HDPE) and Low Linear Density Poly Ethylene (LLDPE). All these processes are critical and controlled by automation & major equipment such as compressors, gas turbines, extruders, bagging machines, etc. It is contributing 24% profit of the large gas utility company's overall profit. Operations & Maintenance function plays a crucial role in achieving the production targets of polymers in this petrochemical complex. The organisation chart is as shown in Figure 5.1 below:



(Source: www.gailonline.co.in)

Figure 5.1 Organisation chart for Petrochemicals O & M

5.2 DATA COLLECTION

Semi structured interview was conducted from the following maintenance personnel in the area related to Petrochemicals plant who are the employees of the large gas utility company using case study protocol.

Table 5.1 - List of Interviewees of Case study-2 (Petrochemicals)

Level of Analysis	**Designation**	**Date of Interview**
Level 2– Gas processing	Manager (Maintenance)	24.07.2013
Level 2 - Petrochemicals	SM (Operations)	30.07.2013
Level 1 - Petrochemicals	SM (Maintenance)	23.08.2013
Level 1 – Corporate	CM (Maintenance)	24.08.2013
Level 3 – Polymer plant	DM (Maintenance)	24.08.2013
Level 3 – Gas Processing	SE (Maintenance)	20.09.2013

Note: The names of the participants are not given in the above table due to confidentiality

Data was collected from a variety of source: (i) Participant observation of team at NG Pipeline terminals located in Delhi NCR region for a month; (ii) Interviews; (iii) Company website, Intranet, and operation & maintenance related documents; and (iv) informal discussions with maintenance team leaders, maintenance mangers, maintenance engineers and maintenance technicians. As discussed in Section 3.5, the data collection was carried out at Petrochemical plant of the large gas utility company. The data collection phase lasted for almost six months. Initial one month was spent for initial contact and making arrangements for data collection (June, 2013). Then, two months were spent in conducting interviews based on the availability of maintenance managers/engineer from various levels (July, 2013 to August, 2013). Thereafter, 2-3 site visits were carried out in Petrochemicals plant at PATA, UP during September, 2013 to November, 2013.

The details of interview participants are shown in above Table 5.1. All interviews were recorded and then transcribed. After completion of the transcription of interviews, one month was spent to collect the interviewees' feedback on the transcripts (November, 2013). The draft of the case study report was shown to CM (O &M), and his suggestions and feedback were incorporated. Follow-up over telephone was done for clarifications and additional information.

Based on the interview data, within case data analysis was undertaken keeping in mind the research questions: How the gas utility company is planning and executing its maintenance strategies & practices to ensure smooth operation process in the company's business vertical Petrochemicals and why the specific maintenance strategy has been selected for a particular operation process/equipment?. This lead to the identification of various factors forms the basis for maintenance strategies selection and maintenance practices in petrochemical of the large gas utility company. Further, maintenance strategies selection processes being practiced in petrochemical and specific maintenance strategies for a particular operation process/equipment were identified. Then, the relationship between maintenance strategies selection processes and the identified factors for maintenance strategies & maintenance practices in petrochemical was analysed. Next Section describes about the detailed data analysis and findings of Petrochemicals case study.

5.3 MAINTENANCE STRATEGIES & PRACTICES IN PETROCHEMICALS

Data Collected from maintenance mangers/engineers of the company in the area of petrochemicals were analysed as per the data analysis strategy described in Chapter 3 (Section 3.6). This section describes about the factors contributing to the maintenance strategies and maintenance practices in petrochemicals of the gas utility company. The detailed data analysis based on initial conceptual constructs and sub-constructs identified & conceptualised from the literature review (Section 2.6) such as Performance Measures, Maintenance Tactics, Planning & Scheduling, Materials Management, Organisation/Human Resources, Employee Empowerment, Information Technologies, and Maintenance Polices/Budget is presented below.

5.3.1 Performance Measures

The interviewee data shows that the sub-constructs such as breakdown records, key performance indicators, training man hours of maintenance staff, maintenance performance measures, and internal & industry norms identified from literature for maintenance performance measures are also being practiced in petrochemicals plant of the gas utility company. A few of the representative quotations from the interviews are as given under:-

"Down time analysis and root cause problem are identified through Trip Analysis Report (TAR) and further action is initiated to prevent those failures in future"- DM (O & M)

In petrochemicals, downtime records are called as breakdown records. Such records are maintained in Trip Analysis Reports (TAR).

"The decision regarding equipment's maintenance should be done in a very careful manner so that equipment healthiness is not getting affected" – SM (O & M).

"...basic objective of the process plant is to make available of the critical equipment on 24 X 7 basis for operations... Because, for critical equipment, we do not have standby..."- SM (O &M- PC)

"Maintenance objective of this unit is ensuring 95% availability of plant. For achieving this target, we are having different maintenance strategies..." – CM (O & M)

"...plant availability is to be maintained at 99% and individual functional departments are also setting their department wise targets such at equipment availability of 99% etc... plant down time for processing plant should be less than 14 hours due to instrumentation systems." – Manager (O &M)

“Benchmarking in our company is that availability of plant should be 95%. We have our own benchmarks such as MOU targets”- CM (O &M)

“Benchmarking can be comparable since the company is one among the market leader. Corporate MOU targets are the basis for bench marking. The targets are being percolated to unit level, plant level, department level and also to individual level” – SM (O &M)

“...we have maintenance man power benchmarks at corporate level. HRD department is having man power data and the same is communicated to individual unit for further planning. We do not have documentation with unit level. But the corporate guidelines are available...” – Manager (O & M).

It is clearly evident from the above quotations that the MOU (Memorandum of Understanding) targets which are agreed upon with Petroleum ministry are only used for the purpose of benchmarking of Operation & Maintenance practices in petrochemicals plant of the gas utility company as conceived by the maintenance managers/engineers. Further, key performance indicators are also MOU targets which are of nature internal/external MOU targets. External MOU targets are set by petroleum ministry of India and internal MOU targets are set by corporate O & M function.

“Training is very important for performing maintenance function. One is on the job training. Another one is HOD is continuously evaluating the training requirements of their employees. The training needs are captured through structured reporting system. GAIL training institute is capable to organize all the technical requirements of maintenance personnel” – SM (O & M- PC).

“Training is very important for maintenance personnel. Maintenance engineer who is working on a particular machine should be given training on the maintenance aspects of that machine from OEM. That is the welcome move. Discussions with OEM personnel will also help maintenance engineers to perform better maintenance function” – SM (O & M)

“On-job training is an important aspect in maintenance. One training per employee is given on functional side to each and every employee by the organisation” – CM (O & M).

As described above by the maintenance managers in gas utility company, training function is being given importance by maintenance managers. From the company’s intranet, further as explained by the maintenance managers, there is a structured process to allot training to the maintenance personnel in the company. However, maintenance managers have emphasized on on-the-job training and OEM trainings in maintenance function.

“Annual audits are being conducted to see the maintenance practices compliance & performance measures of maintenance systems. Such audits are Inter Unit Safety Audit (IUSA), OISD Audit, etc. with different frequency” – CM (O & M)

“Maintenance Audits such as internal audits and external audits also facilitate the maintenance monitoring. We won the British Safety Council Award, this shows our maintenance practices are excellent” – Manager (O &M)

“Maintenance compliance & Maintenance performance are being ensured with the various audit processes such as internal audits by internal employees of GAIL and external audits by external agencies such as OISD, PNGRB, AGA etc.” – DM (O&M)

As described by maintenance mangers, maintenance performance measures are majorly done using methodology of audits. These audits are being conducted internally by company’s employees like Inter-unit audit and Intra-unit audit and further external audit experts from statutory bodies, third party vendors, etc. These audits provide audit reports with recommendations. These audit points are implemented so as to improve the maintenance performance as explained by the maintenance managers. Compliance report is also submitted by maintenance managers within the targeted time assigned by auditors.

"...we are following international standards for industry norms compliance. Internal norms are MOU targets"- SM (O & M)

"...we are following standards such as AGA, PNGRB, SIL level etc. for compiling the Industry Norms" – CM (O&M)

"Maintenance modification is done with the well- structured procedure Change management system. Guidelines for the same is from the standard OISD 178" – SM (O&M- PC)

From the above quotations, it is evident that the company is following certain internal norms such as guidelines from corporate management based on targets assigned by petroleum ministry i.e. MOU targets and industry norms such as international standards (AGA, SIL, etc.) & industrial compliance requirements.

The findings from the case data related to these sub-constructs are also shown in Table 5.2.

Table 5.2 Performance Measures sub-constructs and empirical findings

Initial Conceptual Constructs	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Performance Measures/ Benchmarking	Downtime Records	Performance Measures/ Benchmarking	Breakdown Records	Breakdown/down time analysis is being done in petrochemicals to identify the root cause problem and the same is maintained in Trip Analysis Reports (TAR).

				Such records are being maintained for measuring maintenance performance.
	Key Performance Indicators		Key Performance Indicators	KPIs are available. Basically, these are operational performance derived from MOU Targets with Petroleum Ministry. Few maintenance indicators used are down time hours, equipment availability, etc.
	Training man hours of maintenance staff		Training man hours of maintenance staff	Maintenance managers feel that training is important to maintenance personnel. They emphasized on on-the-job training, OEM training, etc. From the interview data & data evidences, Structured Training Process is available in the gas utility company.
	Maintenance Performance Measures		Maintenance Performance Measures	Maintenance Performance is largely based on Internal & External Audit Process by internal experts & external agencies such as OISD, PNGRB etc. respectively.
	Internal Norms & Industry Norms		Internal Norms & Industry Norms	Petrochemical plant of gas utility company is following relevant Internal & Industry Norms as per applicable standards & statutory requirements.
	Benchmarking measures & targets		Benchmarking measures & targets	No International Benchmarks are being followed. But, MOU targets are treated as benchmarks since the

				company is market leader.
	Labour and material cost		Nil	No evidence could be collected from maintenance managers which support importance being given to labour and material cost in maintenance function.

The qualitative associative network associated with the initial conceptual construct "Performance Measures" is as shown in Figure 5.2.

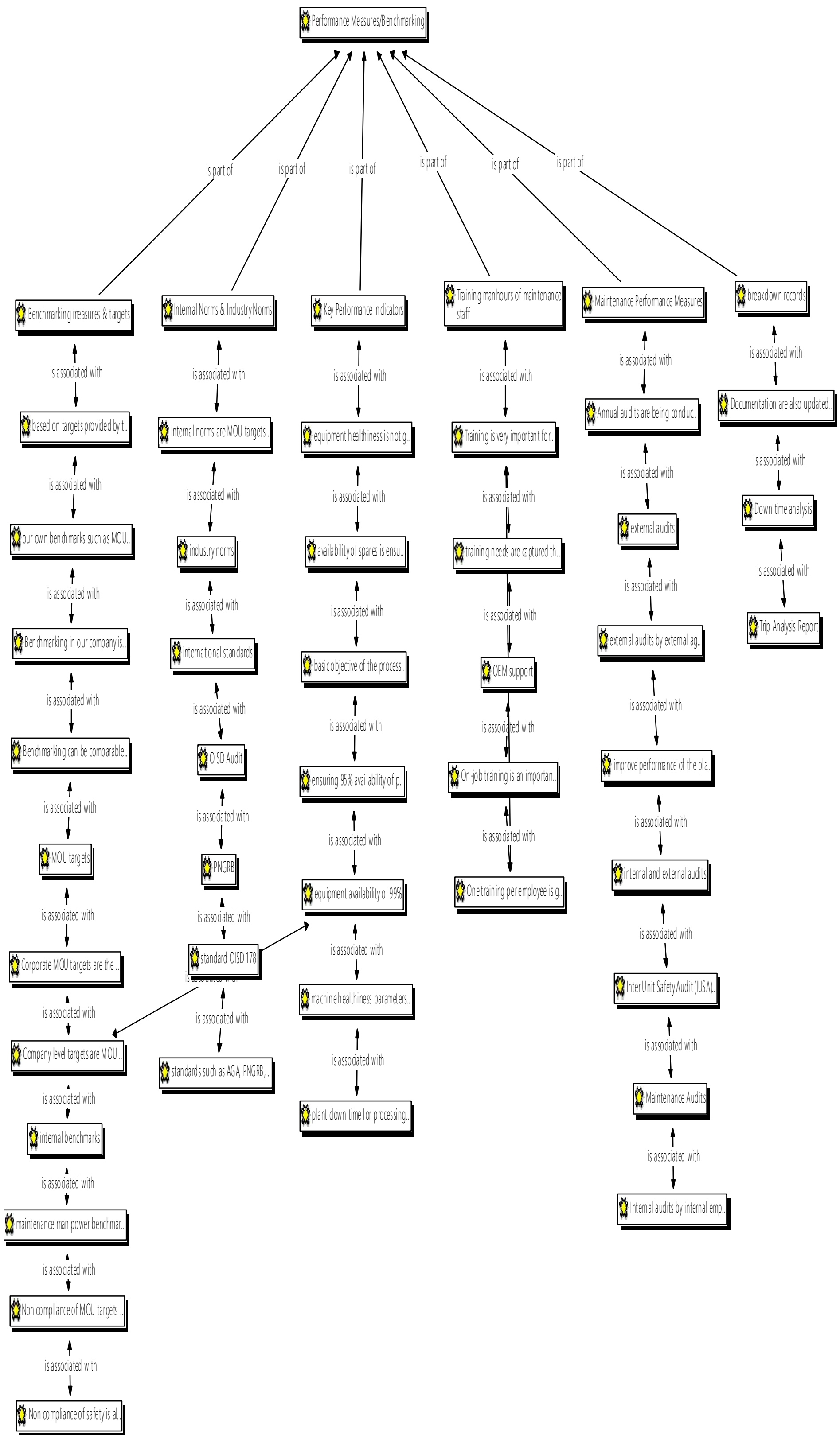


Figure 5.2 QAN for Performance Measures & Benchmarking

5.3.2 Planning & Scheduling

Interviewees indicated that the planning & scheduling is an important factor which plays crucial even at the stage of maintenance strategies formulation. A qualitative network associated with planning & scheduling is shown in Figure 5.3. The categories emerged out from this qualitative associative network are explained next with the help of evidences and descriptions from the case study.

"...SAP system is having beautiful tools. Through SAP, we can monitor spare availability, budget consumption and slippages in preventive maintenance schedules. IT is being well leveraged in our company like communication facility, SAP system etc." – Manager (O &M)

"...we use SAP system for planning maintenance system. All the maintenance schedules along with task list to be performed in the equipment are built-in with SAP system. Accordingly, work orders are being issued and necessary permits are obtained from operations personnel for performing that particular maintenance" – Manager (O &M)

"Maintenance planning, work intimation, spare planning etc. is being done through SAP system" - SM (O &M)

"...we have our IMS maintenance manuals. These manuals state very clearly the maintenance strategies being used in the company... work instructions, standard operating procedures are provided in the maintenance manuals..." – SM (O & M-PC).

"... for preventive maintenance we have maintenance schedules. We sought guidance from OEM for maintenance planning & formulating the maintenance schedules. We also take recommendations from OEM for specific maintenance problem identified in predictive maintenance also" – SM (O&M-PC)

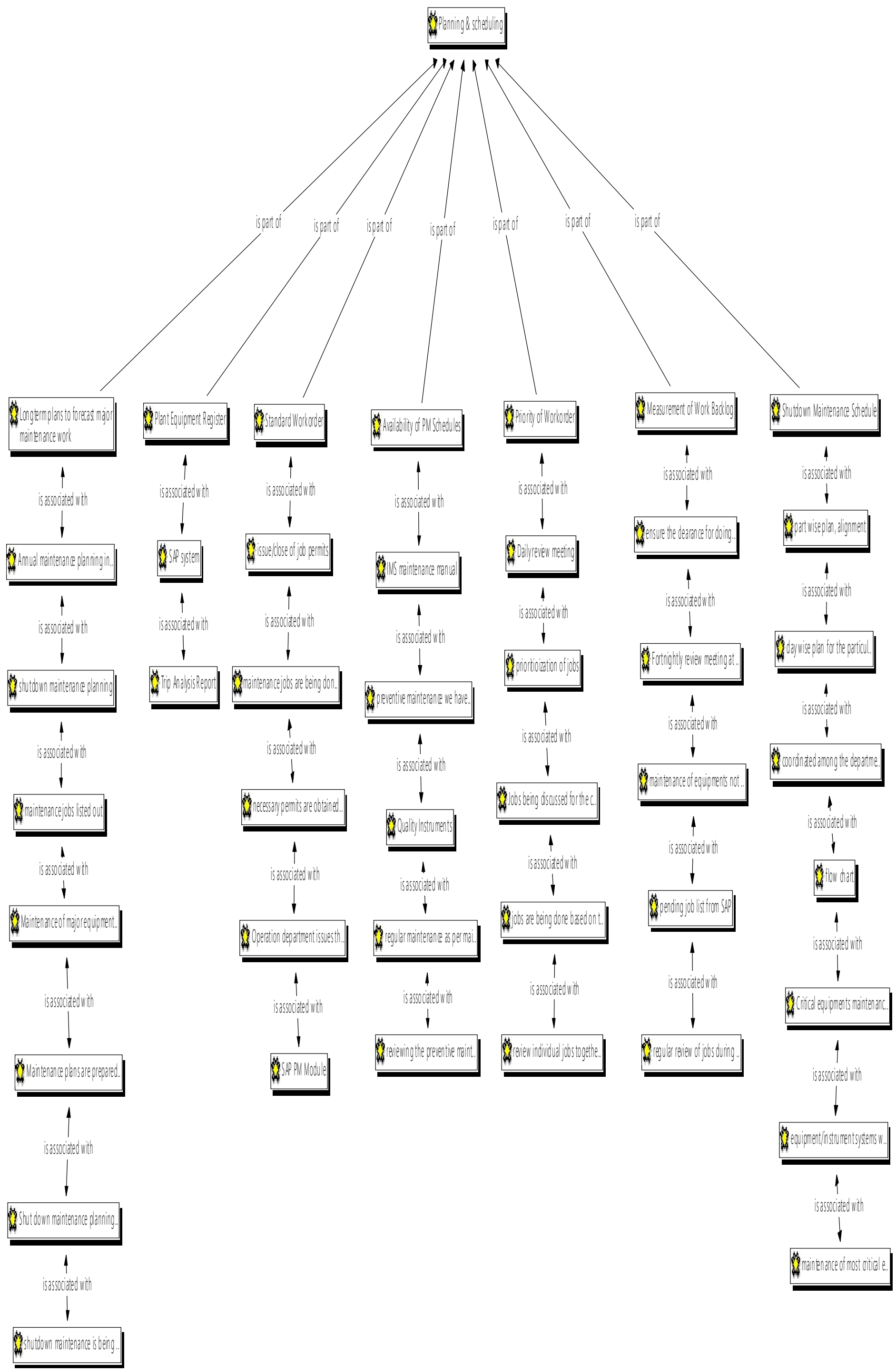


Figure 5.3 QAN for Planning & Scheduling

“...Quality Instruments are being taken to maintenance based on preventive maintenance schedules. And few instruments are also being sent to vendor site for calibration, service etc... In long run, if we do regular maintenance as per maintenance schedules then maintenance cost will be lesser.” – CM (O & M)

“...reviewing the preventive maintenance schedule by 20th of every month for betterment in maintenance function...”- DM (O & M)

“...Planning of maintenance is majorly to reduce the down time of the plant. To take care of this, the major aspects considered during planning of maintenance are manpower planning, prioritisation of jobs and closing of the jobs...” – CM (O & M)

“After discussion with operation/maintenance team at plant control room, we assemble at department level. Jobs being discussed for the current status then distributed to the individual employees. Therefore, the same is monitored during day in Shifts/ G-Shift as per requirement” – CM (O &M)

“Daily we get pending job list from SAP then we decide among our maintenance crew to whom will do which job. After lunch, we review individual jobs together for any requirement of resources such as spares, man power etc.” – DM (O & M)

As explained by the maintenance managers above, the maintenance records used for planning & scheduling such as plant equipment register, standard written work order, availability of PM schedules, priorities of work order, shut down maintenance schedule, and backlog maintenance jobs are being maintained in SAP-PM Module in SAP system installed in the company. Further, issues related to these factors are being reviewed in daily review meeting and accordingly jobs are prioritized and resource allocation is also done.

"Long term planning is being addressed by shutdown maintenance planning. Annual maintenance planning includes major overhauling & modifications job in the particular equipment/machine... Maintenance of major equipment which do not have stand-by will be done during shutdown maintenance"- CM (O&M)

"In my opinion, preventive maintenance should be strictly followed & compiled. Shut down maintenance planning should be done thoroughly and in advance. These will definitely help to improve maintenance practices in the organisation...Maintenance plans are prepared for the year and get it approved by HODs. Then, the same is taken up month wise. Further, if any deviation and the same is get it approved by HOD" – DM (O&M)

"Maintenance in petrochemical is not very simple. After achieving the MOU targets, shutdown maintenance is being planned every year. The maintenance jobs listed out for doing in shutdown maintenance is taken up during this plant shutdown. No surprise should come during equipment maintenance in performing annual shutdown maintenance. This could be achieved through proper planning based on predictive maintenance of that particular equipment"- SM (O & M)

The above quotations represented that in petrochemicals long term maintenance planning is majorly shutdown maintenance planning. Shutdown maintenance planning is being done by maintenance managers well in advance and the same is done for a year. The maintenance performance of petrochemicals is depending on the well execution of shutdown maintenance plan of the plant.

"...for Shutdown maintenance, we usually plan during month of April or May. We make through planning for shutdown maintenance...we get the flow chart which provides information that day wise plan for the particular equipment such as dismantling of machine, part wise plan, alignment etc. The jobs are being coordinated among the departments like mechanical, electrical &

instrumentation. Few jobs are department wise jobs which are required coordination among the departments. Such jobs are taken up individually department wise/unit wise" – DM (O& M)

"Critical equipment maintenance is linked to the annual maintenance shutdown. The maintenance of a particular machine has been decided by HODs in consultation with OEMs. OEM experts will be available to perform the maintenance during plant shutdown to take care of over hauling of a particular equipment" – SM (O & M)

"Those equipment/instrument systems which are critical for plant operation are kept in shut down maintenance scheduling. Suppose, if they have serious maintenance issue, the same has to be rectified by stopping plant operations by taking shutdown"- CM (O & M)

It is evident from the above quotations that in petrochemicals shutdown maintenance play a crucial role in performing maintenance of critical equipment which do not have stand-by equipment and further maintenance of instruments/equipment which cannot be carried out during normal operations of the plant. Therefore, shutdown maintenance schedule is important in planning & execution of shutdown maintenance jobs in an effective manner.

The findings from the case data related to these sub-constructs are also shown in Table 5.3.

Table 5.3 – Planning & Scheduling sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Planning & Scheduling	Plant Equipment Register	Planning & Scheduling	Plant Equipment Register	Equipment details are being maintained in SAP PM module; As part of plant equipment register

				breakdown records & reports and trip analysis reports are also being maintained in SAP system.
	Standard written work order		Standard written work order	Work orders are being maintained in SAP PM module based on ISO Schedules with the frequency of PM jobs planned. Automatic work orders are being generated based on schedule incorporated in the system.
	Availability PM schedules		Availability PM schedules	PM Schedules are available & the same are being maintained in SAP PM Module. PM Schedules are based on frequency & types of maintenance. These schedules are prepared based on OEM recommendations and are equipment specific.
	Priorities of work order		Priorities of work order	Work orders priorities are assigned and being maintained in SAP PM module. The same is based equipment history & criticality of the equipment and during review in daily and fortnightly review meetings.
	Availability of work schedule for a week ahead		Nil	Work schedules are being maintained in SAP PM module and can be accessed any point of time based schedule.
	Shutdown Maintenance Schedule		Shutdown Maintenance Schedule	Detailed shutdown maintenance schedule in the form of flow chart along with day wise jobs break up & department wise job list are being maintained by

				maintenance managers in petrochemicals processing plants.
	Measurement of work backlog		Measurement of work backlog	Backlog maintenance jobs are maintained in SAP PM module. The same is completed in the next available opportunity. Completion of backlog jobs is ensured with proper allocation of resources.
	Long Term Plans to forecast major shutdown/ maintenance work		Long Term Plans to forecast major shutdown/ maintenance work	In Petrochemicals, shutdown maintenance is a major part of the long term maintenance planning. It is well planned in advance and shutdown maintenance jobs are partly derived from the results of predictive maintenance systems.

5.3.3 Materials Management

Materials Management is a critical part in maintenance strategy formulation stage itself. The effective materials management will facilitate efficient implementation of maintenance strategies. A qualitative associative network which is the outcome of data analysis of interviews taken for Petrochemicals case study is presented below in Figure 5.4.

"Material inventory is managed by identifying obsolete parts of equipment/instrument systems. Therefore, material management in operation plant is that we are following regular review of spare parts & reassessment of requirement. Material availability affects the maintenance. Critical spare parts have been identified and their inventory is being maintained properly" – CM (O & M)

"Through SAP, we can monitor spare availability, budget consumption and slippages in preventive maintenance schedules"- Manager (O & M)

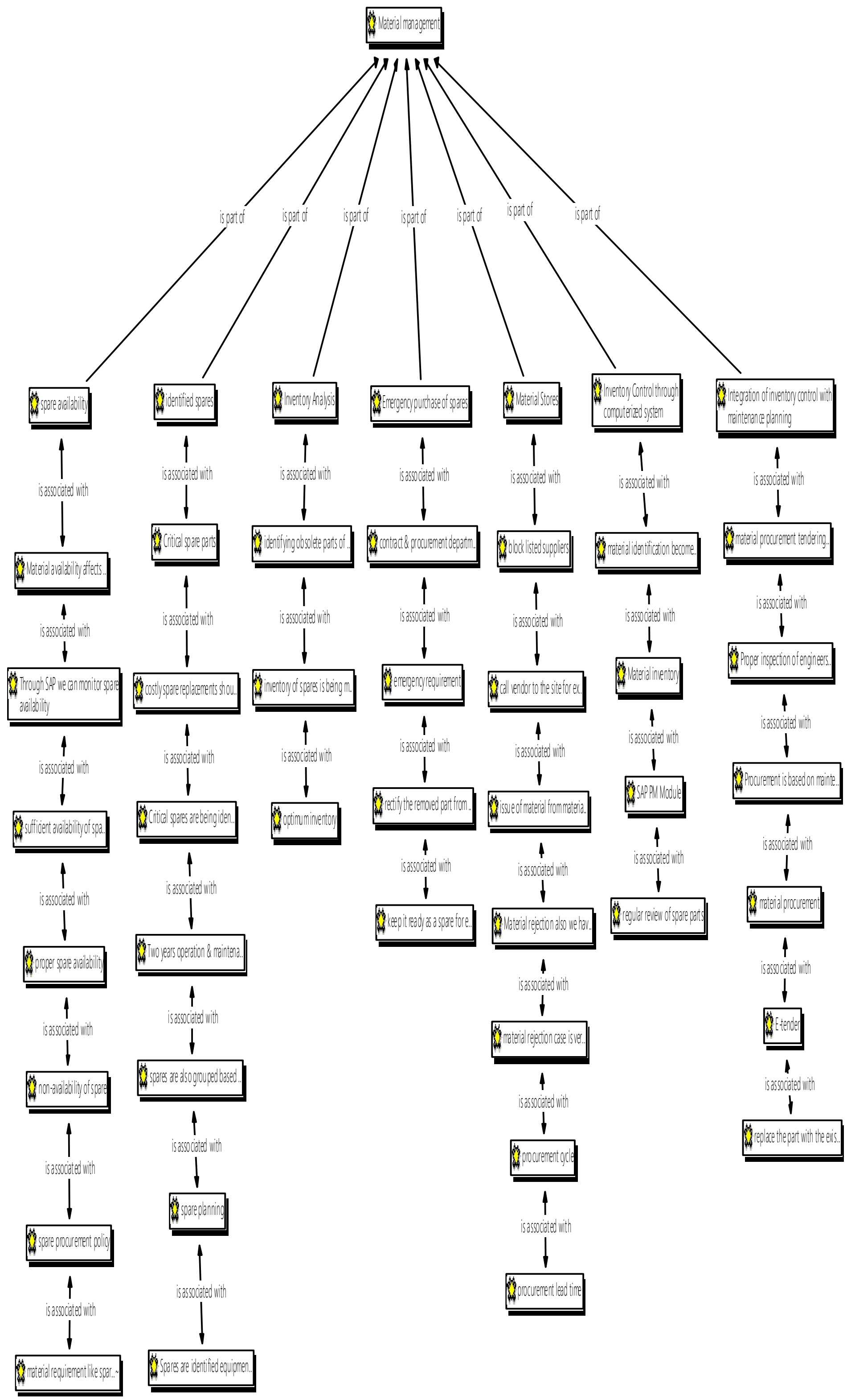


Figure 5.4 QAN for Materials Management

"By our virtue of experience and proper spare availability with the maintenance planning, we need to minimize the shutdown maintenance time" – SM (O & M)

"Material management is very important for performing maintenance function. We have spare procurement policy. Two years operation & maintenance spares are being maintained for all the critical equipment. Critical spares are being identified and such spares availability is ensured so that plant availability does not get affected due to spare availability. Procurement is based on maintenance policy" – SM (O & M-PC)

"Spares are identified equipment wise. All the identified spares are procured and the same is maintained at stock. After consumption, procurement action is initiated for replenishment of spares. This procurement cycle has been structured into process. So that inventory of spares is being maintained at optimum level. Further, these spares are also grouped based on model nos., types, etc. to keep optimum inventory. This reduces the problem of non-availability of spares" – DM (O & M)

In petrochemicals plant, availability of spares is being ensured by maintenance managers by periodic reviewing, reassessment of requirement, maintain proper inventory of critical spares, and spare procurement policy. All these processes are done using SAP system. Further, spares have been grouped based on technical specification so that optimum spares can be procured. Accordingly, optimum inventory can also be maintained. Inventory analysis of spares is being done using types of spares like critical, non-critical, and insurance spares. The same is maintained in SAP MM module (SAP Material Management).

"Basically any maintenance activity is well planned in our company. One of the factors in maintenance is procurement lead time of spares. We initiate the proposal at well early stage. Even if we have any emergency requirement, we have necessary Delegation of Powers to meet such emergency requirements of material, manpower etc."- Manager (O & M)

"In case of spare part requirement, we replace the part with the existing spare. Further, we rectify the removed part from the equipment and keep it ready as a spare for emergency use"- DM (O & M).

Emergency spare requirement is handled by maintenance managers using their delegation of powers such as imprest, contingent purchase, etc. as per Contracts & Procurement procedures of the company. Further, technically the repaired spare part is also kept for emergency use till the receipt of new spare at site.

"Material rejection also we have well- structured process and we call vendor to the site for explaining details about material rejection. But material rejection case is very less... One contract supervisor is nominated to perform coordination job in maintenance such as issue of material from material stores, allocation of jobs to workers, issue/close of job permits etc." - Manager (O & M)

"...material identification becomes easy through SAP system and we could trace required material wherever it is available. Secondly, we could also able to identify surplus spares availability available with other work centres" – DM (O & M)

"Material inventory is managed by identifying obsolete parts of equipment/instrument systems. Therefore, material management in operation plant is that we are following regular review of spare parts & reassessment of requirement" – CM (O & M)

"...while we are going for tendering, we do not have any procedure for avoiding lowest bidder based on quality. This becomes some time challenges while doing maintenance. This is mainly happening in material procurement tendering. In my view, there should be some Low cost cut should be there in tendering process... E-tender is introduced recently so that we can monitor the entire procurement cycle in the SAP Software only so that supplier interaction becomes more effective. Even supplier can view the procurement process information." – Manager (O & M).

From the above quotations from interview data and field observations at petrochemicals plant, the following are evident.

(i) Material stores are available in petrochemicals plant. The stores is responsible for series of activities like receipt of material, conducting inspection by concerned indenting department, once inspection is passed then store the material in proper place, in case of rejection of material then follow up with vendor for replacements, and keep track of inventory of material.

(ii) SAP system is implemented in petrochemicals plant. Therefore, SAP MM module is being used by contract & procurement personnel to keep track of all the above activities and inventory analysis. Inventory analysis is being done based on non-moving items during last 3 years in coordination with the concerned indenting department.

(iii) Maintenance managers are using SAP PM Module for keep tracking of all maintenance activities. C & P managers are using SAP MM Module for keep tracking of contracts and procurement related activities. However, both these modules are well integrated. Therefore, inventory control in line with maintenance planning is possible. It is evident from interview data & informal discussion show that some extent tools available in SAP are being used by GAIL managers but it is required to exploit further.

The case study data along with empirical findings are clearly discussed and depicted in the below given Table 5.4.

Table 5.4 – Materials Management sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Materials Management	Spare parts availability	Materials Management	Availability of Spares	Spares availability is ensured by spare procurement policy and identification of critical spares. Inventory of spares is being monitored periodically using SAP system in order to maintain proper inventory level.
	Reordering of consumables/identified spares		Identified Spares	All the spares have been identified as routine maintenance spares, insurance spares, and critical spares and the same is being maintained by C & P Department at Stores.
	Inventory Analysis		Inventory Analysis	Inventory analysis is being done based on equipment history, spares stock position and identification of non-moving items on annual basis and being maintained in SAP system Materials Management module.
	Emergency purchase of spares		Emergency purchase of spares	Emergency purchase procedures are available with C & P department such procedures are imprest, contingent, and nomination purchase. The same is being done by maintenance department

				in coordination with C & P Department as per procedures. *Further, technically the repaired spare part is also kept for emergency use till the receipt* of new spare at site.
	Average Inventory Turnover		Nil	No evidence of following "Average Inventory Turnover" concept in the company
	Inventory control through computerised system		Inventory control through computerised system	Inventory control is being monitored through SAP system by Stores & concerned maintenance department.
	Availability of stores		Material Stores	Material Stores is available in the petrochemicals plant. The stores department is responsible for receipt of material, conducting inspection along with concerned indenting department, storage in proper place, issue of material as and when required, keep tracking of inventory, rejections, and replacements of material.
	Integration of inventory control with maintenance planning		Integration of inventory control with maintenance planning	Inventory control with maintenance planning is being integrated through SAP-MM Module and SAP- PM Module in SAP system. The same is being monitored by C & P department and Stores. On regular basis notification are being sent

				to concerned maintenance managers/ Engineer-in-charges regarding inventory of spares.

5.3.4 Human Resources

In petrochemicals plant also Human Resources (HR) function plays a critical role in the gas utility company. In maintenance function, experienced engineers who can able to trouble shoot maintenance problem quickly will be an important HR factor in performing the best maintenance practices. The data analysis outcomes is shown in the below given Figure 5.5 qualitative associative network. The network components such as focused codes and categories are discussed in detail below by presenting representative quotations from the interview data collected. Further, the same is also summarised in Table 5.5.

"...where our maintenance jobs are being done by in-house maintenance crew, the maintenance cost is Cost To Company/employee"- CM (O&M)

"Our unit is headed by General Manager and Deputy General Manager is looking after Operations & maintenance of the processing plant. Ours is the functional organisations. Therefore, various functions are divided into departments like mechanical, electrical, instrumentation. These departments are headed by Senior Manager/ Chief Manager Level. The maintenance organisation provides specialised functional departments so that jobs pertaining to function like mechanical are being done with the specialist in this area. At corporate level Director (Projects) is over all in-charge of processing plant. Further, Executive Director is the interface between corporate and plant head GM.... Since it is functional organisation, maintenance personnel only performs the maintenance jobs" – SM (O & M –PC)

From the above quotations from interview and other documentary evidences, it is evident that the maintenance staff level existing in petrochemicals unit such as non-executives and executives. Non-executives are like foreman, supervisors, technicians, etc. Executives are like engineers, managers, general managers, etc. There is proper maintenance organisation structure is available at unit level and also at corporate level of the company.

"...Daily we get pending job list from SAP then we decide among our maintenance crew to whom will do which job. After lunch, we review individual jobs together for any requirement of resources such as spares, and man power etc." – DM (O & M).

"...There should be cordial relation among maintenance technicians, engineers and managers. Each and every aspect of the maintenance activity should be discussed before execution of the maintenance activity" – SM (O & M).

"We have maintenance man power benchmarks at corporate level. HRD department is having man power data and the same is communicated to individual unit for further planning. We do not have documentation with unit level. But the corporate guidelines are available" – Manager (O & M).

Adequacy of staff has been ensured at corporate level. HRD department is ensuring the manpower availability to support maintenance function in the gas utility company in order to provide manpower for petrochemical plant operations & maintenance on 24 X 7 Basis.

"Training is very important for performing maintenance function. One is on the job training. Another one is HOD is continuously evaluating the training requirements of their employees. The training needs are captured through structured reporting system. GAIL training institute is capable to organize all the technical requirements of maintenance personnel" – SM (O & M PC).

"On-job training is an important aspect in maintenance. One training per employee is given on functional side to each and every employee by the organisation" – CM (O & M)

“...Specific technical training helps engineers to perform their jobs more effectively and efficiently. Few more technical trainings may be included” – DM (O & M)

In the gas utility company, there is a structured process existing in training need identification and execution of training programs. GAIL Training Institute is the corporate training centre, which is responsible for providing training to employees of the company. Maintenance mangers have emphasized for more focused technical training programs for engineers in petrochemicals plant and on-the-job training programs.

“One contract supervisor is nominated to perform coordination job in maintenance such as issue of material from material stores, allocation of jobs to workers, issue/close of job permits etc.”- Manager (O & M).

“Job contractor are regularly interacting with our maintenance team. Sometimes they could not understand the requirement of maintenance in the contract. They took contractors by simply quoting lesser amount, then while performing the job actual they face problem to satisfy our job requirement. So, simply they tell our margin is getting affected. We take appropriate action as per contract. This happens some time, we faced this type of problem in past. But, they have been rectified during next time when work is awarded” – CM (O & M)

Manpower for maintenance jobs are being hired through contracts due to lean power of GAIL. Therefore, quality of manpower supplied by contractor is to be ensured. Many times, contract manpower did not turn up during important/critical maintenance jobs. This makes constraint while doing maintenance.

It is evident from the representative quotations from maintenance managers of petrochemicals plant that the contract manpower is being deployed regularly to perform maintenance jobs. However, maintenance managers face problems like quality of manpower, shortage of manpower, proper technical understanding of job by contract manpower, etc. due to contracts & procurement procedure of selection of contractors & attrition of experienced manpower etc.

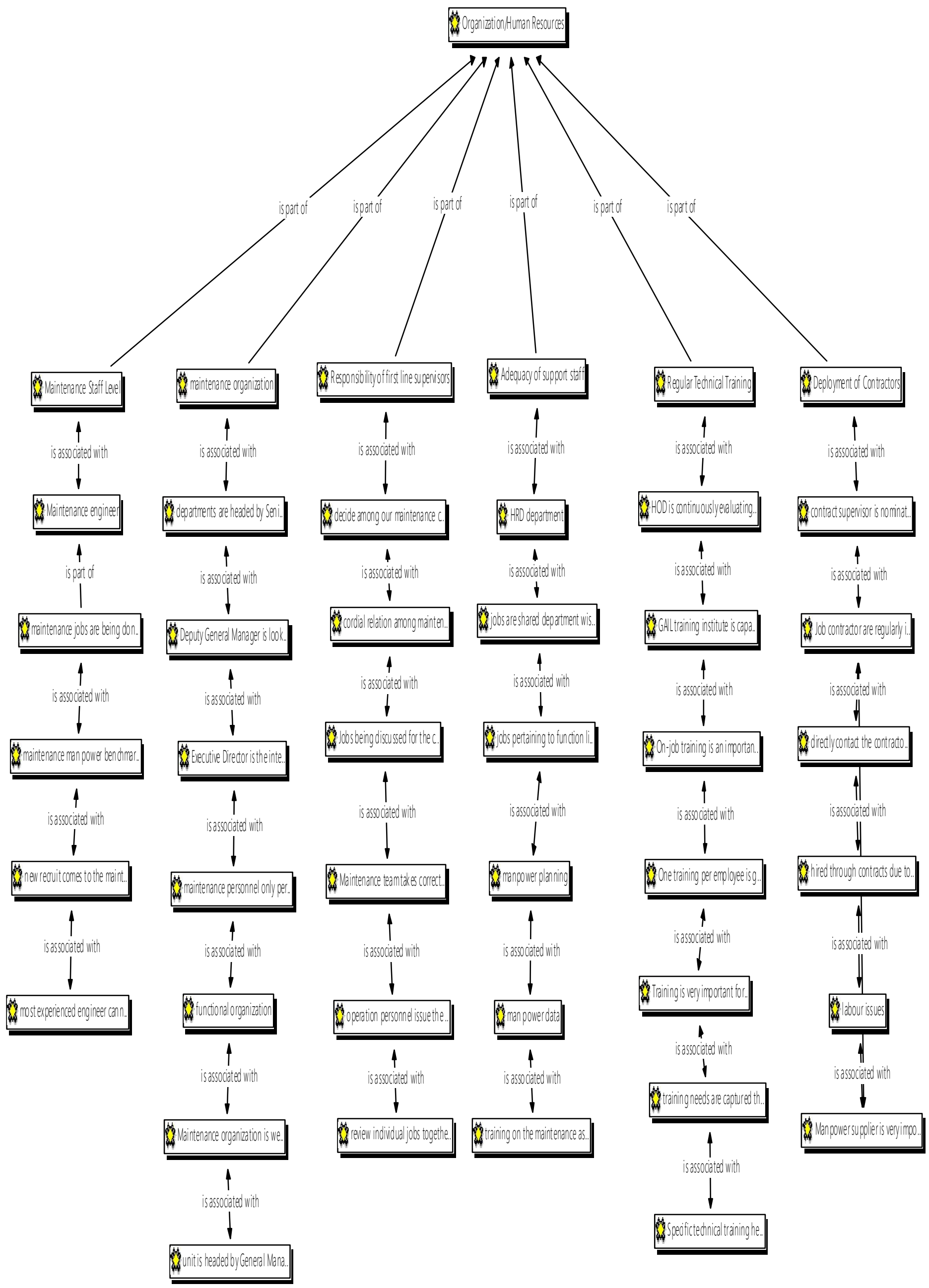


Figure 5.5 QAN for Organisation/Human Resources

Table 5.5 – Organisation/Human Resources sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Organisation/ Human Resources	Maintenance Staff Level	Organisation/ Human Resources	Maintenance Staff Level	Maintenance Staff level exists in petrochemicals plant such as non-executives and executives who take care of maintenance function at unit level of the plant. There is a separate maintenance group at corporate level also.
	Maintenance Organisation		Maintenance Organisation	It is evident from the interview data that well Structured maintenance organisation structure exists in petrochemicals plant of the gas utility company.
	Responsibility of first line supervisors		Responsibility of first line supervisors	Supervisor responsibilities are well defined & they are responsible for execution of day- to-day jobs of their concerned departments and update the job status in SAP system.
	Adequacy of Support staff		Adequacy of Support staff	Support staff is adequate and maintenance personnel are coming in shifts to ensure 24 X 7 basis monitoring & maintenance and for emergency handling

				manpower is also kept in standby.
	Regular Technical Training		Regular Technical Training	Technical training is being imparted to the employees in the structured manner including safety training. However, maintenance managers have emphasized on more focused technical trainings and on-job training of maintenance engineers in petrochemicals plant.
	Apprenticeship program		Nil	No evidences from interview data. However, from company secondary data Apprentice program is available as per statutory requirements.
	Deployment of Contractors		Deployment of Contractors	The company is regularly deploying contract manpower including expert manpower from OEMs etc. for performing routine planned maintenance jobs and also for breakdown/shutdown jobs. Maintenance managers face problems such as poor quality of contract manpower, shortage of manpower, etc.

5.3.5 Information Technology

Maintenance strategy formulation leverages the information technology for effective formulation of maintenance strategies in petrochemicals maintenance. All the sub-constructs related to information technology identified through literature reviews have been emerged out from our case study-2. The same is displayed in the qualitative associative network Figure 5.6 which is developed through Atlas-Ti software.

"...for critical equipment like Gas Turbine, compressors etc., machine healthiness parameters such as vibration, temperature etc. are being monitored through Distributed Control System (DCS) on real time basis i.e., 24 X 7 basis with historical trends" – SM (O & M –PC)

"...We use SAP system for planning maintenance system. All the maintenance schedules along with task list to be performed in the equipment are built-in with SAP system. Accordingly, work orders are being issued and necessary permits are obtained from operations personnel for performing that particular maintenance... SAP system is having beautiful tools. Through SAP, we can monitor spare availability, budget consumption and slippages in preventive maintenance schedules. IT is being well leveraged in our company like communication facility, SAP system etc." – Manager (O & M)

"Information Technology is being leveraged with many systems such as Supervisor Control and Data Acquisition System (SCADA). Further, IT is being used for MIS purpose, online monitoring purpose using Distributed Control System (DCS). Wireless transmitters are being implemented for capturing the process parameters for monitoring plant operation" – CM (O&M)

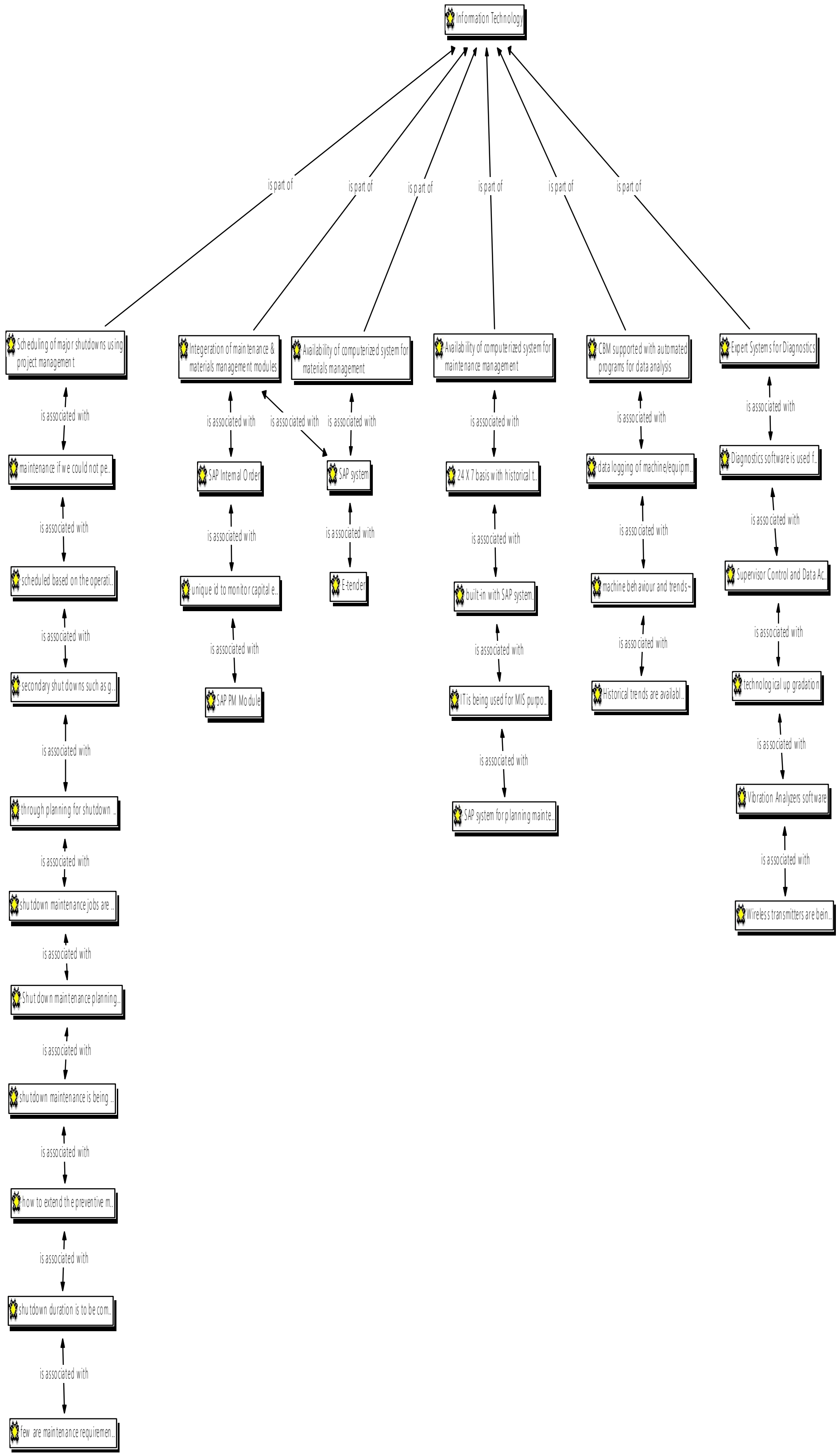


Figure 5.6 QAN for Information Technology

“Information Technology has been leveraged through SAP PM Module. Maintenance planning, work intimation, spare planning etc. is being done through SAP system. Vibration Analysers software is available and the same is done by external experts. The deviation and abnormality is intimated by these experts through reports” – SM (O & M)

“E-tender is introduced recently so that we can monitor the entire procurement cycle in the SAP Software only so that supplier interaction becomes more effective. Even supplier can view the procurement process information” – Manager (O & M)

It is evident from the above representative quotation collected from interview of maintenance managers of Petrochemicals plant of gas utility company that SAP system has been implemented in the plant. SAP- PM Module is performing all the tasks related to maintenance function such as planning, scheduling and execution of maintenance works in the plants. Similarly, SAP-MM Module is performing all the tasks related to material management function such as spare procurement, stores management, inventory control, etc.

Both of these modules PM and MM are integrated well to perform all intermediate functions between maintenance and materials management function.

“...we are doing data logging of machine/equipment on real time basis to keep record of healthiness of that equipment... Parameters measured are vibration, temperature etc. Historical trends are available... Information Technology is being leveraged with may systems such as Supervisor Control and Data Acquisition System (SCADA). Further, IT is being used for MIS purpose, online monitoring purpose using Distributed Control System (DCS). Wireless transmitters are being implemented for capturing the process parameters for monitoring plant operation.” – CM (O & M)

"Predictive maintenance is based on experience, collection of data & analysis of equipment parameters like vibration, temperature etc., and machine behaviour and trends" – SM (O&M-PC)

"Diagnostics software is used for predictive maintenance. This software is integrated with centralised monitoring system Distributed Control System (DCS)" – DM (O & M)

In petrochemicals, expert system such as DCS (Distributed Control System), intelligent vibration systems and other diagnostics software are used for condition based monitoring of all equipment and process system. The case study data along with empirical findings are clearly discussed and depicted in the below given Table 5.6.

Table 5.6 – Information Technology sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Information Technology	Availability of computerised system for maintenance management	Information Technology	Availability of computerised system for maintenance management	Maintenance planning& scheduling and execution of maintenance work orders are being done through SAP PM Module in SAP system for petrochemicals plant.
	Availability of computerised system for materials management		Availability of computerised system for materials management	Petrochemicals O & M team is using SAP- MM module for material procurement, spares management, stores management and inventory analysis & control.
	Integration of maintenance & materials		Integration of maintenance & materials	In Petrochemicals of the gas utility company SAP-MM & SAP-PM Modules

	management modules Scheduling of major shutdown using project management system		management modules Scheduling of major shutdowns using project management system	have been integrated for effective implementation of maintenance strategies.
	CBM supported with automated programs for data analysis		CBM supported with automated programs for data analysis	Real Time condition monitoring systems such as vibration monitoring systems, diagnostics software and integration of such expert systems with centralised control & monitoring system namely Distributed Control System (DCS) are available in Petrochemicals plant.
	Expert Systems for diagnostics		Expert Systems for diagnostics	Distributed Control Systems (DCS), Vibration software systems are available. Historical and real time trends of process parameters are available for trouble shooting and improved operations of petrochemicals plant.
	Scheduling of major shutdowns using project management		Scheduling of major shutdowns using project management	

5.3.6 Employee Empowerment

The qualitative associative network developed through Atlas-Ti software for construct employee empowerment is shown in the below given Figure 5.7.

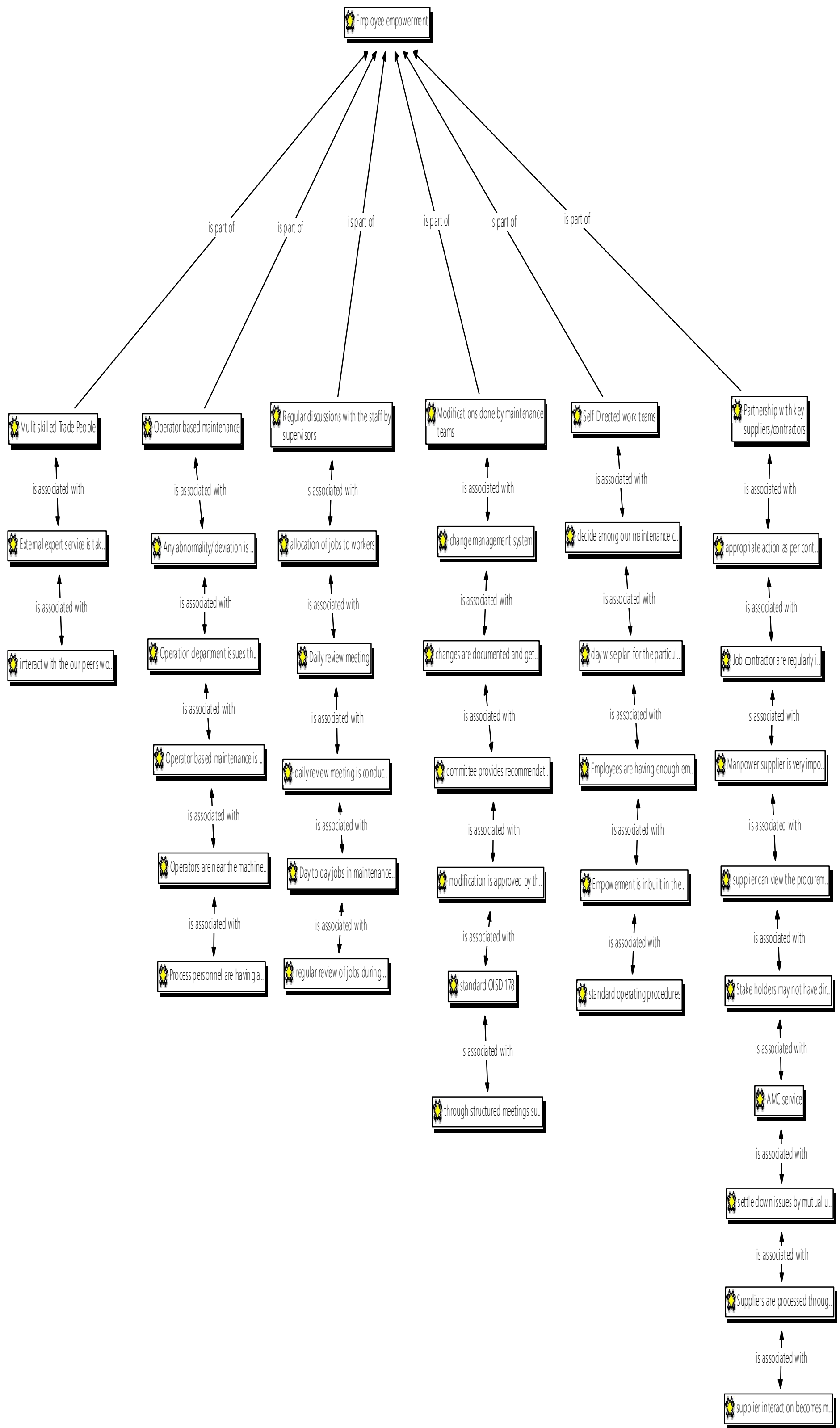


Figure 5.7 QAN for Employee Empowerment

“External expert service is taken from Original Equipment Manufacturers (OEM) where we do not have much expertise on particular machine/instrument/equipment”- CM (O & M)

“Operator based maintenance is prevailing in petrochemicals. Operators are near the machinery and therefore any in machine behaviour is being noticed by operators only. Any abnormality/ deviation is informed by operators to maintenance personnel” – SM (O & M)

“Operator based maintenance is not there in GAIL. Operation department issues the permit and the required jobs are being done by maintenance department”- DM (O & M)

“Operator based maintenance is not available. Process personnel are having authority to hand over the maintenance job to maintenance team. Therefore, they have to ensure proper stoppage of machine and utilities and ensure the clearance for doing the specific maintenance job. Operation personnel are taking care of two things one is plant operations is not getting affected due to performance of maintenance job and ensure safety aspects such as depressurization of fluid lines, isolation of valves, isolation of electrical systems, provision of fire equipment & fire personnel etc.” After ensuring the same only, operation personnel issue the work permit to maintenance personnel- Manager (O &M)

“...Since it is functional organisation, maintenance personnel only performs the maintenance jobs. Operator based maintenance is not existing. However, the operators are monitoring the plant continuously so they report abnormalities/deviations to maintenance group. Maintenance team takes corrective actions” – SM (O & M – LPG)

“Operator based maintenance is not being practices in GAIL. This maintenance culture may be implementing in GAIL”- CM (O&M)

It is evident from the above representative quotations that the operator based maintenance is not being practiced in petrochemicals plant as observed in all the maintenance managers except one. However, the meaning of his description is that the operators are only observing the problem with the machine and informing to maintenance crew and issuing permit to perform work. Maintenance job is being treated as specialised job by maintenance technicians/engineers in their respective discipline such as instrumentation, mechanical, electrical, etc.

“Interaction with maintenance supervisors is being done through day-to-day jobs planning. One contract supervisor is nominated to perform coordination job in maintenance such as issue of material from material stores, allocation of jobs to workers, issue/close of job permits etc. If any situation arises that is beyond supervisor level, we directly contact the contractor to mitigate such issues”- Manager (O & M)

“Interaction with maintenance supervisors is being done through structured meetings such as Daily Review meeting at working level. Most of the problems are attended in early stage. Fortnightly review meeting at HOD level is being conducted to take care of resource issues like material procurement, man power etc.” – SM (O&M-PC)

“...Interaction with supervisors/ maintenance teams is being done by Daily review meeting. After discussion with operation/maintenance team at plant control room, we assemble at department level. Jobs being discussed for the current status then distributed to the individual employees. Therefore, the same is monitored during day in Shifts/ G-Shift as per requirement” – CM (O & M)

“Interaction with maintenance supervisors is very much important. It is not that mere allocation of the job to technicians will not be good maintenance practice. There should be cordial relation among maintenance technicians, engineers and managers. Each and every aspect of the maintenance activity should be discussed before execution of the maintenance activity" – SM (O & M).

As described above by maintenance managers, it is clear that there are regular & structured discussions are being done by staff with supervisors through planned interventions like daily meeting, job distribution during morning hours & review by end of the day. Further, informal discussions with individuals are also being practiced by the maintenance managers in petrochemicals plant.

"Daily we get pending job list from SAP then we decide among our maintenance crew to whom will do which job. After lunch, we review individual jobs together for any requirement of resources such as spare, man power etc."- DM (O&M)

"Maintenance modification is judged for techno-commercial viability by multi-functional committee. Then committee recommends the proposal to the competent authority for approval. There is a process of change management system. Documentation are also updated accordingly" – Manager (O &M)

"...Maintenance modification is done with the well- structured procedure Change management system. Guidelines for the same are from the standard OISD 178. Any modification is approved by the Officer in-charge. HAZOP analysis is done by the multi- functional team for studying the proposed modification. Then committee provides recommendations. Post review modification is also reviewed by operation in-charges" – SM (O&M-PC)

"For modifications in maintenance, we have a policy called as Change management system. Same is reviewed by multidisciplinary committee and recommended for approval by Competent Authority. After approval, the jobs are shared department wise and completed accordingly. Structured maintenance system is available"- CM (O & M)

“Maintenance modification is done by individual initiative. For example, we face a technical problem in Gas turbine bleed valve. I proposed to introduce bleed valve feedback interlock with speed increase of Gas turbine. The same was sent through Change management system to central engineering cell. After necessary approval, the modification was implemented” – DM (O & M)

As described by maintenance managers, in petrochemicals there is a well-structured & documented change management system procedure available for performing modifications jobs which is duly approved by multi-disciplinary committee & Competent Authority. Accordingly, modifications are being carried out by maintenance personnel & documented.

“Job contractor are regularly interacting with our maintenance team. Sometimes they could not understand the requirement of maintenance in the contract. They took contractors by simply quoting lesser amount, then while performing the job actual they face problem to satisfy our job requirement. So, simply they tell our margin is getting affected. We take appropriate action as per contract. This happens some time, we faced this type of problem in past. But, they have been rectified during next time when work is awarded ... Supplier is getting benefitted in maintenance. Manpower supplier is very important aspect of maintenance. We need plan early & proper planning of manpower enables the supplier to support with proper manpower” – CM (O&M)

“E-tender is introduced recently so that we can monitor the entire procurement cycle in the SAP Software only so that supplier interaction becomes more effective. Even supplier can view the procurement process information... Suppliers are processed through Vendor Rating system, block listed suppliers, etc. is available in our GAIL Intranet. Maintenance decisions are influenced with such data regarding selection of suppliers...” – Manager (O&M)

“Stake holders may not have direct impact due to maintenance. But, maintenance is the deciding factor for the product quality and quantum.

Contractors are playing a very crucial role in maintenance. Their role should be limited to" – SM (O & M)

From the above quotations from maintenance managers and the documentary evidences show that there is well documented procedures are available such as Delegation of Powers and Contracts & Procurement (C & P) procedure which facilitate the partnership with suppliers. Therefore, contractors & suppliers are playing crucial role in executing the maintenance strategies planned. The case study data along with empirical findings are clearly discussed and presented in the below given Table 5.7.

Table 5.7 Employee empowerment related sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Employee Empowerment	Multi skilled trade people	Employee Empowerment	Multi skilled trade people	Multi skilled people are being developed in petrochemicals plant. They are being given training in various skills such as fire & safety, security to handle the emergency situation in the plant.
	Operators based maintenance		Operators based maintenance	OBM is not being followed in petrochemicals. Interview data is emerging clearly that operator is responsible for issuing work permits & to bring the equipment problems/failures to the knowledge of

				maintenance crew.
	Regular discussions with the staff by supervisors		Regular discussions with the staff by supervisors	Formal interactions such as daily review meeting, job distribution, etc. & informal interactions as and when required are being practiced by maintenance managers with the supervisors in petrochemicals plant.
	Self-directed work teams		Self-directed work teams	Maintenance teams are self-directed. Evidences are there such as adopting safety norms, ready with emergency work plan, etc.
	Minor modifications done by maintenance teams		Modifications done by maintenance teams	Modifications are being carried out by maintenance managers/engineers with the structured process of "Change Management System" exist in the company.
	Partnership with key suppliers/contractors		Partnership with key suppliers/contractors	Well defined & documented Delegation of Powers and Contracts & Procurement procedures are facilitating the partnership with key suppliers/contractors.

5.3.7 Maintenance Tactics

Interview data has been analysed through Atlas-Ti software. Maintenance Tactics has been emerged out as a category and data analysis outcome is qualitative associative network as shown in Figure 5.8

“We are basically using preventive maintenance, predictive maintenance and particularly in processing plant, we use shut down maintenance. As I already told to you, maintenance of most critical equipment is planned during annual shut down maintenance” – Manager (O &M)

“Apart from this, predictive maintenance is also being following in process plant. For example, for critical equipment like Gas Turbine, compressors etc., machine healthiness parameters such as vibration, temperature etc. are being monitored through Distributed Control System (DCS) on real time basis i.e., 24 X 7 basis with historical trends... Predictive maintenance is based on experience, collection of data & analysis of equipment parameters like vibration, temperature etc., and machine behaviour and trends.. We sought guidance from OEM for maintenance planning & formulating the maintenance schedules. We also take recommendations from OEM for specific maintenance problem identified in predictive maintenance also” – SM (O & M-PC)

“Another maintenance strategy is Predictive maintenance i.e., condition based maintenance. For that we are doing data logging of machine/equipment on real time basis to keep record of healthiness of that equipment. Parameters measured are vibration, temperature etc. Historical trends are available” –CM (O & M)

As described by maintenance managers with reference to above quotations, *predictive maintenance is used in petrochemicals maintenance*. The key observations from interview data and field observations are,

- Predictive maintenance is majorly used for critical equipment such as compressors, gas turbines, etc. All equipment parameters are logged in intelligent computerised systems such as Distributed Control System (DCS) and other specific systems to monitor equipment parameters for keeping healthiness of equipment in good condition.

- Predictive maintenance planning & execution is based on maintenance managers' experience, data analysis, analysis of historical trends and OEM recommendations.

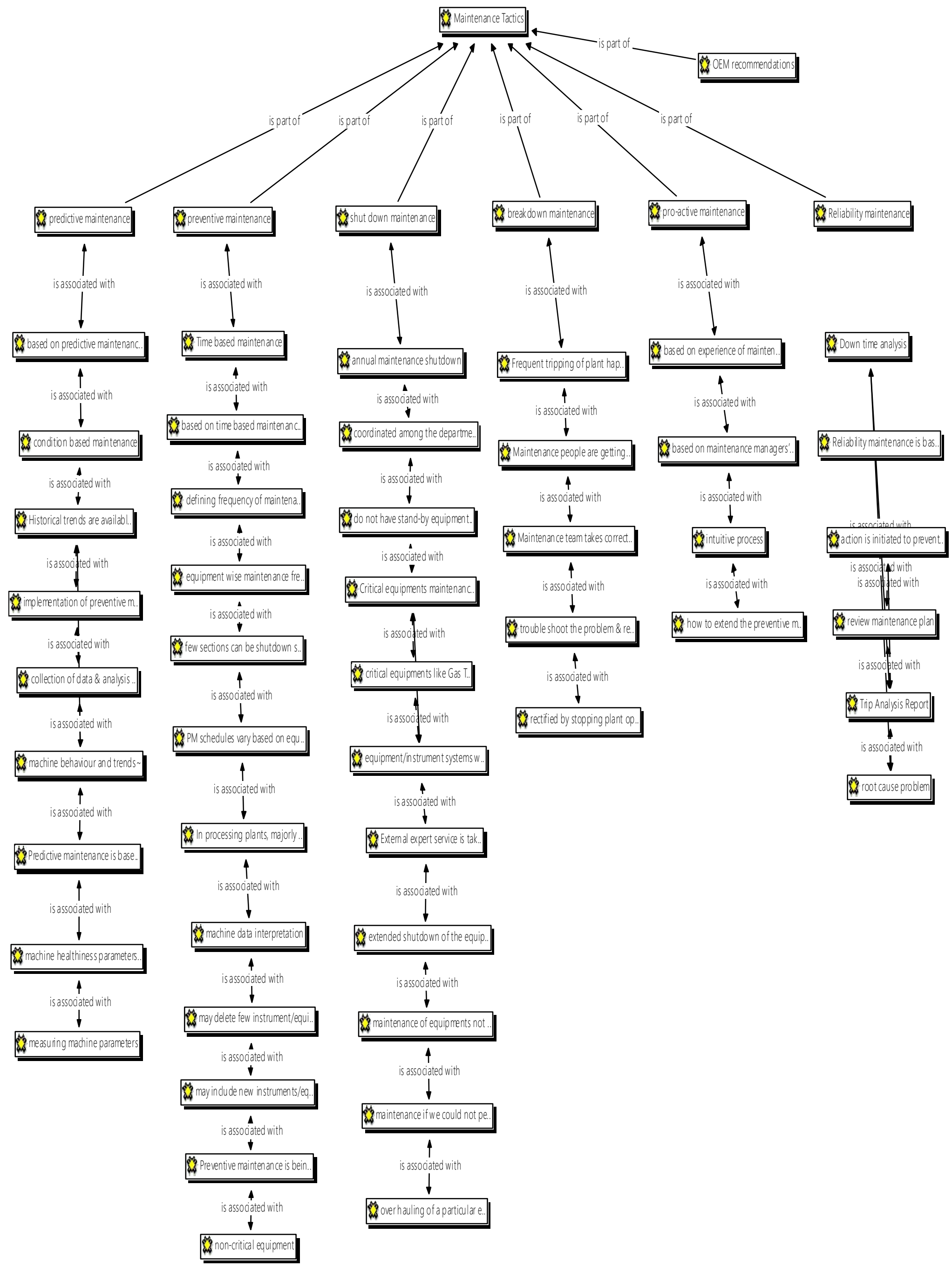


Figure 5.8 QAN for Maintenance Tactics

“Maintenance methods are preventive maintenance, predictive maintenance and break down maintenance. 98 % is of preventive maintenance are based on preventive maintenance schedules. Based on these schedule maintenance is being plant in plant operations” – SM (O & M-PC)

“...My unit is processing plant. Maintenance objective of this unit is ensuring 95% availability of plant. For achieving this target, we are having different maintenance strategies. One of the maintenance strategies is Preventive maintenance. i.e., Time based maintenance... Preventive maintenance is used for stand-by equipment. So that one machine maintenance can be done, while other machine is running.” – CM (O&M)

“Maintenance methods are being practiced in petrochemicals is preventive maintenance, predictive maintenance and breakdown maintenance. Preventive maintenance is being used to reduce the downtime and to ensure no problem arises due to equipment/system failure... The equipment/instrument systems are classified into 3 categories such as critical, quality and normal systems. Accordingly, maintenance is being followed by defining frequency of maintenance in preventive maintenance schedules... The equipment/instrument systems are classified into 3 categories such as critical, quality and normal systems. Accordingly, maintenance is being followed by defining frequency of maintenance in preventive maintenance schedules” – DM (O & M)

“...We have to reduce the breakdown of the equipment with the available resources and time. To achieve this objective, we follow the maintenance methods such as preventive maintenance, predictive maintenance and shutdown maintenance. One more type of maintenance is pro-active maintenance, which does wonder for maintenance in process plants. Preventive and predictive maintenance are the existing practices available in most of the processing plants and they have documentation and records” – SM (O &M)

"PM schedules vary based on equipment/process areas such as LG compressor, Gas Sweetening unit, C3/C4 recovery unit, IG Compressor, IA compressor etc. We take permits month wise to do preventive maintenance as per schedule" – DM (O & M)

As described by maintenance managers with reference to above quotations, *preventive maintenance is used in Petrochemicals maintenance*. The key observations are,

- Preventive Maintenance method is largely used in petrochemicals to achieve the plant availability of 95% in a year.
- Preventive Maintenance planning & execution is based on preventive maintenance schedules. These schedules are prepared on types of equipment, criticality of equipment such as critical, quality, and normal, OEM recommendations, and previous experience of maintenance managers.
- No specific category of preventive maintenance was told by maintenance managers during interview. However, during field observations it is found that these preventive maintenance schedules jobs can be categorised department wise such as mechanical, electrical, and instrumentation.
- Preventive maintenance schedules are included in ISO procedure and ISO system. Completion of PM schedules ensured through ISO internal audits & external audits.

"Maintenance in petrochemical is not very simple. After achieving the MOU targets, shutdown maintenance is being planned every year. The maintenance jobs listed out for doing in shutdown maintenance is taken up during this plant shutdown. No surprise should come during equipment maintenance in performing annual shutdown maintenance. This could be achieved through proper planning based on predictive maintenance of that particular equipment" – SM (O & M)

“...One more maintenance method is shutdown maintenance. Maintenance of major equipment which does not have stand-by will be done during shutdown maintenance... Long term planning is being addressed by shutdown maintenance planning. Annual maintenance planning includes major overhauling & modifications job in the particular equipment/machine.” – CM (O &M)

“...Shutdown maintenance is the maintenance if we could not perform during running of the plant/equipment. Such equipment maintenance is taken up during shutdown maintenance. The list of the shutdown maintenance jobs are listed out & also scheduled based on the operation requirement, and few are maintenance requirement. For example, we do maintenance of critical valves during maintenance by dropping them and checking passing of these valves...”- DM (O & M)

It is evident from above representative quotations from maintenance managers that shutdown maintenance is a crucial maintenance method used in petrochemicals plant. Shutdown maintenance is a long term maintenance planning method and it is planned in well advance and jobs are being reviewed & updated before start of shut down maintenance. In petrochemicals, critical equipment do not have stand-by equipment, therefore, major overhauling of these equipment are planned during annual shutdown maintenance.

“Breakdown maintenance is maintenance being done during break down of the particular equipment/ plant. During break down maintenance, we trouble shoot the problem & rectify the failure. In case of spare part requirement, we replace the part with the existing spare. Further, we rectify the removed part from the equipment and keep it ready as a spare for emergency use...Frequent tripping of plant happened i.e., 14 times during last year. The same was analysed and found that the root cause problem was level switch of separator. Then we included the level switch in monthly preventive maintenance schedule. After monitoring regularly, plant tripping improved this year. Further, to ensure smooth operation we do regular maintenance, modification and upgradation of systems...” – DM (O & M)

“...Those equipment/instrument systems which are critical for plant operation are kept in shut down maintenance scheduling. Suppose, if they have serious maintenance issue, the same has to be rectified by stopping plant operations by taking shutdown...”- CM (O & M)

“...Un-avoidable circumstances, we face break down maintenance. But, we ensure to minimize such kind of break down maintenance at unit level & also in department level...”- Manager (O& M)

“....One more type of maintenance is pro-active maintenance, which does wonder for maintenance in process plants. Preventive and predictive maintenance are the existing practices available in most of the processing plants and they have documentation and records. But, pro-active maintenance is the type of maintenance which is based on experience of maintenance personnel. This is not having documentation or records. But, it can be done. It may help to achieve 100% availability of the plant...” – SM (O&M)

As described of maintenance managers, even after following preventive and predictive maintenance methods to minimize the breakdown maintenance, still they face breakdown maintenance during normal plant operations. Such kind of maintenance are taken care by maintenance crew so as to start plant operations at the earliest after rectifying the problem. The case study data along with empirical findings are clearly discussed and depicted in the below given Table 5.8.

Table 5.8 Maintenance Tactics sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Maintenance Tactics	Use of Condition Based Maintenance (CBM)	Maintenance Tactics	Predictive Maintenance (CBM)	Predictive maintenance method is being practiced in petrochemicals. Predictive maintenance is based on equipment type, criticality and previous experience of maintenance managers, OEM recommendations, and data analysis from expert predictive analysis systems.
	CBM is favoured over Time Based Maintenance (TBM)		Nil	Predictive Maintenance (CBM) & preventive maintenance (TBM) both are used in petrochemicals based equipment classification such as critical, semi-critical & Non-critical. However, Preventive Maintenance is largely used to ensure 95% plant availability.
	Total maintenance man hours devoted to Preventive/Predictive maintenance (PM)		Preventive Maintenance (TBM)	Preventive Maintenance method is being practiced in petrochemicals plant of the company. Preventive Maintenance procedures/schedules are prepared based on OEM recommendations,

				OEM manual, equipment types & history, recommended standards for the system, and previous experience by maintenance managers.
	Compliance of PM Schedules		Nil	PM Schedules are included in ISO Schedules/ ISO Procedures. Timely completion of PM schedules is being ensured through ISO internal/external audits. PM Schedules are also being reviewed by the company on annual basis.
	OEM recommendations for an equipment regarding PM		OEM Recommendations	OEM recommendations are used to prepare preventive maintenance schedules and predictive maintenance systems & procedures for equipment in petrochemicals plant.
	Use of Total Productive Maintenance (TPM)		Nil	No evidence of following TPM
	Use of formal Reliability Based Maintenance (RBM)		Use of Reliability Based Maintenance	No RCM is being followed in the company. However, maintenance managers are interested to implement.
	Total maintenance man hours devoted to emergencies/b		Emergency Maintenance	Emergency maintenance is being carried out in petrochemicals but the same is minimized by

	reak down maintenance			using various preventive & predictive maintenance techniques.
			Shutdown Maintenance	This maintenance method is very crucial for petrochemicals since no stand-by strategy is available. It is a method practiced as part of long term maintenance planning.
			Pro-active maintenance	This maintenance method is emerging out of this study and pro-active maintenance is based on previous experience of maintenance mangers. One of the maintenance managers suggested for documentation of such tacit knowledge available with the maintenance managers/engineers.

5.3.8 Reliability Analysis

Reliability Analysis is one among the category emerged out from the data analysis. The qualitative associative network related to Reliability Analysis is presented below in Figure 5.9. The same is prepared through Atlas- Ti software based on interview data from maintenance managers of a large gas utility company in India.

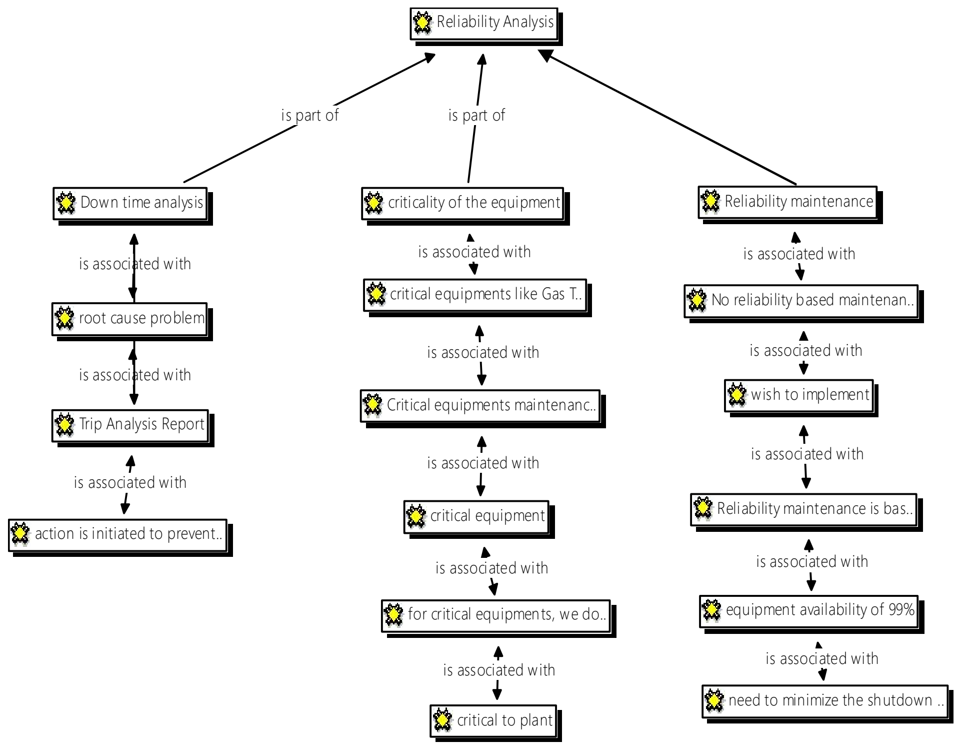


Figure 5.9 QAN for Reliability Analysis

"Reliability maintenance is based on Trip Analysis Report (TAR) of equipment failures and instrument failures. Down time analysis and root cause problem are identified through TAR and further action is initiated to prevent those failures in future"- DM (O & M)

"...During maintenance planning, first of all we identify the criticality of the equipment. Based on the equipment critically, equipment wise maintenance frequency is determined according to plant operations requirement" – Manager (O & M)

"Maintenance objectives are based on critically of the equipment. Accordingly, equipment is classified in to critical, semi-critical and non-critical. Based on this criticality, maintenance is being planned... Critical equipment maintenance is linked to the annual maintenance shutdown. HODs in consultation with OEM decide the maintenance of a particular machine.

OEM experts will be available to perform the maintenance during plant shutdown to take care of over hauling of particular equipment... Reliability maintenance is equipment should available whenever required. This is in line with the maintenance policy of the company." – SM (O & M)

"No reliability based maintenance practices are followed in the company. But we wish to implement" – CM (O & M)

As explained by maintenance managers, the key observations on Reliability Based Maintenance practice at petrochemicals plant of gas utility company are as given under:-

- Reliability Centred Maintenance (RCM) technique is not implemented in petrochemicals maintenance.
- Few basic metrics related to Reliability maintenance such as Trip Analysis Report (TAR), Breakdown records, Criticality of the equipment are being used in petrochemicals in order to identify root cause problem of down time.
- Maintenance mangers of gas utility company suggesting to implement RCM techniques.

The case study data related to the above constructs are discussed & presented in the below given Table 5.9

Table 5.9 Reliability Analysis sub-constructs and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Reliability Analysis	Documentation of Equipment History	Reliability Analysis	Nil	No evidence from interview data shows that equipment history records are being maintained in petrochemicals.

				However, such records are available in the form of break down records and break down reports while interacting with maintenance managers during field observations.
	Root Cause Analysis/Incident Analysis		Root Cause Analysis	Trip Analysis Reports' (TAR) are being prepared by maintenance managers in petrochemicals and the same is available.
	Mean Time Between Failures (MTBF)		Nil	No evidence found in using such metrics in maintenance practice.
	Value Risk Study of maintenance program		Nil	No evidence found in using such study in maintenance practice.
	Equipment Criticality		Equipment Criticality	Equipment criticality is being used in formulating maintenance schedules and based on criticality of the equipment maintenance strategy has been decided.
	Reliability Statistics of equipment/assets		Nil	Basic metrics are being used such equipment availability, plant availability etc. Advanced metrics based on RCM are not being practiced in petrochemicals plant.

	Reliability Cantered Maintenance based analysis		Nil	RCM based Analysis in maintenance is not adopted in Petrochemicals maintenance.

5.3.9 Maintenance Polices/Maintenance Budget

Maintenance Policy and Maintenance Budget is another category emerged out from the data analysis. The qualitative associative network related to Maintenance Policy/Maintenance Budget is presented below in Figure 5.10 & Figure 5.11. The same has been developed through Atlas- Ti software based on interview data from maintenance managers of a large gas utility company in India. Few representative quotations from interview data are presented below:

"Maintenance policy is available at corporate level. At site level, we prepare maintenance objectives in-tune with the corporate maintenance policy. Unit is having their own targets. For example, if plant availability is to be maintained at 99% and individual functional departments are also setting their department wise targets such at equipment availability of 99% etc." – Manager (O & M)

"GAIL, we have a maintenance policy. As per guidelines provided in the policy, we frame maintenance strategies. We have our IMS maintenance manuals. These manuals state very clearly the maintenance strategies being used in the company. Work instructions, standard operating procedures are provided in the maintenance manuals... Maintenance objectives are based on critically of the equipment. Accordingly, equipment is classified in to critical, semi-critical and non-critical. Based on this criticality, maintenance is being planned... Maintenance mission & objectives are defined in maintenance manual. The basic objective of the process plant is to make available of the critical equipment on 24 X 7 basis for operations. We do not have stand-by for critical equipment." – SM (O & M –PC)

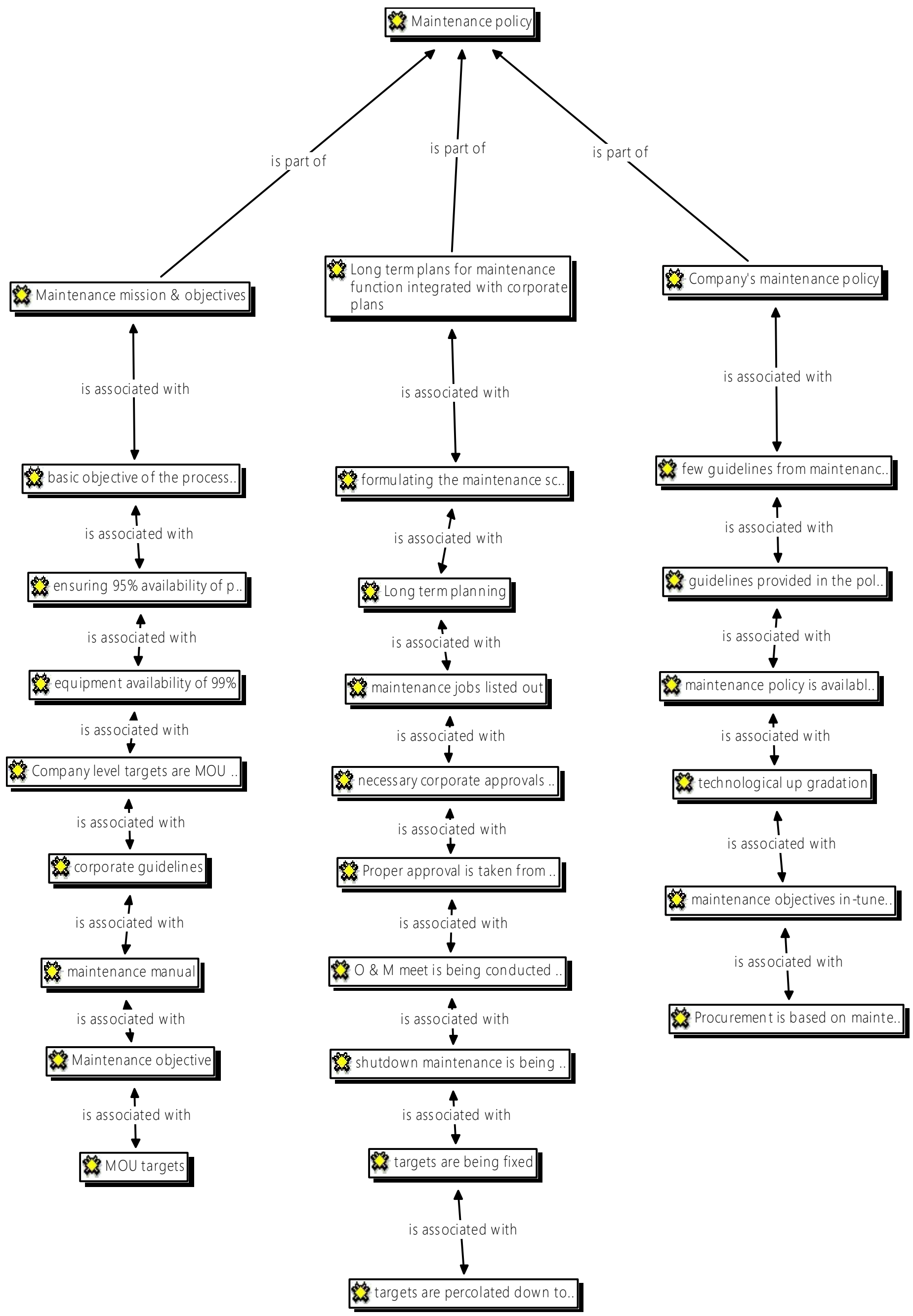


Figure 5.10 QAN for Maintenance Policy

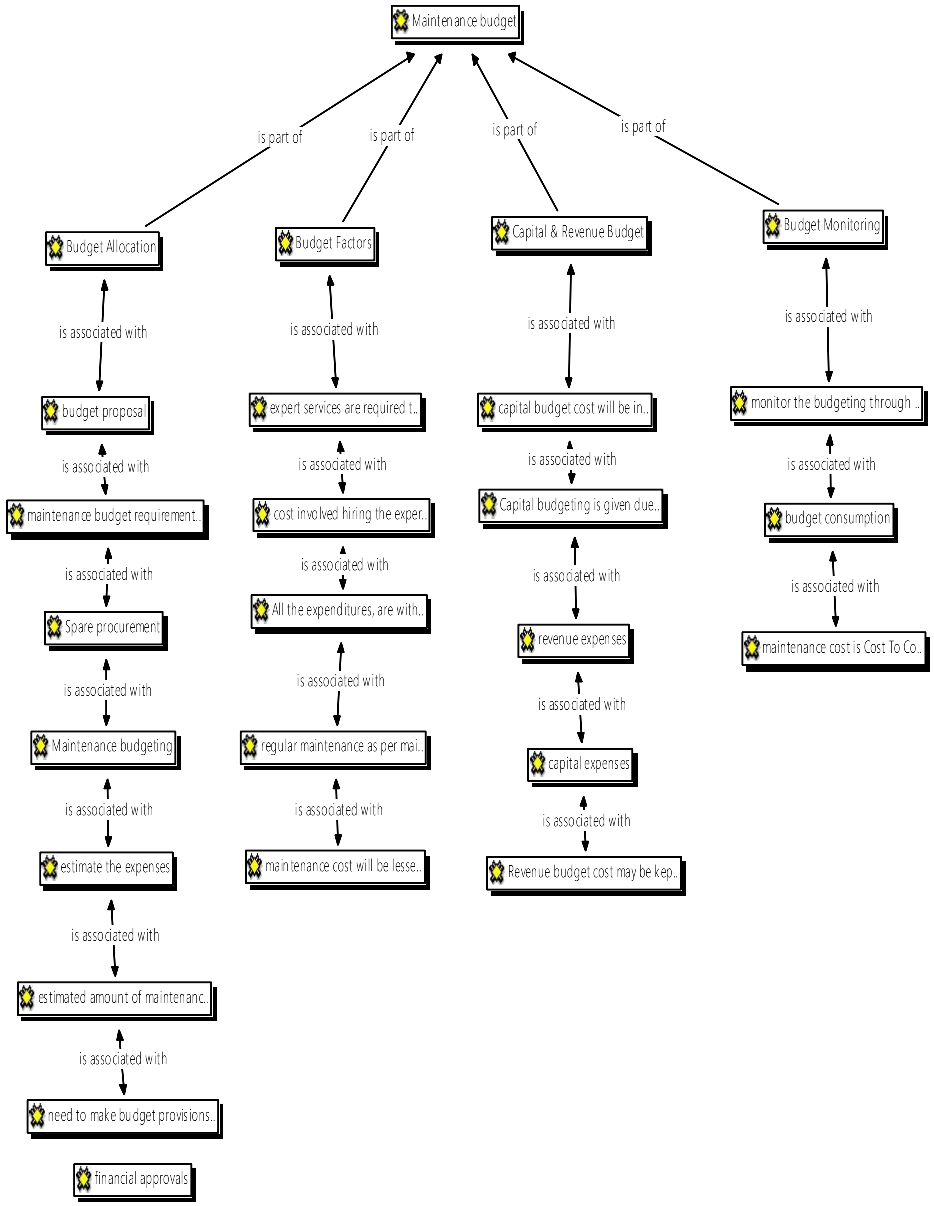


Figure 5.11 QAN for Maintenance Budget

"Our company is having well documented maintenance policy. The maintenance policy is available in our GAIL Intranet. Maintenance guidelines are available in the maintenance policy. As maintenance personnel, we should follow each word of the maintenance policy for implementing the maintenance practices" – SM (O & M)

“My unit is processing plant. Maintenance objective of this unit is ensuring 95% availability of plant. For achieving this target, we are having different maintenance strategies... Long term planning is being addressed by shutdown maintenance planning. Annual maintenance planning includes major overhauling & modifications job in the particular equipment/machine...” – CM (O & M)

“Maintenance objective is majorly based on targets provided by top management. For example, plant down time for processing plant should be less than 14 hours due to instrumentation systems. Similarly, the targets are being fixed for other departments also. These targets are unit level targets. Company level targets are MOU targets. Further, these targets are percolated down to unit level, departmental level targets” – DM (O & M)

It is evident from above representative quotations that the well documented corporate maintenance policy is available with gas utility company for petrochemicals. In maintenance policy, maintenance mission, maintenance objectives, etc. has been clearly defined and the same is made available on company’s intranet so that all units follow the maintenance policy uniformly. However, operational targets are based on MOU targets executed with petroleum ministry. Further, long term maintenance planning i.e., shut down maintenance planning is being done rigorously by maintenance crew and shut down maintenance is being executed every year as annual turnaround shutdown.

“Maintenance budget is being done on annual basis. We identify the maintenance budget requirement based on past experience. Based on this, we put up the budget proposal. The same is reviewed by unit head & corporate level by ED. All the expenditures are within this budget only... Capital budgeting is given due importance in our company. All these expenses are properly mapped in SAP system. Through SAP Internal Order, which is the unique id to monitor capital expenditures, capital budgeting is being monitored. At a single go, one can monitor the budgeting through SAP system which is linked to maintenance activities." – Manager (O & M)

"Maintenance budget is to be within the budget of overall budget allocated by GAIL. There is no resource constraint. GAIL maintenance department needs to put up proposal with proper justifications for necessary approval and we know the estimated amount of maintenance based on our previous experience" – SM (O & M)

"Maintenance budget has impact from the spares procurement. If proper preventive maintenance is being followed, spare consumption is reduced and also breakdown of the equipment is minimized" – DM (O & M)

"Maintenance budgeting is based on few factors. Where our maintenance jobs are being done by in-house maintenance crew, the maintenance cost is Cost To Company/employee. Where the expert services are required to do maintenance, the cost involved hiring the expert is the cost of maintenance. Spare procurement is also another factor to be considered during maintenance budgeting. During long run, if we do regular maintenance as per maintenance schedules then maintenance cost will be lesser... capital budget cost will be increased due to lapses in maintenance. Revenue budget cost may be kept optimum by using proper preventive and predictive maintenance monitoring." – CM (O & M)

"As a common philosophy of the companies, we also prepare budget on annual basis. In budget, equipment wise maintenance cost like capital expenses & revenue expenses are proposed by plant and the same is get it approved from Board of directors. This is a yearly approval process" – SM (O & M –PC)

As described by the maintenance managers, the following are evident:-

- Well-structured annual budgeting process existing in the company and all petrochemicals maintenance expenditure such as capital, revenue, etc. are mapped in annual budgeting process. Expenditures are being bone accordingly.

- Few maintenance factors affecting maintenance budget are cost of hiring experts from outside for performing maintenance, unnecessary inventory of spares, lack in completion of regular maintenance
- Budgeting exercise is integrated with SAP Finance Module and Budget is also being monitored regularly & reviewed during mid-term.

The case data for the above sub constructs are discussed and presented in the below shown Table 5.10.

Table 5.10 Maintenance Policy/ Budget sub-construct and empirical findings

Initial Conceptual Construct	**Sub Constructs**	**Categories from empirical data**	**Focused codes from empirical data**	**Observation on Data Analysis**
Maintenance policies/ budget	Maintenance mission & objectives	Maintenance Policies/ Budget	Maintenance mission & objectives	Clear maintenance mission & objectives are available in the company as per Maintenance Policy & MOU targets. The targets have been further divided into objectives of individual units/ maintenance departments.
	Long term plans for maintenance function integrated with corporate plans		Long term plans for maintenance function integrated with corporate plans	Company's mission & vision is integrated with the maintenance policy & objectives
	Maintenance Policies		Company's maintenance policy	Maintenance Policy is documented & available in company's Intranet in the company.
	Maintenance budget		Maintenance budget	Well defined budgeting system is available in the

				company. Maintenance Budget is function of Preventive maintenance, predictive maintenance, and shutdown maintenance job requirements/plan; Budget allocation/resource requirement is being reviewed by the company every six months. Budget is integrated in SAP Finance Module.

5.3.10 Maintenance Challenges

A new category has been emerged from the interview data which is collected from maintenance managers of the large gas utility company in India. Maintenance managers are of the opinion that the maintenance challenges are actually helping in formulating maintenance strategies for the company. The data analysis outcomes shows that the new category maintenance challenges contributing to maintenance strategy formulation, selection, and implementation of maintenance strategies. Qualitative Associative Network developed for this category is presented in the Figure 5.12 and few representative quotations from maintenance managers are also discussed below.

"The basic challenge of maintenance is that how to ensure the 24 X 7 basis availability of critical equipment for plant operations. To keep the equipment availability on continuous basis with the existing maintenance practices is a challenge for maintenance personnel ... Maintenance challenges are there. While we are going for tendering, we do not have any procedure for avoiding lowest bidder based on quality. This becomes some time challenges while doing maintenance. This is mainly happening in material procurement tendering. In my view, there should be some Low cost cut should be there in tendering process. Obviously maintenance challenges are there. However, we are capable to meet those challenges with Delegation of Powers, sufficient availability of spares and, OEM support. We are in the position to cope-up with any situation with the flexibility in our company and come out with the solutions for maintenance challenges...” – Manager (O & M)

“When the machinery/equipment undergoes maintenance, one cannot what well predict the equipment failure. Even the most experienced engineer cannot predict the exact failure of the equipment. Therefore, the extended shutdown of the equipment may be possible. This is the major maintenance challenge. So one should be well prepared for such kind of situation and planning should be done accordingly and costly spare replacements should be limited. Predictive and pro-active maintenance strategies should take care of this” – SM (O & M)

“Maintenance Challenges in implementing the above maintenance schedules are like, 1) Spare availability suppose we isolated one instrument and take up the maintenance of that instrument, if we require any spare, we need to replace the same to bring the instrument to working condition; 2) Proper work permit is to be taken and then only the maintenance to be done in that particular equipment” – DM (O & M)

“One contract supervisor is nominated to perform coordination job in maintenance such as issue of material from material stores, allocation of jobs to workers, issue/close of job permits etc. If any situation arises that is beyond supervisor level, we directly contact the contractor to mitigate such issues... We have certain problems with contractors such as statutory issues like PF deduction, labour issues etc. But, these issues are being controlled with contract terms like contract penalties etc. Online PF system has been introduced by Government of India. This facilitates our work...” – Manager (O & M)

“Manpower for maintenance jobs is being hired through contracts due to lean power of GAIL. Therefore, quality of manpower supplied by contractor is to be ensured. Many times, contract manpower did not turn up during important/critical maintenance jobs. This makes constraint while doing maintenance” – DM (O& M)

“For example, we may have a case that supplier who is supplying gas to GAIL for processing and consumer who is using the lean gas for their plant operations like power plant. The specific situation can arise that consumer do not want to shut down the plant. Then, we also cannot shut down our plant for preventive maintenance. Therefore, we should have alternative to prolong our preventive maintenance schedule with the proper OEM recommendations” – SM (O & M – PC)

“In AMC service, we face some problem with the contractor; we try to settle down issues by mutual understanding of the issues. Inn worst case, we refer the same to our contract & procurement department. We have well- structured procedure to block-list the contractor for not delivering the required outputs as per contract terms & conditions. This is also not a very frequent phenomenon. But we have in two such cases at our unit level” – Manager (O & M)

“...Fortnightly meeting is being conducted regularly along with top management to identify critical jobs and arrangements of resources to complete those jobs such as material procurement, manpower, assistance from peer departments and expert services if any etc.” – CM (O & M)

“...more decision making power may be given to plant O & M personnel to decide on preventive maintenance schedules based on their experience and machine data interpretation. So that PM schedule frequency can be fixed at actual experience of maintenance personnel...” – SM (O & M PC)

“No standardisation of Maintenance practices in the industry. Therefore, maintenance compliance is based on past experience and few guidelines from maintenance policy of the company” – CM (O & M).

“Maintenance challenges during implementation of particular maintenance strategy are there like 1)External expert service is taken from Original Equipment Manufacturers (OEM) where we do not have much expertise on particular machine/instrument/equipment; 2) Obsolete of technology. To keep with face of technological changes & improve performance of the plant equipment, obsolete of technology is being reviewed according to the maintenance policy; 3) Innovation in new technological changes is also being tracked for necessary implementation” – CM (O & M)

The case data for the above sub constructs are discussed in detail and presented in the below given Table 5.11.

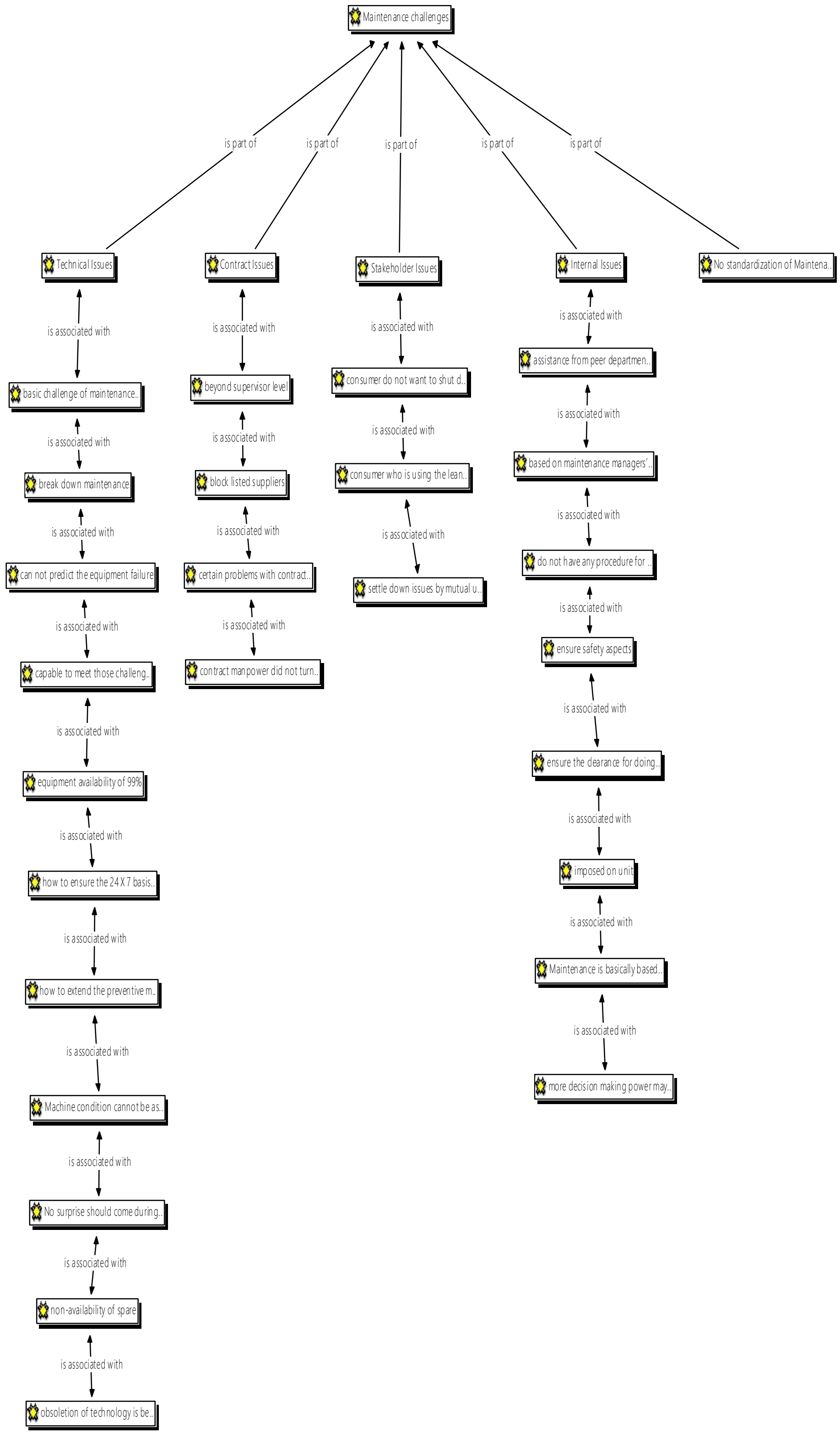


Figure 5.12 QAN for Maintenance Challenges

Table 5.11 Maintenance Challenges factors and empirical findings.

Categories from empirical data	**Focused codes from empirical data**	**Observation on Data Analysis**
Maintenance Challenges	Technical Issues	Few technical issues have been identified from the data analysis such as ensuring availability of plant on 24 X 7 basis, prediction of equipment failures, quick restoration of equipment after breakdown, availability of spares, obsolete of technology, innovation in new technological implementation etc.
	Contact Issues	Few contract related issues have been identified from data analysis. They are deployment of contractor manpower, contract selection based on lowest bid (L1) basis, training of newly deployed contract manpower, deviation in statutory and labour requirements by contractors etc.
	Stakeholder Issues	Few stakeholders related issues identified from data analysis are customer & supplier related issues in consuming gas, issues with vendors, etc.
	Internal Issues	The issues faced in maintenance due to internal functions are ensuring cooperation among peer departments, no standard/uniform maintenance procedures among the units of the plant, more independency to maintenance managers to decide on maintenance jobs, etc.
	No Standardisation of maintenance practices	New factor emerging out from this study i.e., maintenance managers are of opinion that there is no standardisation in maintenance practices. This may lead to poor execution of maintenance strategies even though world class maintenance strategies have been selected.

5.4 MAINTENANCE STRATEGIES SELCTION PROCESSES IN PETROCHEMICALS

This section describes about maintenance strategies selection related activities in petrochemicals plant of the large gas utility company. Data collected from the maintenance managers/engineers of the company were analysed as per the data analysis strategy described in Section 3.6. After Phase I, the conceptual analysis of the case study was undertaken in order to identify various activities carried out by the maintenance managers for maintenance strategies selection and their practices in Petrochemicals. Then, these activities were combined into categories/concepts based on processes related to maintenance strategies & maintenance practices. The detailed data analysis based on literature review Section 2.5.3 (selection of maintenance strategies) and Section 2.5.5 (maintenance decision support system).

Interview data has also been analysed in terms of selection of formulated maintenance strategies. A Qualitative Associative Network has been developed to understand the existing methods available in the gas utility company for maintenance strategy selection. QAN for maintenance strategy selection is shown in Figure 5.13 and the same is supported with the representative quotations as described by the maintenance managers of petrochemicals plant of gas utility company.

“Maintenance strategies are varied based on equipment/ instrument systems types. Based on the type of the system, frequency of maintenance is fixed. For example, mass flow meters calibration is fixed every five years. Further, based on system reliability and accuracy maintenance schedules are being planned... We are also using few inputs to formulate maintenance strategy planning which are observed & noted from shop floor operation personnel. They can tell about the machine/equipment behaviour change during running of that equipment” – CM (O & M)

“...We sought guidance from OEM for maintenance planning & formulating the maintenance schedules. We also take recommendations from OEM for specific maintenance problem identified in predictive maintenance also...” – SM (O & M – PC)

“Maintenance in petrochemical is not very simple. After achieving the MOU targets, shutdown maintenance is being planned every year. The maintenance jobs listed out for doing in shutdown maintenance is taken up during this plant shutdown. No surprise should come during equipment maintenance in performing annual shutdown maintenance. This could be achieved through proper planning based on predictive maintenance of that particular equipment... Vibration Analysers software is available and the same is done by external experts. The deviation and abnormality is intimated by these experts through reports” – SM (O & M)

“...Technical obsolesces of the system is being reviewed every year and accordingly upgradation of systems is done...” – DM (O & M)

“...online monitoring purpose using Distributed Control System (DCS). Wireless transmitters are being implemented for capturing the process parameters for monitoring plant operation” – CM (O & M)

“...We are following international standards for industry norms compliance. Internal norms are MOU targets...”- SM (O & M)

“...We are following standards such as AGA, PNGRB, SIL level etc. for compiling the Industry Norms... Annual audits are being conducted to see the maintenance practices compliance & performance measures of maintenance systems. Such audits are Inter Unit Safety Audit (IUSA), OISD Audit, etc. with different frequency...” – CM (O & M)

The case data for the sub constructs related to maintenance strategy selection process is discussed & presented in the below given Table 5.12.

Figure 5.13 QAN for maintenance strategy selection process in petrochemicals

Table 5.12 Maintenance Strategies Selection Processes-empirical findings.

Categories from empirical data	**Focused codes from empirical data**	**Data Analysis**
Selection of Maintenance Strategy for particular operation process/equipment	Factors Contributing to maintenance strategy selection	Few factors which are contributing to the selection of maintenance strategy have been identified from the data analysis. Such factors are previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, Maintenance Policy, equipment complexity, equipment availability, process severity, complexity of the process
	Specific maintenance strategy for Petrochemicals	Shutdown maintenance is a specific & crucial maintenance method in petrochemicals plant.
	Internal & Industry Norms	Gas utility company is following industry norms such as standards of OISD, PNGRB and other international standards such as AGA, API, ASME etc. and internal norms are such as IMOU targets, sharing maintenance problems among units and maintain SAP system so that all data can be accessed by all among petrochemicals units like GPU, GCU, HDPE & LLDPE etc. These norms help the petrochemicals plant to implement uniform maintenance strategy selection process across the units in the plant.

5.5 RELATIONSHIP BETWEEN MAINTENANCE STRATEGY SELECTION PROCESS AND MAINTENANCE STRATEGIES & PRACTICES

This section describes the relationship between factors contributing to maintenance strategies and maintenance practices and maintenance strategy selection processes in Petrochemicals plant of the gas utility company. As shown above in Figure 5.14, maintenance strategies & maintenance practices planning and execution in NG Pipelines of the gas utility company depends on the factors contributing to maintenance strategies & maintenance practices including benchmarking practices and reliability maintenance practices in the company. Maintenance strategies selection process identified in section 5.4 play a crucial role in maintenance strategies & practices.

The key findings from the above discussion are summarised as given under: Predictive Maintenance (CBM) & preventive maintenance (TBM) both are used in petrochemicals based equipment classification such as critical, semi-critical & Non-critical; Total Productive Maintenance (TPM) technique is not being practiced in the gas utility company Petrochemicals; Planned Shutdown maintenance is the major maintenance tactics being used for the equipment/systems where standby is not available in Petrochemicals. This is the new tactics emerged out from this study; Proactive maintenance is the new maintenance tactics emerged out from this study. This is in nascent stage in the company. The same to be further explored & implemented; Reliability Centred Maintenance (RCM) technique is not being practiced in the gas utility company Petrochemicals. Therefore, the RCM metrics such as MTBF, Value Risk Study are not being used in maintenance; No International Benchmarks are being followed. But, MOU targets are treated as benchmarks. From the documentary evidence, it is found that maintenance cost is benchmarked i.e., 0.83 % of Gross Block (Inflation Adjusted); Maintenance managers are referring MOU targets/ operational targets as Key Performance Indicators (KPI) for maintenance also. This shows that there is no specific KPIs are identified for measuring maintenance performance; Maintenance performance is assessed through Internal Audits & External Audits. Since, these audits are being conducted based on some standards such as OISD, API standards etc., these audit recommendations & their implementations are guiding the maintenance performance in the large gas utility company; there is no evidence of awareness or usage of metric related to labour cost/material cost from the interview data. However, maintenance cost is benchmarked by the company as given above; No evidence of following “Average Inventory Turnover” concept in the company; during interview, maintenance managers are not telling about Apprentice program. However, from company secondary data Apprentice program is available as per statutory requirements; Maintenance Challenges is the new category of maintenance strategies emerged out from this study. This includes the major issues being faced by maintenance managers in their day-to-day jobs. These are grouped in to technical issues, contract issues, stake holder issues, internal issues & unexpected issues. These factors will play crucial role in development of maintenance strategies & maintenance practices. Presently, these challenges are managed by individual/team as and when required. The same has to be formalised & documented for better maintenance practice; Key maintenance challenges of Petrochemicals plant which are to be considered before formulating the maintenance strategy and while implementation of maintenance practices are time extension preventive maintenance scheduled time based on informed decision, technology obsolesce of equipment & systems, earlier prediction of equipment failure, surprises during overhauling of equipment, deployment of contract manpower & workmanship of contract employees, award of contracts, legal & statutory requirements, customer/supplier plant issues, quality of maintenance & inexperience maintenance personnel, and dependency on OEM support.

Further, selection of maintenance strategies for a particular equipment/operation process in petrochemicals includes factors such as past experience of maintenance managers, OEM recommendations, etc., specific maintenance strategies for Petrochemicals are shutdown maintenance, proactive maintenance, industry norms based international & national level standards and internal norms based on MOU targets & other practices such as SAP system for integration of maintenance function.

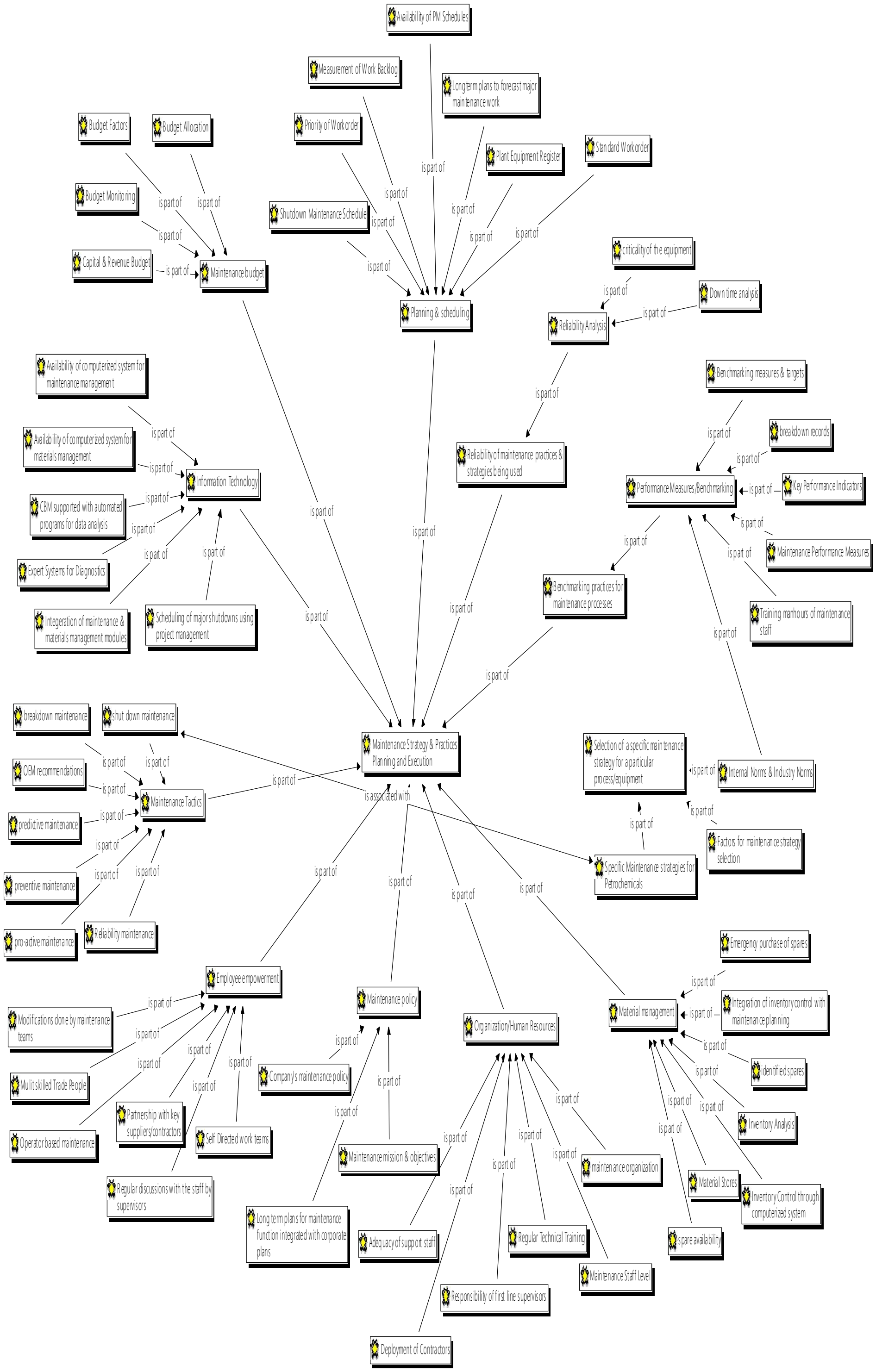


Figure 5.14 QAN for Case Study 2 (Petrochemicals)

This completes the description of relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in Petrochemicals. This also concludes the reporting of findings of the petrochemicals case study. Next section discusses the findings of the petrochemical case.

5.6 FINDINGS AND DISCUSSIONS

This section discusses the findings from empirical data analysis on maintenance strategies & maintenance practices of the large gas utility company business vertical Petrochemicals, maintenance strategy selection processes specific to Petrochemicals equipment/process and further relationship between maintenance strategies selection process and maintenance strategies & maintenance practices in the company.

5.6.1 Maintenance Strategies & Maintenance Practices in Petrochemicals

The above detailed data analysis results with the following categories which contributes to maintenance strategies selection and maintenance practices.

1. Performance Measures/Benchmarking
2. Planning & Scheduling
3. Materials Management
4. Organisation/ Human Resources
5. Employee Empowerment
6. Information Technology
7. Maintenance Policies/Budget
8. Maintenance Tactics
9. Reliability Analysis
10. Maintenance Challenges

Earlier literature on maintenance strategies & maintenance practices has identified nine categories of factors contributing to maintenance strategies selection & practices as discussed in the literature review chapter section 2.6.

This research study could find evidence for all these nine contributing factors. There are one new factor emerged out from this study is maintenance challenges.

Earlier literature on performance measures as discussed in section 2.6.3 has identified sub-constructs such as labour and material cost, breakdown records, maintenance performance measures, key performance indicators, downtime records, training man hours of maintenance staff, internal norms/industry norms, benchmarking measures & targets. From the data analysis, there is evidence of all these constructs except labour/material cost. Even though, maintenance cost is the only benchmarked parameter in the gas utility company's document, no evidence is found from interview data. i.e., maintenance managers/engineers are practically not using this measure. The interviewees indicated that the key performance measures and benchmarking parameters are based on MoU (Memorandum of Understanding) with concerned ministry of Government of India. It is observed that the most of the parameters are related to operational targets and maintenance performance is not being measured. Benchmarking exercise was carried out by the gas utility company during 2002 only. Benchmarking is majorly related to operational/financial aspects of the business. There is no separate maintenance benchmarking parameters available.

Earlier literature identified the construct planning & execution to cover the sub-constructs (Refer section 2.6.4) such as plant equipment register, standard written work order, availability of PM schedules, priorities of work order, availability of work schedule for a week ahead, shutdown maintenance schedule, measurement of work backlog, long term plans to forecast major shutdown/maintenance work. This case study has found the evidences for all these elements. As indicated by maintenance managers/engineers of the gas utility company, planning & execution activities of the gas utility company in Petrochemicals are being executed, maintained, and documented in the SAP system.

Earlier literature on material management as discussed in section 2.6.5 has identified with sub-constructs such as spares availability, identified spares, inventory analysis, emergency purchase of spares, average inventory turnover, availability of stores, inventory control through computerised system, and integration of inventory control with maintenance planning. This case study has found the evidences for the all these elements except average inventory turnover. This concept has not been used by the gas utility company. As per interview data analysis, the material management activities in Petrochemicals of the company are being managed through SAP MM Module in SAP system. Further, material management module is also integrated with SAP PM Module which is used for maintenance planning & execution. Therefore, practice of proper planning, organising, and controlling of the spare procurement in alignment with the maintenance planning process exists in Petrochemicals of the company.

Earlier literature identified the construct organisation/human resources to cover the sub-constructs (Refer section 2.6.6) such as maintenance staff level, maintenance organisation, responsibility of first line supervisors, adequacy of support staff, regular technical training, apprenticeship program, and deployment of contractors. Evidences are found for all these elements of organisation/human resources from interview data except apprenticeship program. However, interaction during site visits and documentary evidences show that the company is following apprentice program and this is statutory also. Especially, training systems are well structured in the company as indicated by interviewees. This facilitates technical training in maintenance in order to ensure smooth operation and quick restoration of equipment/processes after breakdown.

Earlier literature on employee empowerment as discussed in section 2.6.7 has identified the sub-constructs such as multi-skilled trade people, operators based maintenance, regular discussion with the staff by supervisors, self-directed work teams, minor modifications done by maintenance teams, and partnership with key suppliers/contractors. This case study could find evidences for all these elements. Operator based maintenance is not being practiced in petrochemicals. As indicated by the maintenance mangers/engineers and observed during site visits, operator is responsible for issuing work permits and bring the equipment failures to the knowledge of maintenance personnel by issuing job intimation slip. Further, modification process in petrochemicals is managed by “central engineering cell” in the plant through well- structured change management system.

Earlier literature identified the construct information technology to cover the sub-constructs (Refer section 2.6.8) such as availability of computerised system for maintenance management, availability of computerised system for materials management, integration of maintenance management & materials management modules, scheduling of major Shutdown using project management system, CBM supported with automated programs for data analysis, and Expert systems for diagnosis. This case study could find evidences for all these elements of activities related leveraging information technology in Petrochemicals of the gas utility company. Expert systems used in Petrochemicals in operation & maintenance are Distributed Control Systems (DCS) and Vibration analysis software.

Earlier literature on maintenance polices and maintenance budget has identified the sub-constructs as discussed in section 2.6.9 such as maintenance mission & objectives, long term maintenance plans integrated with business plans, maintenance policies, and maintenance budget. Interview data analysis provides evidences for all these elements related to maintenance policies and maintenance budget. Interviewees indicated that clearly defined maintenance mission and maintenance objectives are available in the maintenance policy document. Further, maintenance managers/engineers have explained about well-structured budget system and its role in maintenance.

Earlier literature on maintenance tactics has identified the sub-constructs as discussed in section 2.6.1 such as use of Condition Based Maintenance/ Predictive Maintenance, Condition Based Maintenance is favoured over Time

Based Maintenance (TBM), total maintenance hours devoted to Predictive Maintenance/ Preventive Maintenance, compliance of PM Schedules, OEM (Original Equipment Manufacturer) Recommendations for an equipment regarding PM, use of formal Reliability Based Maintenance (RBM), and use of Total Productive Maintenance (TPM). This case study could found evidences for all these elements of maintenance tactics in NG Pipelines of the gas utility company except use of Reliability Based Maintenance and Total Productive Maintenance. *Shutdown maintenance is the maintenance method which has emerged out from this case study.* Maintenance jobs cannot be carried out when the petrochemicals plant is under production. All such maintenance jobs are listed out by maintenance managers and planned to execute during pipelines shutdown (shutdown is the period in which Petrochemicals plant is under planned annual shutdown). During shutdown period, maintenance jobs are carried out. This type of maintenance is called as shutdown maintenance. One more category has emerged out from this case study i.e., *Proactive Maintenance.* This type of maintenance method is based on previous experience of maintenance managers/engineers and maintenance strategies are selected based on that. This type of maintenance exists in petrochemicals. However, maintenance managers/engineers are of the opinion that the proactive maintenance must be documented and standardisation can be done in maintenance systems.

Earlier literature identified on reliability analysis to cover documentation of equipment history, equipment criticality, Root Cause Analysis (RCA)/Incident Analysis (IA), Mean Time Between Failures (MTBF), Value Risk Study of maintenance program, reliability statistics of equipment/assets, and Reliability Centred Maintenance (RCM) based analysis. This case study could not find evidences for most of the elements from interview data analysis. Interviewees has indicated that the reliability based maintenance or reliability centred maintenance is not being practiced in Petrochemicals plant. However, few reliability measures like RCA/IA and equipment history are being practiced in petrochemicals of the large gas utility company as indicated by maintenance managers/engineers of the company.

This case study could find evidences of *Maintenance Challenges as a new category* of factor contributes to maintenance strategies planning and execution in the company. This includes the major issues being faced by maintenance managers in their day-to-day jobs. These are grouped in to technical issues, contract issues, stake holder issues, internal issues & standardisation of maintenance practices. These factors play crucial role in maintenance strategies & maintenance practices. Presently, these challenges are managed by individual/team as and when required. These maintenance challenges factors are to be formalised and documented for better maintenance practices in the company as indicated by the interviewees.

5.6.2 Maintenance Strategies Selection Process in Petrochemicals

As discussed in Chapter 2, section 2.5.3, literature indicated that the maintenance strategies selection process is being carried out using mathematical modelling. In the organisations, selection of maintenance strategies for particular equipment/process is treated as Multiple Criteria Decision Making (MCDM) Problem. This type of problem can be solved using techniques like AHP, Fuzzy AHP, VIKOR model etc. This case study could not find any evidences of using such techniques in Petrochemicals of the gas utility company for maintenance strategies selection process.

Further, as discussed in section 2.5.5, literature indicated that Decision Support System (DSS) models have been used for optimizing the maintenance strategies mix use in the organisations in order to ensure better implementation of maintenance strategies and improving maintenance. No evidences are found in this case study regarding implementation DSS models in Petrochemicals plant of the gas utility company.

As detailed above in section 5.4, Petrochemicals maintenance strategies selection process includes the following elements such as previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process in selecting a particular maintenance strategy for a specific equipment/process. Shutdown maintenance is a specific maintenance method applicable to Petrochemicals. It plays a crucial role in maintenance of petrochemicals plant. Further, maintenance strategies selection is based on the internal norms & industry norms in petrochemicals. Internal norms are the procedures such as Integrated Management Systems (IMS), Standard Operating Procedures (SOPs), etc. Industry norms are the guidelines from OISD, PNGRB, etc.

5.6.3 Relationship between Maintenance Strategies Selection Processes and Maintenance Strategies & Practices in Petrochemicals

Earlier literature identified with various maintenance strategies related models to explain the processes related to maintenance strategies selection and maintenance practices and contributing factors as discussed in chapter 2, section 2.6 & section 2.7. Such processes are deliberated like formulation of maintenance strategies (McAllister, 1999; Waeyenbergh & Pintelon, 2002; Kelly, 2006), maintenance strategy selection (Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy, Atrens & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Lin et al., 2009), and implementation of maintenance strategies (Campbell & Picknell, 2006; Eti M.C., 2006; Crespco, 2005; Pinjala, Pintelon & Vereecke, 2006; Veldman, Klingenberg & Wortmann, 2011), e-maintenance and its impact (Liptrot, David & Palarchio, Gino, 2000; Muller, Alexander; Crespo, Marquez, Adolfo & Lung, Benoit, 2007; Swanson,2003; Elliot & Tobias, 2005). Maintenance performance provides key inputs to maintenance strategies selection and maintenance practices as indicated by various literatures (Albert et al., 1999; Tsang, 1999; Sherwin,, 2000; Swanson, 2001; Kutucuoglu et al., 2001; Visser & Pretorious, 2003; Weber & Thomas, 2006; Parida & Chattopadhyay, 2007; Parida & Uday, 2009; Muchiri et al., 2011; Simoes et al., 2011).

This case study could find evidences of relationship among the processes related to maintenance strategies & maintenance practices such as formulation of maintenance strategies, maintenance strategy selection, and implementation of maintenance strategies. e-maintenance implementation in Petrochemicals is majorly based on the implementation of SAP system and other intelligent diagnostic systems. There is an evidence of using maintenance performance assessment in framing maintenance strategies and improvement in maintenance practices.

This case study could find evidences showing maintenance processes in the gas utility company such as maintenance strategies formulation, maintenance strategy selection, implementation of maintenance strategies and practices in the company. Further, this case study could come out with the factors contributing to those maintenance strategy related processes.

5.6.4 Case Study Findings in terms of Research Questions

The constructs and sub-constructs identified through literature review have been verified in data analysis of empirical data collected from maintenance managers/engineers of the large gas utility company in India. The detailed discussions, observations and findings have been presented above in section 5.3 & section 5.4. Further, the relationships among these factors emerged from data analysis and holistic picture for answering the central research question, a Qualitative Associative Network has been developed and the same is shown in section 5.5. The case study findings are summarised in terms of research questions and discussed in subsequent paragraphs.

- *Findings related to CRQ (Maintenance strategies & practices planning and Execution & specific maintenance strategies of gas utility company):*
    - Petrochemicals of gas utility company is planning & executing its maintenance strategies majorly based on: overall company's maintenance policy guidelines, MOU/ IMOU targets, maintenance challenges faced by maintenance

managers/engineers such as ageing of assets, dependency on OEM, contract issues, etc.

- Specific maintenance strategies are selected in Petrochemicals majorly based on: OEM (Original Equipment Manufacturer) recommendations, standard industry practices and past experience of maintenance managers.

- *Findings related to ARQ1- Common & different maintenance strategies between petrochemicals & NG Pipelines:*
  - Preventive maintenance is used more in petrochemicals than NG Pipelines
  - Emergency maintenance is minimized by applying various maintenance tactics in petrochemicals
  - Shutdown maintenance plays a crucial role in petrochemicals
  - Maintenance challenges play a crucial role in deciding on maintenance strategies & impact the maintenance practices in Petrochemicals.

- *Findings related to ARQ2- Benchmarking in Maintenance of Petrochemicals:*
  - Benchmark report (2002) is available but it is not being practiced fully in petrochemicals of the gas utility company
  - It is found that one parameter maintenance cost is benchmarked i.e., 0.83 % of Gross Block (Inflation Adjusted) from the documentary evidence
  - MOU targets are being treated as benchmarks by the maintenance managers and these targets are mostly based on operational targets
  - Maintenance performance is assessed through Internal Audits & External Audits by OISD, PNGRB, etc. and through these audits maintenance practices are validated in petrochemicals of the large gas utility company.

- *Findings related to ARQ3- Reliability in maintenance:*
    - Reliability Centered Maintenance (RCM) technique is not being practiced in Petrochemicals of the large gas utility company
    - RCM metrics such as MTBF, Value Risk Study are not being used in Petrochemicals maintenance practices
    - However, Root Cause Analysis (RCA) of maintenance failure & Incident Analysis Report (IAR) are being used to identify root cause failure of equipment and report failure incident respectively.

5.7 CONCLUDING REMARKS

This chapter presented and discussed the analysis and results of petrochemicals case study of Indian gas utility company. Categories of factors contributing to maintenance strategies & maintenance practices and maintenance strategy selection process in Petrochemicals of the large gas utility company have been presented and discussed. One new type of category maintenance challenges and two new types of maintenance tactics/methods such as shutdown maintenance and proactive maintenance emerged out from the empirical data.

The relationship between maintenance strategies selection process in Petrochemicals and categories of factor contributing to maintenance strategies & maintenance practices have been presented and discussed. The findings of the case study illustrate that interviewees considered the following categories such as performance measures, planning & Scheduling, materials management, human resources, information technology, employee empowerment, maintenance tactics, reliability analysis, maintenance policies/maintenance budget, and maintenance challenges are important in deciding on maintenance strategies selection process & maintenance practices in Petrochemicals of the large gas utility company.

Further, interviewees indicated that the maintenance strategies selection process is not based on mathematical modelling using quantitative techniques & tools and it is based on previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity/complexity, and internal and industry norms.

This chapter presented and discussed petrochemicals case study. Next chapter presents and discusses the cross case analysis and its findings of both the case studies NG Pipelines & Petrochemicals.

CHAPTER 6

CROSS CASE ANALYSIS AND FINDINGS

6.1. INTRODUCTION

This chapter presents the cross case analysis of Natural Gas Pipelines and Petrochemicals plant of the large gas utility company cases and discusses the findings. In first section similarities and dissimilarities between the two case studies are presented along with summary of major observations. Then findings of these two case studies are compared for maintenance strategies & maintenance practices, maintenance strategies selection processes, and relationship between the factors contributing to maintenance strategies & maintenance practices and maintenance strategies selection processes. Propositions suggesting relationships between factors related to maintenance strategies & practices and the processes of maintenance strategies selection are also developed.

6.2 SIMILARITIES AND DISSIMILARITIES BETWEEN CASES

A brief comparison of the business verticals NG Pipelines and Petrochemicals of the large gas utility company is presented in Table 6.1 for ready reference.

Table 6.1 Comparison of business verticals of the large gas utility company

Parameters	**NG Pipelines (Case Study- 1)**	**Petrochemicals (Case Study -2)**
Nature of Business	Gas Transmission, Processing, and Distribution	Polymer & Liquid Hydrocarbon production
Capacity	10,700 KMs of NG pipeline	0.45 MMTPA of Polymers

Existing	network; 210 MMSCMD	LLDPE & HDPE
Capacity Expansion	Expanding to 15,000 KMs of pipeline network	0.45 MMTPA of Polymers LLDPE & HDPE
Domestic Market Share	70 %	20%
No. of Employees	Approx. 1300	Approx. 900
Location	All across India (Majorly in North part of India)	PATA, UTTAR PRADES, 100 KMs away from KANPUR

In this cross-case analysis of the study, data has been analysed across both the cases (Petrochemicals & NG Pipelines) in order to identify similarities and differences in maintenance strategy formulation and maintenance practices of the gas utility company. By identifying similarities and differences, further insight into issues concerning the maintenance strategy selection & maintenance practices (analytically) by generalizing the case study results. The details of similarities and differences are as given under in the Table 6.2.

Table 6.2 Similarities & Dissimilarities between Case Study 1 & Case Study 2

Categories from empirical data (Case Study-1 & Case Study-2)	**Focused codes from empirical data (Case Study-2) –Petrochemicals**	**Observation on Data Analysis (Case Study-2) Petrochemicals**	**Focused codes from empirical data (Case Study -1) NG Pipeline**	**Observation on Data Analysis (Case Study -1) NG Pipeline**	**Cross –Case Analysis Observations**
Maintenance Tactics	Predictive Maintenance/ Condition Based Maintenance (CBM)	CBM is being used in Petrochemicals unit	Predictive Maintenance/ Condition Based Maintenance (CBM)	CBM is being used in NG Pipelines maintenance	Both units are using CBM techniques in their maintenance planning
	Preventive Maintenance/ Time Based Maintenance (TBM)	TBM is being practiced in Petrochemicals	Preventive Maintenance/ Time Based Maintenance (TBM)	TBM is being practices in NG Pipelines also.	Both units are using TBM in maintenance strategy planning & scheduling
	Ratio between Predictive Maintenance (CBM) & Preventive Maintenance (TBM)	Predictive Maintenance (CBM) & preventive maintenance (TBM) both are being used in petrochemicals	Ratio between Predictive Maintenance (CBM) & Preventive Maintenance (TBM)	Predictive Maintenance (CBM) is more in NG Pipelines than preventive maintenance	Both the units are using CBM & TBM techniques. However, application of these techniques is depending on

		based on equipment classification such as critical, semi-critical & Non-critical		(TBM)	equipment type, process type, pipelines, and compressor stations.
	PM schedule completion	Timely completion of PM schedules is being followed in Petrochemicals	PM schedule completion	Timely completion of PM schedules is being followed in NG Pipelines	PM schedule completion is being monitored through ISO Schedules & SAP system in both the units.
	OEM Recommendations	Maintenance schedules are being prepared based on OEM recommendations of critical equipment such as Compressor, Gas Turbine, Extruder, Bagging Machines, etc.	OEM Recommendations	Maintenance schedules are being prepared based on OEM recommendations for Compressors, UPS systems, etc.	The interview data shows that the maintenance managers are using OEM recommendations for preparing maintenance schedules of critical equipment.
	Total Productive Maintenance (TPM)	No evidence of following TPM	Total Productive Maintenance (TPM)	No evidence of following TPM	TPM is not followed in both Petrochemicals & NG Pipelines
	Use of Reliability Based Maintenance	No RCM is being followed in the company. However, maintenance managers are interested to implement.	Use of Reliability Based Maintenance	No RCM is being followed in the company. However, maintenance managers are interested to implement.	RCM Techniques are not followed in both Petrochemicals & NG Pipelines.
	Emergency Maintenance	Emergency maintenance is being carried out in petrochemicals as and when required. However, the same is minimized by using various preventive & predictive maintenance techniques.	Emergency Maintenance	Emergency maintenance is lesser in NG pipelines due to standby equipment strategy are being followed.	Emergency maintenance is rare in NG Pipelines & minimum in Petrochemicals.
	Shutdown Maintenance	Shutdown maintenance is	Shutdown Maintenance	Shutdown maintenance is	Both the units are using shutdown

		crucial in petrochemicals unit since no stand-by strategy is available. Annual Turnaround Shutdown is being planned every year in petrochemicals		rare in NG Pipelines. Due to ageing of pipelines, the shutdown maintenance is being carried out in NG Pipelines also.	maintenance method. This method is emerging out from this empirical study.
	Pro-active maintenance	This maintenance method is based on experience of maintenance managers. Therefore, maintenance managers decide on selection of maintenance strategy considering their previous experience.	Nil	Nil	Pro-active maintenance is emerged out in case study 2 petrochemicals interview.
Reliability Analysis	Documentation of Equipment History	No evidence is found from interview data. However, documentary evidence show that Equipment History records are being maintained in Petrochemicals	Documentation of Equipment History	Equipment history is being documented in Compressor Stations of NG Pipelines unit	Documentation of Equipment History is being followed in both Petrochemicals & NG Pipelines.
	Root Cause Analysis (RCA)	Root Cause Analysis of plant shutdowns are being done & well documented by maintenance managers.	Root Cause Analysis	Root Cause Analysis (RCA) of incidents of pipeline & compressor shutdowns are being done and documented	RCA is being followed in both the units.
	MTBF	No evidence found in using such metrics in maintenance practice.	MTBF	No evidence found in using such metrics in maintenance practice.	No RCM metrics is used in both Petrochemicals & NG Pipelines.
	Value Risk Study of maintenance program	No evidence found in using such study in maintenance	Value Risk Study of maintenance program	No evidence found in using such study in	No RCM technique is used in both Petrochemicals & NG

		practice.		maintenance practice.	Pipelines.
	Equipment Criticality	Equipment & other instruments are being classified in to critical, semi-critical & non-critical; Accordingly, maintenance is being carried out.	Equipment Criticality	Equipment criticality is not applicable since stand-by strategy is being followed in NG Pipelines	Equipment criticality factor is common to both the units.
	Reliability Statistics of equipment/ assets	Not being is used. Simple metrics is being used such equipment availability, plant availability etc.	Reliability Statistics of equipment/ assets	Not being is used. Simple metrics is being used such equipment availability, plant availability etc.	Few basic metrics of Reliability Statistics is being practiced in both Petrochemicals & NG Pipelines.
	RCM based analysis	RCM Analysis is not being used in Petrochemicals maintenance	RCM based analysis	RCM Analysis is not being used in NG Pipelines maintenance	RCM Analysis is not being used in both petrochemicals & NG Pipelines.
Performance Measures/ Benchmarking	Breakdown Records	Records are being maintained by petrochemicals unit for measuring maintenance performance	Breakdown Records	Records are being maintained by NG Pipelines for measuring maintenance performance	Breakdown records are available in both the units & being maintained
	Key Performance Indicators	KPIs are available. Basically, these are derived from MOU Targets with Petroleum Ministry	Key Performance Indicators	KPIs are available. Basically, these are derived from MOU Targets with Petroleum Ministry	KPIs are based on MOU Targets assigned by Petroleum Ministry in both the units.
	Training man hours of maintenance staff	Each employee gets 2 days/ year training in Technical areas & behavioural skills in petrochemicals	Training man hours of maintenance staff	Each employee gets 2 days/ year training in Technical areas & behavioural skills in NG Pipelines	Structured Training process is available in the company
	Maintenance Performance Measures	Maintenance Performance is largely based on Internal & External Audit Process being conducted by external agencies like OISD, etc.	Maintenance Performance Measures	Maintenance Performance is largely based on Internal & External Audit Process being conducted by external agencies like PNGRB, etc.	Both units assessing their maintenance performance based on audits only. No separate Performance metrics are available.

	Internal Norms & Industry Norms	Petrochemical unit is following relevant Internal & Industry Norms as per applicable standards & statutory requirements.	Internal Norms & Industry Norms	NG Pipeline is following relevant Internal & Industry Norms as per applicable standards & statutory requirements.	Both units are following applicable industry norms & internal norms are being practiced as per standards.
	Benchmarking measures & targets	No International Benchmarks are being followed. But, MOU targets are treated as benchmarks since the company is market leader.	Benchmarking measures & targets	No International Benchmarks are being followed. But, MOU targets are treated as benchmarks since the company is market leader.	Industry Benchmarking measures being followed internationally does not exist in both the units' petrochemicals & NG Pipelines.
	Labour & Material Cost	No evidence of maintenance managers are giving importance to labour and material cost.	Labour & Material Cost	No evidence of maintenance managers are giving importance to labour and material cost.	Common to both & No evidence of cost consciousness among maintenance managers.
Planning & Scheduling	Plant Equipment Register	Being maintained in SAP PM module	Plant Equipment Register	Being maintained in SAP PM module	Both the units are maintaining the equipment registers in SAP ERP System.
	Standard written work order	Work orders are being maintained in SAP PM module based on ISO Schedules with the frequency of PM jobs planned.	Standard written work order	Work orders are being maintained in SAP PM module based on ISO Schedules with the frequency of PM jobs planned.	In both petrochemicals and NG Pipelines work order generation is being done automatically through SAP system based on ISO PM schedules.
	Availability PM schedules	PM Schedules are developed & configured in SAP PM module	Availability PM schedules	PM Schedules are developed & configured in SAP PM module and ISO Schedules are maintained in Pipelines.	Both petrochemicals & NG Pipelines are keeping PM schedules available
	Priorities of work order	Work orders priorities are assigned and being maintained in SAP PM module. The same is based equipment history &	Priorities of work order	Work orders priorities are assigned and being maintained in SAP PM module. The same is based	Both units are following the practice of prioritization of work orders.

		criticality of the equipment & process application type.		equipment history & criticality of the equipment.	
	Availability of work schedules for a week ahead	Work schedules are being maintained in SAP PM module and can be accessed any point of time based schedule.	Availability of work schedules for a week ahead	Work schedules are being maintained in SAP PM module and can be accessed any point of time based schedule.	Both units are following the practice of prioritization of work orders.
	Shutdown Maintenance Schedule	Shutdown jobs schedules are being maintained by maintenance managers separately. The shutdown jobs schedules are being prepared based on standards provided by OISD.	Shutdown Maintenance Schedule	Shutdown maintenance is rare. Therefore, there is no such detailed planning available with NG Pipelines.	Petrochemicals unit is maintaining detailed shutdown maintenance schedule. But, NG Pipelines is not maintaining such schedule due to nature of their operations.
	Measurement of work backlog	Backlog maintenance jobs are maintained in SAP PM module. The same is completed in the next available opportunity.	Measurement of work backlog	Backlog maintenance jobs are maintained in SAP PM module. The same is completed in the next available opportunity.	In SAP system, both the units are maintaining work backlog schedules. This gives measurement of work backlog.
	Long Term Plans to forecast major shutdown/ maintenance work	Shutdown maintenance planning is the long terms plans to forecast major jobs in petrochemicals unit. Each sub-unit maintains detailed shutdown maintenance plan.	Long Term Plans to forecast major shutdown/ maintenance work	Intelligent pigging is the primary activity from which long term planning is being done in the company. Long term planning is based on types of equipment, processes in plant and centralised procurement facilitates such planning in NG Pipelines' compressor stations.	Type of long term plan varies between petrochemicals & NG Pipelines due to nature of their operations.

Materials Management	Availability of Spares	Being ensured by maintenance department &	Availability of Spares	Availability of spares are being ensured by maintenance department using Centralised procurement method in NG pipelines for optimum cost of procurement & long term planning.	Availability of spares are ensured by Contracts & Procurement department in both the units
	Identified Spares	Being maintained by C & P Department	Identified Spares	Being maintained by C & P Department	Identification of spares is being done through SAP MM Module by C & P Department.
	Inventory Analysis	Being maintained in SAP MM module	Inventory Analysis	Being maintained in SAP MM module	Inventory Analysis is being done through SAP MM Module by C & P Department in both the units.
	Emergency purchase of spares	Being done by maintenance department in coordination with C & P Department	Emergency purchase of spares	Being done by maintenance department in coordination with C & P Department	Both units following the same methods as per C & P Department procedures.
	Average Inventory Turnover (AIT)	No evidence of following "Average Inventory Turnover" concept in the company	Average Inventory Turnover	No evidence of following "Average Inventory Turnover" concept in the company	AIT is not being practiced in both the units.
	Inventory control through computerised system	Being maintained in SAP PM module by Stores & concerned maintenance department	Inventory control through computerised system	Being maintained in SAP PM module by Stores & concerned maintenance department	Inventory control is being ensured in both the units through SAP system.
	Material Stores	Material Stores is available in all in the petrochemical plant	Material Stores	Material Stores is available in all the major work centres' in the company	Material stores available in both the units. In NG pipelines, the practice of centralised stores is there.
	Integration of inventory control	It is being done through SAP PM	Integration of inventory control with	It is being done through SAP PM	Integration of inventory control and

	with maintenance planning	Module by C & P department	maintenance planning	Module by C & P department	maintenance planning is done through SAP system.
Organisation/ Human Resources	Maintenance Staff Level	Maintenance Staff level is existing in the organisation	Maintenance Staff Level	Maintenance Staff level is existing in the organisation	Maintenance staff level is maintained in both the units.
	Maintenance Organisation	Well Structured maintenance organisation is existing	Maintenance Organisation	Well Structured maintenance organisation is existing	Common to both & followed
	Responsibility of first line supervisors	Supervisors' responsibilities are well defined.	Responsibility of first line supervisors	Supervisors' responsibilities are well defined.	Common to both & followed
	Adequacy of Support staff	Support staff is adequate. And staffs are also kept for emergency situations.	Adequacy of Support staff	Support staff is adequate. And staffs are also kept for emergency situations.	Common to both & followed
	Regular Technical Training	Technical training is being imparted to the employees in the structured manner including safety training.	Regular Technical Training	Technical training is being imparted to the employees in the structured manner including safety training.	Common to both & followed
	Apprenticeship program	No evidences from interview data. However, from company secondary data Apprentice program is available as per statutory requirements.	Apprenticeship program	No evidences from interview data. However, from company secondary data Apprentice program is available as per statutory requirements.	Common to both & followed
	Deployment of Contractors	The company is regularly deploying contract manpower including expert manpower from OEMs etc.	Deployment of Contractors	The company is regularly deploying contract manpower including expert manpower from OEMs etc.	Common to both & followed
Employee Empowerment	Multi skilled trade people	Multi skilled people are working in the company. They are being given training in various skills to handle the emergency.	Multi skilled trade people	Multi skilled people are working in the company. They are being given training in various skills to handle	Common to both & followed

				the emergency.	
	Operators based maintenance	OBM is not being followed in petrochemicals. Interview data is emerging clearly that operator is responsible for issuing work permits & to bring the equipment failures to the knowledge of maintenance personnel.	Operators based maintenance	OBM is being followed in small gas terminals/work centers and not being followed in major work centers. Interview data is emerging with contra arguments among the interviewees.	OBM is based on nature of gas terminal/ compressor station/ petrochemical. Therefore, depends on the work centre.
	Regular discussions with the staff by supervisors	Formal & informal interactions are being done by maintenance managers with the supervisors.	Regular discussions with the staff by supervisors	Formal & informal interactions are being done by maintenance managers with the supervisors.	Common to both & followed
	Self-directed work teams	Maintenance teams are self-directed. Evidences are there such as adopting safety norms, ready with emergency work plan, etc.	Self-directed work teams	Maintenance teams are self-directed. Evidences are there such as adopting safety norms, ready with emergency work plan, etc.	Common to both & followed
	Modifications done by maintenance teams	Modifications are being taken care by maintenance with the structured process of "Change Management System".	Minor modifications done by maintenance teams	Minor modifications are being taken care by maintenance with the structured process of "Change Management System".	Common to both & followed but nature varies in both the cases
	Partnership with key suppliers/contractors	Delegation of Powers and C&P procedures are facilitating the partnership with key suppliers/contractors.	Partnership with key suppliers/contractors	Delegation of Powers and C&P procedures are facilitating the partnership with key suppliers/ contractors.	Common to both & followed
Information Technology	Availability of computerised	SAP PM module is being used in the	Availability of computerised system	SAP PM module is being used in	Common to both & followed

	system for maintenance management	company	for maintenance management	the company	
	Availability of computerised system for materials management	SAP PM module is being used in the company	Availability of computerised system for materials management	SAP PM module is being used in the company	Common to both & followed
	Integration of maintenance & materials management modules Scheduling of major shutdowns using project management system	SAP PM module is being used in the company & SAP Sales module for material management	Integration of maintenance & materials management modules Scheduling of major shutdowns using project management system	SAP PM module is being used in the company & SAP GMS module for material management	Common to both & followed
	CBM supported with automated programs for data analysis	Real Time systems are available.	CBM supported with automated programs for data analysis	Real Time systems are available.	Common to both & followed
	Expert Systems for diagnostics	Distributed Control Systems (DCS), Vibration software systems are available.	Expert Systems for diagnostics	SCADA, Intelligent Pigging & Satellite based monitoring are available.	Common to both. Types of expert systems vary between two cases.
Maintenance Policies/ Budget	Maintenance mission & objectives	Clear maintenance mission & objectives are available in the company as per Maintenance Policy & MOU targets	Maintenance mission & objectives	Clear maintenance mission & objectives are available in the company as per Maintenance Policy & MOU targets	Common to both & followed
	Long term plans for maintenance function integrated with corporate plans	Company's mission & vision is integrated with the maintenance policy & objectives	Long term plans for maintenance function integrated with corporate plans	Company's mission & vision is integrated with the maintenance policy & objectives	Common to both & followed
	Company's maintenance policy	Maintenance Policy exists in the company.	Company's maintenance policy	Maintenance Policy exists in the company.	Common to both & followed
	Maintenance budget	Well defined budgeting system is available in the company.	Maintenance budget	Well defined budgeting system is available in the company.	Common to both & followed
Maintenance Challenges	Technical Issues	New factor emerging out from	Technical Issues	New factor emerging out from	Depends on individual case

		this study		this study	
	Contact Issues	New factor emerging out from this study	Contact Issues	New factor emerging out from this study	Depends on individual case
	Stakeholder Issues	New factor emerging out from this study	Stakeholder Issues	New factor emerging out from this study	Depends on individual case
	Internal Issues	New factor emerging out from this study	Internal Issues	New factor emerging out from this study	Depends on individual case
	No Standardisation of maintenance practices	New factor emerging out from this study	Unexpected Issues	New factor emerging out from this study	Depends on individual case
Selection of Maintenance Strategy for particular operation process/ equipment	Factors Contributing to maintenance strategy selection	New factor emerging out from this study	Factors Contributing to maintenance strategy selection	New factor emerging out from this study	Depends on individual case
	Specific maintenance strategy for Petrochemicals	New factor emerging out from this study	Specific maintenance strategy for NG pipeline	New factor emerging out from this study	Depends on individual case
	Internal & Industry Norms	New factor emerging out from this study	Internal & Industry Norms	New factor emerging out from this study	Depends on individual case

From the above Table 6.2, the critical observations are summarised as given under:-

Refers to the maintenance methods/maintenance approaches, the key observations are predictive maintenance is more used compare to preventive maintenance in NG Pipelines than petrochemicals, TPM & RCM techniques are not followed in both NG Pipelines & Petrochemicals, emergency maintenance is rare in NG Pipeline where in Petrochemicals the same is minimized by various maintenance tactics, and shutdown maintenance is crucial and plays an important role in petrochemicals.

Further, there is no evidence of cost minimisation concepts in maintenance in both NG Pipelines & petrochemicals. Operator based maintenance is being followed in small terminals/ SV stations in NG Pipelines. However, it is not followed in other major plants & compressor stations. Expert Systems used in equipment diagnosis are very specific to NG Pipelines & Petrochemicals and cannot be used interchangeably. The maintenance techniques used are also specific to a particular equipment/process in both NG Pipelines & Petrochemicals.

Proactive maintenance is the new maintenance tactic emerged out from the case study of petrochemicals and there is no evidence found regarding practice of proactive maintenance in NG Pipelines. It is worth to understand the maintenance challenges described by maintenance managers in order to effective maintenance planning. As mentioned above, these maintenance challenges are specific to a particular plant/process.

6.3 MAINTENANCE STRATEGIES & MAINTENANCE PRACTICES IN THE LARGE GAS UTILITY COMPANY– CROSS CASE FINDINGS

Based on the earlier literature on maintenance strategies & maintenance practices, nine constructs such as maintenance tactics, reliability analysis, performance measures/benchmarking, planning & scheduling, materials management, organisation/Human Resources, employee empowerment, information technology, maintenance policies/budget were expected to be identified as discussed in Chapter 2 (Section 2.6). This study has found evidences for all the nine constructs as empirical data categories in the cases of NG Pipelines and petrochemicals. One new category "maintenance challenges" is emerged out from this study in both the cases. Table 6.3 given below shows the cross case comparison of presence of processes and categories of constructs related to maintenance strategies & maintenance practices in both the case studies Petrochemicals & NG Pipelines of the large gas utility company in India. '1' in a column denotes the presence of the corresponding category in that case, where as a '0' denotes the absence. Shaded cells show the difference between both cases.

Table 6.3 Cross case Comparison of Case Study 1 & Case Study 2

Categories from empirical data (Case Study-1 & Case Study-2)	**Sub-categories from empirical data (Case Study-1 & Case Study-2)**	**(Case Study-2) Petro-chemicals**	**(Case Study -1) NG Pipelines**
Maintenance Tactics	Predictive Maintenance (CBM)	1	1
	Predictive Maintenance (CBM) & preventive maintenance (TBM) Ratio	1	1
	Preventive Maintenance (TBM)	1	1
	Completion of PM schedules	1	1
	OEM Recommendations	1	1
	Total Productive Maintenance (TPM)	0	0
	Reliability Based Maintenance (RCM)	0	0
	Emergency Maintenance	1	1
	Shutdown Maintenance	1	1
	Pro-active maintenance	1	0
Reliability Analysis	Documentation of Equipment History	0	1
	Root Cause Analysis	1	1
	Mean Time Between Failures (MTBF)	0	0
	Value Based Risk Study	0	0
	Equipment Criticality	1	1
	Reliability Statistics	0	0
	RCM Based Analysis	0	0
Performance Measures/ Benchmarking	Breakdown Records	1	1
	Key Performance Indicators	1	1
	Training man hours of maintenance staff	1	1
	Maintenance Performance Measures	1	1
	Internal Norms & Industry Norms	1	1
	Benchmarking measures & targets	1	1
	Labour & Material Cost	0	0

Planning & Scheduling	Plant Equipment Register	1	1
	Standard written work order	1	1
	Availability PM schedules	1	1
	Priorities of work order	1	1
	Availability of work schedules	1	1
	Shutdown Maintenance Schedule	1	1
	Measurement of work backlog	1	1
	Long Term Plans to forecast major shutdown/ maintenance work	1	1
Materials Management	Availability of Spares	1	1
	Identified Spares	1	1
	Inventory Analysis	1	1
	Emergency purchase of spares	1	1
	Average Inventory Turnover	0	0
	Inventory control through computerised system	1	1
	Material Stores	1	1
	Integration of inventory control with maintenance planning	1	1
Organisation/Human Resources	Maintenance Staff Level	1	1
	Maintenance Organisation	1	1
	Responsibility of first line supervisors	1	1
	Adequacy of Support staff	1	1
	Regular Technical Training	1	1
	Apprenticeship Program	1	1
	Deployment of Contractors	1	1
Employee Empowerment	Multi skilled trade people	1	1
	Operators based maintenance	1	1
	Regular discussions with the staff by supervisors	1	1
	Self-directed work teams	1	1
	Modifications done by maintenance teams	1	1
	Partnership with key suppliers/contractors	1	1

Information Technology	Availability of computerised system for maintenance management	1	1
	Availability of computerised system for materials management	1	1
	Integration of maintenance & materials management modules	1	1
	Scheduling of major shutdowns using project management system	1	1
	CBM supported with automated programs for data analysis	1	1
	Expert Systems for diagnostics	1	1
Maintenance Policies/ Budget	Maintenance mission & objectives	1	1
	Long term plans for maintenance function integrated with corporate plans	1	1
	Company's maintenance policy	1	1
	Maintenance budget	1	1
Maintenance Challenges	Technical Issues	1	1
	Contact Issues	1	1
	Stakeholder Issues	1	1
	Internal Issues	1	1
	Standardisation of maintenance practices	1	0
	Unexpected Issues	0	1

Refers to the above Table 6.3, certain inferences about the nature of maintenance strategies selection processes and maintenance practices in the large gas utility company can be drawn as discussed below.

Both the case studies found evidences for all the maintenance tactics types such as Preventive maintenance/time based maintenance, predictive maintenance/condition based maintenance, emergency maintenance, OEM Recommendations except Total Productive Maintenance (TPM) and Reliability Centred Maintenance (RCM). These maintenance methods are not being practiced in both the business verticals of the large gas utility company. Two new categories emerged out from this study such as shutdown maintenance and proactive maintenance. Both the case studies show the evidences for shutdown maintenance. However, case study-2 on petrochemicals shows the evidences for proactive maintenance. Maintenance managers/engineers indicated that the NG Pipeline uses the predictive maintenance to the large extent compare to preventive maintenance since because NG Pipelines are operating on continuous basis (24 X 7 Basis) and it is having standby equipment. It does not require any shutdown maintenance. But, in petrochemicals shutdown maintenance plays a crucial role because the plant does not have standby equipment. Based on these inferences following propositions are made with regard to maintenance tactics used for maintenance strategies formulation.

P1 (a): *Predictive Maintenance approach is more likely to be used compare to Preventive Maintenance approach in NG Pipelines*

P1 (b): *Shutdown Maintenance approach plays a crucial role in Petrochemicals plant*

Evidences were found for all the sub-categories (focused codes) in reliability analysis category of empirical data in both the case studies. As indicated by the maintenance managers/engineers during interview, the reliability based analysis, reliability statistics, value based risk study, and MTBF metrics are not being practiced in the company. However, the maintenance mangers/engineers know the important of these statistics & analysis. Further, they wish to implement the same.

Both the case studies have found evidences for all the sub-categories in performance category of empirical data except “labour & material cost” in both the case studies as shown in Table 6.3. Benchmarking exercises was carried out by the gas utility company 12 years back. Benchmark parameters are not related to maintenance measures instead the parameters are mostly of operational targets.

Evidences were found for all the sub-categories in planning & scheduling category of empirical data from both the case studies. All these sub-categories emerged out are being practiced by the large gas utility company. The activities related to planning & scheduling are managed by enterprise resource planning application SAP in the company. Since shutdown maintenance is crucial to petrochemicals plant, the long term planning & scheduling is more relevant to petrochemical plant. Based on this inference, following proposition is made with regard to planning & scheduling of maintenance strategies and their implementation.

P2: *Petrochemicals plant is more likely to use long-term planning & scheduling as compared to NG Pipelines.*

Both the case studies have found evidences for all the sub-categories in materials management category of empirical data. All these sub-categories emerged out are being practiced by the large gas utility company. Material management is being done through enterprise resource planning application SAP MM Module. Both NG Pipelines & petrochemicals are using similar systems & methods for materials management. Based on the inferences following proposition is made with regard to materials management approaches used in maintenance.

P3: *There is no difference in use of materials management approaches in both NG Pipelines & Petrochemicals plant.*

Evidences were found for all the sub-categories in organisation/HR category of empirical data on both the case studies. All these sub-categories emerged out are being practiced by the large gas utility company. Human resources support for maintenance practices are same in both NG Pipelines & petrochemicals plant as described by maintenance managers. Based on the inferences following proposition is made with regard to organisation/HR support to maintenance strategies development and implementation.

P4: *There is no difference in nature of organisation/HR support to both NG Pipelines & Petrochemicals plant.*

This study has found evidences for all the sub-categories in information technology category of empirical data in both the case studies. The gas utility company has leveraged information technology to the possible extent in implementing maintenance activities in the organisation. For material management, maintenance management and their integration with planning & execution are being managed through enterprise resource planning application SAP in the gas utility company. The category emerged out expert systems for diagnostics category from empirical data reveals that the expert systems are different in both business vertical. Further, expert systems are based nature of process and type of equipment. These inferences lead to the following proposition with reference to information technology application in maintenance strategies selection and maintenance practices.

P5: *There is a difference in types of expert systems used for maintenance diagnostics in NG Pipelines & Petrochemicals and the expert systems are likely to be based on the nature of process & type of equipment.*

Evidences were found for all the sub-categories in maintenance policies/budget category of empirical data in both the case studies. Maintenance policies provide guidelines for maintenance strategy selection in NG Pipelines & Petrochemicals. Well-structured budget system helps maintenance mangers to streamline maintenance related jobs. Based on these inferences following proposition is made with regard to maintenance policies & maintenance budget systems prevailing in the gas utility company.

P6: *There is no difference in maintenance policies/maintenance budget systems in both NG Pipelines & Petrochemicals plant.*

The empirical data analysis of both the case studies has emerged out with the new category "Maintenance Challenges". The first four sub-categories are technical issues, contract issues, internal issues, and stakeholder issues are depending on the individual case. i.e., the issues are difference in both NG pipelines & petrochemicals. Similarly, NG Pipelines case study emerged with a sub-category unexpected issues which are pertaining to NG Pipeline only. Petrochemicals case study emerged with a sub-category standardisation of maintenance practices. These inferences lead to the following propositions with reference to role of maintenance challenges in maintenance strategies selection and maintenance practices.

P7 (a): *Maintenance challenges are likely to be of different nature in Petrochemicals & NG Pipelines. These challenges are likely to be specific to plant operations/processes/equipment.*

P7 (b): *Unexpected issues in NG Pipelines are the major maintenance challenges to maintenance managers/engineers in NG Pipelines.*

P7 (c): *Standardisation of maintenance practices in Petrochemicals is the major maintenance challenge to maintenance managers/engineers in Petrochemicals.*

The categories identified from the empirical data are found similar with the Initial Conceptual Constructs identified from literature review. But, the extent of application of these categories varies in both the cases NG Pipelines & Petrochemicals. The details of cross case findings in terms of these categories are presented in above Table 6.2. Therefore, this study indicates that the categories emerged out such as maintenance tactics, reliability analysis, performance measures, planning & scheduling, employee empowerment, materials management, human resources, information technology, maintenance policy/budget, and maintenance challenges which forms the basis for maintenance strategies selection & maintenance practices in the large gas utility company. Based on these inferences, the following proposition is developed.

P8: *The factors such as maintenance tactics, reliability analysis, performance measures, planning & scheduling, employee empowerment, materials management, human resources, information technology, maintenance policy/budget, and maintenance challenges form basis for maintenance strategies selection & maintenance practices.*

This completes the cross case comparison of factors contributing to maintenance strategies & maintenance practices in the gas utility company. Next, section discusses the cross case findings for maintenance strategies selection processes.

6.4 MAINTENANCE STRATEGIES SELECTION PROCESSES IN THE LARGE GAS UTILITY COMPANY – CROSS CASE FINDINGS

Based on the earlier literature on Section 2.5.3 (selection of maintenance strategies) and Section 2.5.5 (maintenance decision support system), it is expected to identify the processes related to maintenance strategy selection such as application of mathematical models such as AHP, Fuzzy AHP, VIKOR, etc. and use of optimisation models for selection of maintenance strategy mix. As discussed in section 4.4 & section 4.5, no evidences are found of using such mathematical or optimisation models for selection of maintenance strategies in NG Pipelines and Petrochemicals of the large gas utility company.

As indicated by maintenance managers of the large gas utility company, maintenance strategies selection process of the company involve the following major activities (i) maintenance strategies selection based on previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process, (ii) specific maintenance strategies pertaining to NG

Pipelines/Petrochemicals, and (iii) internal & industry norms. Based on these activities, the cross case comparison is as shown in Table 6.4 below.

Table 6.4 Cross case findings: maintenance strategies selection process

Activities related maintenance strategies selection	**NG Pipelines (Case Study -1)**	**Petrochemicals (Case study- 2)**
Maintenance strategies selection guidelines & practices	Previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process.	Previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process.
Specific maintenance strategies	Intelligent pigging, vibration monitoring system, standby equipment, cathodic protection, helicopter patrolling & pipeline integrity management.	Shutdown maintenance, upgradation of equipment based on technology changes, implementation of vibration analysis application, and use of smart instruments.
Internal & industry norms	Implementation of T4S standard, PNGRB guidelines, and OISD standards. & Internal norms such Integrated Management Systems (IMS).	Implementation of international standards, OISD standards like OISD 178, PNGRB guidelines & Internal norms such Integrated Management Systems (IMS).

As discussed in the above Table 6.3, almost all of the processes/sub-processes was found to be present in both the case studies. Based on these inferences, the following propositions are made with regard to maintenance strategies selection processes in the gas utility company.

P9 (a): *In NG Pipelines & Petrochemicals operations, mathematical modelling and maintenance optimisation models are least likely to be used for maintenance strategy selection process.*

P9 (b): *Maintenance strategy selection process involves maintenance strategies selection guidelines & practices, specific maintenance strategies for a particular process/equipment, and internal & industry norms.*

6.5 RELATONSHIP BETWEEN MAINTENANCE STRATEGIES & PRACTICES AND MAINTENANCE STRATEGIES SELECTION PROCESSES - CROSS CASE FINDINGS

Earlier literature has found various models in chapter 2 (section 2.7) which explains the relationship among various factors contributing to maintenance strategies & maintenance practices. Such models/frameworks discuss about maintenance strategies formulation, selection of maintenance strategies, and implementation of the selected maintenance strategies. A common thread in all these models/frameworks is alignment between business strategies and maintenance strategies in an organisation (McAllister, 1999; Kelly, 2006; Salonen, 2011). In a model proposed by Pintelon & Parodi (2008), outcome of maintenance strategies are shown as maintenance concepts such RCM, TPM, BCM, LCC, etc. and maintenance policies such as Preventive Maintenance, Predictive maintenance, etc. A framework for maintenance strategic planning identified nine function such as identification of major stakeholders, formulation mission statement, setting of the strategic objectives of maintenance, analysis of the current situation, identification of the strategic issues, strategic options, strategy selection, development of performance measures, and implementation planning (Umar, 2011). Further, a framework on maintenance strategies formulation, selection and implementation and its impact on maintenance function discuss about factors contributing to maintenance strategy formulation and selection such as maintenance tactics, reliability analysis, performance measures/benchmarking, planning & scheduling, materials management, organisation/HR, information technology, and maintenance policies/budget based on detailed literature survey (Velmurugan & Dhingra, 2014).

The study could find evidence of relationship between the factors contributing to maintenance strategies & maintenance practices and the maintenance strategies selection processes in both the case studies. As indicated by the maintenance managers/engineers during interview, the alignment between business strategies and maintenance strategies are done through the MOU/IMOU targets in the gas utility company. Corporate MOU targets are formulated based on business strategies. Further, these targets are percolated to work centre level, unit level, and individual level by linking corporate MOU targets to individual level targets. Further, strategy 2020 activities of the large gas utility company are broken into department levels to achieve the overall objectives of the company. Based on these inferences the following proposition is made with reference to relationship between the factors contributing maintenance strategies selection and its processes.

P10: *Business objectives & operations objectives are most likely to be aligned with maintenance objectives at an organisation level in the gas utility company.*

Organisation's business strategy has been aligned with maintenance strategy with the help of MOU targets. These targets are developed at corporate level aligning with the company's business strategy. Then, these targets are percolated down into the level to work centre level, unit level, department level and further to individual level. There is a clear evidence is available for such an integration in the gas utility company from the empirical data.

P11: *Integration between organisation's business strategy and maintenance strategy provides an effective implementation of maintenance strategies.*

There is sufficient evidence available from empirical data that both the petrochemicals & NG Pipelines are using the e-maintenance concepts for effective & efficient implementation of maintenance strategies. Few such maintenance concepts are shown in the below given Table 6.5.

Table 6.5 e-Maintenance concepts being practiced in NG Pipelines & Petrochemicals

e- Maintenance Concept	**Petrochemicals**	**NG Pipeline**
Distributed Control System (DCS)	Majorly used in Plant Operations & process optimisation.	Not used
Supervisory Control And Data Acquisition (SCADA) System	Not used	Majorly used in NG Pipeline Operations & Remote monitoring of gas terminals/stations
Vibration Monitoring System & Software	Used to monitor the healthiness of equipment such as Compressors, turbines etc. Inputs are being used to do predictive maintenance.	Used to monitor the healthiness of equipment such as Compressors. Inputs are being used to do predictive maintenance.
SAP – Plant Maintenance Module (SAP PM)	Used to integrate all maintenance process and co-processes such as material management, sales management etc.	Used to integrate all maintenance process and co-processes such as material management, sales management etc.

Based on the above inferences the following proposition is made with reference to e-maintenance concept in implementation of maintenance strategies.

P12: *e- maintenance concepts are likely to be used for efficient implementation of the maintenance strategies.*

In the gas utility company, e-maintenance concepts are implemented through enterprise resource planning application SAP system. In SAP system, specific module is available for managing maintenance function i.e., Plant

Maintenance module (SAP-PM module). SAP PM Module manages and integrates the maintenance activities such PM scheduling, planning, issuing of work permits, maintaining equipment history, work instructions records etc., Further, PM Module is integrated with material management module (SAP-MM module) for planning of spares, issuing of material etc. The data available in the SAP system helps the company to review its maintenance policy at the company level.

P13 (a): *Enterprise resource planning application is likely to be used in the company to integrated maintenance management activities with material management activities.*

P13 (b): *Enterprise resource planning application is likely to be used to implement the maintenance strategies & formulate maintenance policies at company level.*

It is evident from the empirical data that manufacturing/production capabilities of the company are getting enhanced by integrating maintenance strategy companywide. For example, all gas processing plants of the large gas utility company are grouped and uniformity maintained in maintenance activities, production targets, MOU targets, internal norms, etc. Similar common processes/norms are available in the company for petrochemicals, NG pipelines and LPG pipelines. Such kind of companywide integration helps the company to enhance its production capabilities.

P14: *The manufacturing/ production capabilities of the large gas utility company enhances by integrating maintenance strategies companywide.*

6.6 CROSS CASE FINDINGS INTERMS OF RESERACH QUESTIONS

The cross case study findings are summarised in terms of research questions and presented below:-

Findings related to CRQ: *How the gas utility company is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as petrochemicals & pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?*

Maintenance strategies & maintenance practices of the gas utility company are based on the activities in the areas of categories such as performance measures/benchmarking, planning & execution, materials management, organisation/HR, employee empowerment, information technology, maintenance policies, maintenance budgeting systems, reliability in maintenance, and maintenance challenges. Further, maintenance strategies selection process of the company involve the following major activities (i) maintenance strategies selection based on previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process, (ii) specific maintenance strategies pertaining to NG Pipelines/Petrochemicals, and (iii) internal & industry norms.

The large gas utility company in India is planning & executing its maintenance strategies majorly based on: overall company's maintenance policy guidelines, MOU/ IMOU targets, maintenance challenges faced by maintenance managers/engineers such as ageing of assets, dependency on OEM, and contract issues. Specific maintenance strategies are selected in the gas utility company majorly based on: OEM (Original Equipment Manufacturer) recommendations, standard industry practices and past experience of maintenance managers.

Findings related to additional RQ1:- *What are the common and different maintenance strategies & practices to both the business verticals (and) how the maintenance strategy & practices differ with the specific assets available* *in one operation process/plant/pipeline network from others business verticals?*

In both business verticals such as NG Pipelines & petrochemicals, the maintenance methods in practices are preventive maintenance, predictive maintenance, emergency/breakdown maintenance. Predictive Maintenance is more used compare to preventive maintenance in NG Pipelines than petrochemicals. Emergency maintenance is very rare in NG Pipeline where in Petrochemicals the same is minimized by various maintenance tactics. Shutdown maintenance is very crucial & plays an important role in petrochemicals. Maintenance techniques used are also very specific to systems in NG Pipelines & Petrochemicals. For example cathodic protection, intelligent pigging, helicopter patrolling, etc. are the specific maintenance strategies used in NG Pipelines. However, shutdown maintenance is the specific maintenance strategy in Petrochemicals. Also, proactive maintenance is the new maintenance tactic emerged out from the case study of petrochemicals and the same is not being practiced in NG Pipelines. Proactive maintenance is based on experience of maintenance managers/engineers. Maintenance challenges are different in petrochemicals & NG Pipelines. Standardisation of maintenance practices is the major maintenance challenge in Petrochemicals. However, natural disaster & sabotage of pipelines are the major maintenance challenges in NG Pipelines.

Findings related to additional RQ2:- *How the reliability of the operation process/ equipment/assets is ensured by the maintenance strategy used for the particular operation process/equipment/assets?*

Reliability Centred Maintenance (RCM) technique is not being practiced in the large gas utility company. Therefore, the RCM metrics such as MTBF, Value Risk Study are not being used in maintenance. To take care of reliability of maintenance, the methods being practiced in the company that is Root Cause Analysis of maintenance failure & Incident Analysis Report (IAR).

Findings related to additional RQ3: *What are the benchmarks being used in petrochemicals/ NG pipelines? What is extent of achievement of benchmark parameters in practices?*

Benchmark report (2002) is available but it is not being practiced fully in the company. From the documentary evidence, it is found that one parameter maintenance cost is benchmarked i.e., 0.83 % of Gross Block (Inflation Adjusted). MOU targets are being treated as benchmarks by the maintenance managers since the company is market leader in NG Pipelines. Maintenance performance is assessed through Internal Audits & External Audits.

Benchmarks parameters related to maintenance performance are being used in the company are very few. Most of the parameters are operational parameters which are derived from MOU targets. Comparison of benchmark was done with *Benchmark metrics (John S Mitchell, 2002).* From the comparison, it is found that the gas utility company is not using most of the maintenance benchmark practices in practice. Detailed cross case findings on benchmarking in maintenance are discussed in next section.

6.6.1 Bench marking in Maintenance – Cross Case Findings

Further to understand the existing practices of benchmarking of the gas utility company, it is evident benchmarks are being used in both the business verticals petrochemicals & NG pipelines of the large gas utility company. However, few maintenance managers feel that the company is the market leader in the NG Pipeline, therefore whatever achieving in their business can be claimed as benchmarks. "Internal norms are based on MOU & IMOU targets which are defined by ministry & corporate management. GAIL is a market leader in gas industry therefore, GAIL's operating parameters itself can be taken as benchmarks which are comparable to global benchmarks" – Senior Manager (Mechanical). Another view is the company could achieve 99 percentage pipelines availability therefore, no benchmarking is required. "The bench mark for NG pipeline is availability of pipeline must be 99.9 %. GAIL is always achieving this target. Therefore, bench marks may be taken as parameters which come from MOU targets" – Manager (Pipeline O & M). However, industry practices of benchmarking have been studied for comparison of existing maintenance practices of the large gas utility company. The details are discussed in subsequent paragraphs thoroughly.

Benchmarking is an evolutionary process. The types of benchmarking are internal benchmarking, similar Industry/Competitive industry benchmarking, and best practices benchmarking (Wireman, 2002). Internal benchmarking involves different departments or processes within a plant/company. The greatest disadvantage of internal benchmarking is that it is unlikely to result in any major breakthrough in improvements. Nevertheless, internal benchmarking will lead to small, incremental improvements and should provide adequate return on investment (ROI) for any improvements that are implemented. Similar industry or competitive benchmarking uses external partners in similar industries or processes. In competitive benchmarking, small or incremental improvements are noted, but paradigms for competitive businesses are similar. Thus, the improvement process will be slow.

Best practice benchmarking focuses on finding the unarguable leader in the process being benchmarked. This search, which crosses industry sectors and geographical locations, provides the opportunity for developing breakthrough strategies for a particular industry. The organisation studies business processes outside its industry, adapts or adopts superior business processes, and makes a quantum leap in performance compared to its competitors. Being the early adaptor or adopter will give the organisation an opportunity to lower costs or aggressively capture market share.

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John S Mitchell et.al (2002) discussed benchmark parameters for maintenance in their book. The same is as shown in the below given Table 6.6. These metrics are based on the data collected from various industries. These metrics may vary from industry to industry and with time.

Table 6.6- Benchmark Metrics (John S Mitchell, 2002) for Maintenance & Comparison with GAIL's Metrics

Category	**Metrics**	**Benchmark**	**GAIL's Metrics**
Yearly Maintenance Costs	Total Maintenance Cost/ Total Manufacturing Cost	< 10-15 %	0.83% of Gross Block (Inflation Adjusted)
	Maintenance Cost/ Replacement Asset Value of the plant or equipment	< 3 %	No metric is available
Hourly Maintenance workers as a % of Total		15 %	No metric is available
Planned Maintenance	Planned Maintenance / Total Maintenance	>85 %	No metric is available
	Planned and Scheduled maintenance as a % of Hours Worked	85% - 95%	No metric is available
Unplanned Down Time		0 %	No metric is available
Reactive Maintenance		< 15%	No metric is available
Run-To-Fail (Emergency + Non-Emergency)		< 10%	No metric is available
Maintenance Overtime	Maintenance Overtime/ Company's total overtime	< 5%	No metric is available
Monthly maintenance	Work orders Reworked / Total Work orders	0 %	No metric is available

Rework			
Inventory Turns	Turns Ration of Spare Parts	>2-3	No metric is available
Training	For at least 90% of workers, hrs./year	>80 hrs./year	Training Policy is available 2 days training/ per employee/per year to cover all the employees
	Spending on worker training (% of payroll)	4%	2%
Safety Performance	OSHA recordable injuries per 200,000 labour hours	<2	Yes available
	House keeping	96%	No metric is available
Monthly Maintenance Strategies	PM= Total PM Hours / Total Maintenance Hours Available	20%	No metric is available
	PDM/CBM = Total PDM Hours / Total Maintenance Hours Available	50%	No metric is available
	PRM = Total PRM Hours / Total Maintenance Hours Available	20%	No metric is available
	REM= Total REM Hours / Total Maintenance Hours Available	2%	No metric is available
	RNEM = Total RNEM Hours / Total Maintenance Hours Available	8%	No metric is available
Plant Availability	Available Time/ Maximum Available Time	>97%	Metric is available for NG pipelines availability is 99% & for Petrochemicals plant availability is 95%
Contactor's Cost	Contractor's Cost/ Total Maintenance Cost	35-64 %	No metric is available

In addition to the above comparison, one more comparison with industry benchmarks is also presented below. While some metrics are easier to quantify than others, below table (Table 6.7) provide guidelines for tracking and trending metrics against industry benchmarks (NASA 2000).

Table 6.7- Benchmark Metrics (NASA, 2000) for Maintenance & Comparison with GAIL's Metrics of both the Case Studies 1 & 2

Metric	**Variables and Equation**	**Benchmark**	**GAIL's Metrics**	**NG Pipelines (Case Study 1)**	**Petrochemicals (Case Study 2)**
Equipment Availability (%)	% = [Hours each unit is available to run at capacity / Total hours during the reporting time period]	> 95%	% Availability = [Total hours - (Planned & Unplanned Down Time)] x 100 Total Hours	> 99%	> 95%
Schedule Compliance (%)	% = [Total hours worked on scheduled jobs/ Total hours scheduled]	> 90%	No metric is available	-	-
Emergency Maintenance Percentage	% = [Total hours worked on emergency jobs /Total hours worked]	< 10%	No metric is available	-	-
Maintenance Overtime Percentage	% = [Total maintenance overtime	< 5%	No metric is available	-	-

	during period/ Total regular maintenance hour during period]				
Preventive Maintenance Completion Percentage	% = [Preventive maintenance actions completed /Preventive maintenance actions scheduled]	> 90%	No metric is available	-	-
Preventive Maintenance Budget/Cost	% = [Preventive maintenance cost /Total maintenance cost]	15% – 18%	No metric is available	-	-
Predictive Maintenance Budget/Cost	% = [Predictive maintenance cost /Total maintenance cost]	10% – 12%	No metric is available	-	-

Based on above data, it is clearly understood that gas utility company is not using various benchmark metrics which are being used by various industries. Even though, all the maintenance strategies highlighted in the metrics are being practiced by the company, these practices are not being measured in formal way.

6.7 CONCLUDING REMARKS

This chapter presented and discussed the cross-case analysis of Petrochemicals and Natural Gas Pipeline of large gas utility company cases. Similarities and dissimilarities between these two case studies have been discussed in detail.

The findings from the two cases were compared for maintenance strategies & maintenance practices, maintenance strategies selection processes, and relationship between the factors contributing to maintenance strategies & maintenance practices and maintenance strategies selection processes. All the initial conceptual constructs related to maintenance strategies & maintenance practices from literature were found to present in both the case studies NG Pipelines and Petrochemicals. Even all the sub constructs from literature are also common to both the case studies. Inference were drawn from the cross case comparisons and these inferences were converted into propositions. A total of 14 propositions have been developed.

Next chapter summarises the research findings and provides conclusions of this research study.

CHAPTER 7
CONCLUSIONS

7.1 INTRODUCTION

This chapter summarises the findings and results of this research study. The contributions of this research to theory and management practice are discussed in detail in this chapter. First, the theoretical framework is revisited covering all qualitative associative networks for maintenance strategies & maintenance practices, maintenance strategies selection processes, and the relationship between these processes & maintenance strategies (Section 7.2). Next emergent categories of activities are described (Section 7.3) along with the detailed contributions to theory and practice (Section 7.4 & 7.5). This chapter concludes with a discussion on the limitations of this research and the scope for future research (Section 7.6 & 7.7).

7.2 REVISITING THEORETICAL FRAMEWORK

Chapter two describes the theoretical framework developed for maintenance strategies & maintenance practices. Initial conceptual constructs and sub-constructs for maintenance strategies & maintenance practices are discussed in section 2.6. Maintenance strategies selection processes are discussed in section 2.5.3 & 2.5.5. Further, relationship between maintenance strategies selection and maintenance strategies & practices are discussed through various maintenance strategy models/frameworks in section 2.5.7. This section presents the updated conceptual framework by incorporating the findings of the research for maintenance strategies selection processes and maintenance strategies & practices.

7.2.1 Maintenance Strategies and Maintenance Practices

As shown in Table 7.1, earlier literature discussed nine conceptual constructs which forms the basis for maintenance strategies & maintenance practices (Section 2.6). These constructs were expected to be found in the maintenance strategies & maintenance practices of the large gas utility company. Ten categories have been found from the empirical data in this research study which includes the new category emerged out i.e., Maintenance Challenges. A list of all the categories found from empirical data is as given under:-

1. Maintenance Tactics
2. Reliability Analysis
3. Performance measures/Benchmarking
4. Planning & Scheduling
5. Organisation/ Human Resources
6. Materials Management
7. Employee Empowerment
8. Information Technology
9. Maintenance Policies/ Budget
10. *Maintenance Challenges*

Table 7.1 Categories contributing to Maintenance Strategies & Maintenance Practices

Initial conceptual construct identified in LR	**Sub-constructs identified in LR**	**Categories emerged out from this study**	**Sub-categories emerged out from this study**
Maintenance Tactics	Predictive Maintenance/ Condition Based Maintenance (CBM)	**Maintenance Tactics**	Predictive Maintenance/ Condition Based Maintenance (CBM)
	Preventive Maintenance /		Preventive Maintenance /

	Time Based Maintenance (TBM)		Time Based Maintenance (TBM)
	Total maintenance hours devoted to Predictive Maintenance / Preventive Maintenance		Ratio between Predictive Maintenance / Preventive Maintenance
	Compliance of PM Schedules		PM Schedules completion
	OEM (Original Equipment Manufacturer) Recommendations		OEM (Original Equipment Manufacturer) Recommendations
	Reliability Based Maintenance (RBM)		*No evidences for use of RBM*
	Total Productive Maintenance (TPM)		*No evidences for use of TPM*
	Emergency/breakdown Maintenance		Emergency Maintenance
	Nil		*Shutdown Maintenance*
	Nil		*Proactive Maintenance*
Reliability Analysis	Documentation of Equipment History	**Reliability Analysis**	Documentation of Equipment History
	Equipment Criticality		Equipment Criticality
	Root Cause Analysis (RCA)/Incident Analysis (IA)		Root Cause Analysis (RCA)/Incident Analysis (IA)
	Mean Time Between Failures (MTBF)		*No evidences found regarding use of this metric MTBF*
	Value Risk Study of maintenance program		*No evidences found in this study regarding value risk study*
	Reliability statistics of equipment/assets		Evidences found regarding use of few basic metrics. However, reliability statistics are not being practiced.
	Reliability Centred Maintenance (RCM) based analysis		*No evidences found in this study regarding use of RCM*
Performance	Labour and material cost	**Performance**	*No evidences found*

Measures/ Benchmarking		**Measures/ Benchmarking**	*regarding use of Labour cost/Material cost for maintenance performance measurement*
	Maintenance Performance Measures		External/ Internal Audits
	Key Performance Indicators (KPI)		*MOU Targets*
	Downtime Records		Downtime Records
	Training man hours of maintenance staff		Training man hours of maintenance staff
	Internal Norms & Industry Norms		Internal Norms & Industry Norms
	Benchmarking measures & targets		*No evidences found regarding benchmarks*
Planning & Scheduling	Plant Equipment Register	**Planning & Scheduling**	Plant Equipment Register
	Standard written work order		Standard written work order
	Availability of PM Schedules		Availability of PM Schedules
	Priorities of work order		Priorities of work order
	Availability of Work schedule for a week ahead		Availability of Work schedule for a week ahead
	Shutdown Maintenance Schedule		Shutdown Maintenance Schedule
	Measurement of work backlog		Measurement of work backlog
	Long Term Plans to forecast major shutdown/maintenance work		Long Term Plans to forecast major shutdown/maintenance work
Materials Management	Spares availability	**Materials Management**	Spares availability
	Identified spares		Identified spares
	Inventory analysis		Inventory analysis
	Emergency purchase of spares		Emergency purchase of spares
	Average Inventory Turnover		Average Inventory Turnover
	Availability of Stores		Availability of Stores
	Inventory control through computerised system		Inventory control through computerised system

	Integration of Inventory Control with maintenance planning		Integration of Inventory Control with maintenance planning
Organisation/ Human Resources	Maintenance staff level	**Organisation/ Human Resources**	Maintenance staff level
	Maintenance organisation		Maintenance organisation
	Responsibility of first line supervisors		Responsibility of first line supervisors
	Adequacy of support staff		Adequacy of support staff
	Regular Technical training		Regular Technical training
	Apprenticeship program		Apprenticeship program
	Deployment of Contractors		Deployment of Contractors
Employee Empowerment	Multi-skilled Trade People	**Employee Empowerment**	Multi-skilled Trade People
	Operators Based Maintenance		Operators Based Maintenance
	Regular discussion with the staff by supervisors		Regular discussion with the staff by supervisors
	Self-directed work teams		Self-directed work teams
	Minor modifications done by maintenance teams		Minor modifications done by maintenance teams
	Partnership with key suppliers/contractors		Partnership with key suppliers/contractors
Information Technology	Availability of computerised system for maintenance management	**Information Technology**	Availability of computerised system for maintenance management
	Availability of computerised system for materials management		Availability of computerised system for materials management
	Integration of maintenance management & materials management modules		Integration of maintenance management & materials management modules
	Scheduling of major Shutdown using project management system		Scheduling of major Shutdown using project management system
	CBM supported with automated programs for data analysis		CBM supported with automated programs for data analysis
	Expert systems for diagnosis		Expert systems for diagnosis
Maintenance	Maintenance mission &	**Maintenance**	Maintenance mission &

Policies/ Maintenance Budget	objectives	**Policies/ Maintenance Budget**	objectives
	Long term maintenance plans integrated with business plans		Long term maintenance plans integrated with business plans
	Maintenance Policies		Maintenance Policies
	Maintenance budget		Maintenance budget

As shown in above Table 7.1, two new sub-categories have also been emerged out from this research study. They are,

1. Shutdown Maintenance
2. Proactive Maintenance

These two types of maintenance tactics play a vital role in maintenance strategies selection & maintenance practices of the large gas utility company.

Further, this research uncovered the above categories related to maintenance strategies & maintenance practices planning and execution in detail. Figures (Figure 7.1 & 7.2) below show the all-inclusive qualitative associative networks for both the case studies such as NG Pipelines and Petrochemicals. Even though, all most all of the categories & sub-categories emerged out from empirical data are matching in both the case studies, the extent of maintenance practices related to these categories & sub-categories are different in both these cases.

Major differences lie in the cases of NG Pipelines & Petrochemicals are (i) maintenance challenges and (ii) specific maintenance strategies for a particular equipment/ process used in maintenance strategies selection process. It is clearly evident from the empirical findings that these two factors have large impact in maintenance strategies and practices planning & execution in the gas utility company. The reasons behind are as given under:-

Maintenance Challenges are specific to the type of environment the business is operating. For example, in NG Pipelines maintenance, involvement of various stakeholders is quite evident from the study but this is not the case in petrochemicals wherein stakeholders involvement comparatively less and manageable. Therefore, maintenance strategies have to be formulated and selected accordingly. No maintenance related theory is clearly explaining about such kind of maintenance challenges. Presently these maintenance challenges are being handled by maintenance managers based on their previous experiences but they need to be documented and standardisation can be done; Maintenance strategies are equipment oriented (or) process oriented, therefore maintenance strategies are either recommended by Original Equipment Manufacturer (OEM) or by the process licensor. Maintenance managers are required to implement such strategies as recommended by the manufacturer or licensor and deviations can be taken by doing thorough analysis of equipment data with the justifying reasons for delay in maintenance schedules.

As shown in Table 7.1, earlier literature on performance measures covers labour and material cost, breakdown records, maintenance performance measures, key performance indicators, downtime records, training man hours of maintenance staff, internal norms/industry norms, benchmarking measures & targets. The key findings based empirical data analysis are, MOU targets of the large gas utility company are treated as key performance indicators; no separate metrics are used for maintenance performance measures in the company, external/internal audits are used to measure maintenance performance compliances as indicated by the maintenance managers/engineers.

As per Table 7.1, earlier literature identified planning & execution activities cover plant equipment register, standard written work order, availability of PM schedules, priorities of work order, availability of work schedule for a week ahead, shutdown maintenance schedule, measurement of work backlog, long term plans to forecast major shutdown/maintenance work as part of it. The large gas utility company is using all these elements in their maintenance planning & execution and these activities are integrated through enterprise resource planning software.

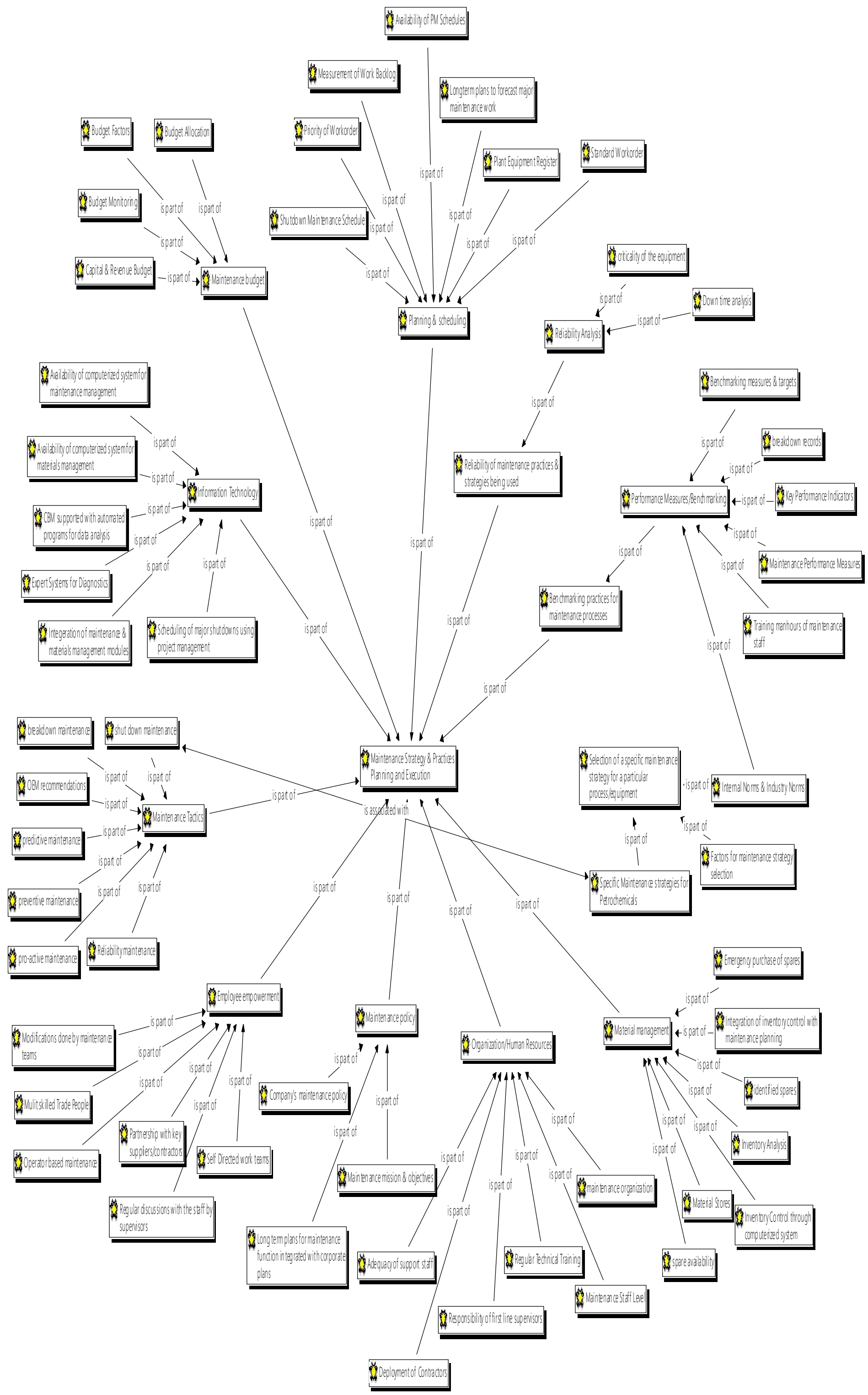

Figure 7.1 NG Pipelines Maintenance Strategies and Practices Planning & Execution

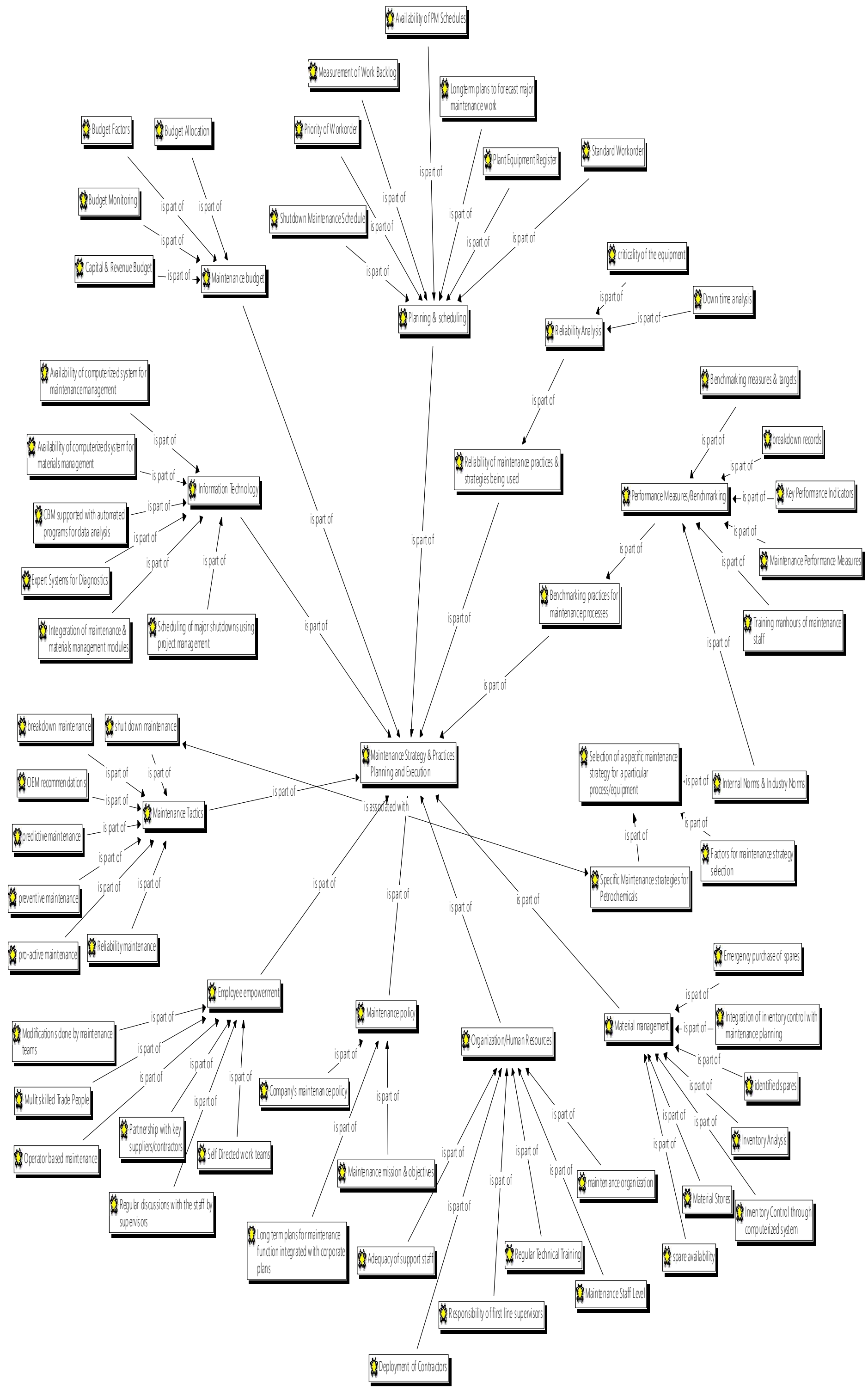

Figure 7.2 Petrochemicals Maintenance Strategies and Practices Planning & Execution

As per Table 7.1, earlier literature on materials management cover spares availability, identified spares, inventory analysis, emergency purchase of spares, average inventory turnover, availability of stores, inventory control through computerised system, and integration of inventory control with maintenance planning. All these activities related to materials management are integrated through enterprise resource planning software application in the gas utility company. As indicated by the maintenance managers/engineers, it is found that the annual inventory turnover concept is not being practiced in the company.

As per Table 7.1, earlier literature identified organisation/human resources to cover the elements such as maintenance staff level, maintenance organisation, responsibility of first line supervisors and adequacy of support staff, regular technical training, apprenticeship program, and deployment of contractors. This research found these elements are well integrated with the maintenance strategies & maintenance practices processes in the company. The findings are well-structured training system & maintenance organisation and systematic interventions are available for interaction with first line supervisors & contractors in the company.

As per Table 7.1, earlier literature on employee empowerment covers the aspects of multi skilled trade people; operators based maintenance, regular discussion with the staff by supervisors, self-directed work teams, minor modifications done by maintenance teams, and partnership with key suppliers/contractors. The key findings in this research study are maintenance personnel are multi skilled; operator based maintenance are not completely adopted in the company; interactions among the maintenance personnel and also with suppliers/contractors are through structured daily/weekly/monthly meeting among the operations & maintenance groups; modifications are carried out through “change management” system in the gas utility company.

As per Table 7.1, earlier literature identified information technology construct to cover the sub constructs such as availability of computerised system for maintenance management, availability of computerised system for materials management, integration of maintenance management & materials management modules, scheduling of major shutdown using project management system, CBM supported with automated programs for data analysis, and Expert systems for diagnosis. This research study could find evidences to all these elements of information technology. The key findings from empirical data are maintenance management & material management activities are well integrated through enterprise resource planning software application; maintenance managers/engineers are maintaining long term/shut down planning schedules; CBM monitoring are supported with the expert systems like DCS, SCADA, Vibration monitoring system, etc.; Expert diagnostics systems are specific to NG Pipelines/Petrochemicals.

As per Table 7.1, earlier literature on maintenance polices and maintenance budget covers maintenance mission & objectives, long term maintenance plans integrated with business plans, maintenance policies, and maintenance budget. This research study could provide evidences for all these elements related to maintenance policies and maintenance budget. The key findings of this research study are business plans are integrated with unit level, individual level plans through MOU/IMOU targets; well written maintenance policy, maintenance mission/objectives are available with the large gas utility company; structured budgeting system is also available and maintenance managers are practicing religiously.

As per Table 7.1, earlier literature on maintenance tactics has identified the sub constructs such as use of Condition Based Maintenance (CBM)/ Predictive Maintenance, Condition Based Maintenance is favoured over Time Based Maintenance (TBM), total maintenance hours devoted to Predictive Maintenance/ Preventive Maintenance, compliance of PM Schedules, OEM (Original Equipment Manufacturer) Recommendations for an equipment regarding PM, use of formal Reliability Based Maintenance (RBM), and use of Total Productive Maintenance (TPM). The key findings of this research study are CBM & TBM methods are majorly used in the large gas utility company and these methods and they play critical role in selection of maintenance strategies in the gas utility company; OEM recommendations are used for selection of maintenance strategies for a particular equipment/process; TPM & RBM maintenance methods are not being used in the gas utility company as indicated by the maintenance managers/engineers.

As per Table 7.1, earlier literature on reliability analysis covers documentation of equipment history, equipment criticality, Root Cause Analysis (RCA)/Incident Analysis (IA), Mean Time Between Failures (MTBF), Value Risk Study of maintenance program, reliability statistics of equipment/assets, and Reliability Centred Maintenance (RCM) based analysis in this category. The key finding of this research study is that no element of reliability analysis is being practices in the company except RCA/IA in identifying root cause problem of plant/ equipment failure. However, maintenance managers/engineers show their wish for implementation of reliability based maintenance.

7.2.2 MAINTENANCE STRATEGIES SELECTION PROCESSES

As per Table 7.2, earlier literature discussed two types of maintenance strategies selection processes, which were expected to be found in the large gas utility company (Section 2.5.3 & 2.5.6). They are,

1. Mathematical modelling which treats maintenance strategies selection as Multi Criteria Decision Problem (MCDM). This problem is solved with the techniques AHP, Fuzzy AHP, VIKOR, etc.
2. Maintenance optimisation models to choose right mix of maintenance strategies such as Preventive Maintenance, Predictive Maintenance, RCM, etc. using Decision Support Systems (DSS)/ Plant Maintenance Decision Support Systems (PMDSS).

This research study could not find evidences of using above mathematical models for maintenance strategies selection in the large gas utility company. The key finding is that the maintenance managers/engineers did not share any such use of mathematical models in maintenance strategies selection during interview and further during site visits also the researcher could not find any evidences of using such models.

However, empirical data show that how maintenance managers/engineers are selecting maintenance strategies in the gas utility company. The key findings are summarised in Table 7.2.

Table 7.2 Maintenance Strategies Selection Processes

Literature review outcomes on maintenance strategies selection processes	**Empirical data analysis outcomes on maintenance strategies selection processes**	**Key inferences**
Selection of maintenance strategies is the selection among the maintenance approaches such as TBM, CBM, etc.; Selection of maintenance strategies is treated by authors' as Multiple Criteria Decision Making (MCDM) problem. The same was solved with the techniques AHP, FAHP, VIKOR, etc.	Factors contributing to maintenance strategies selection are previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy, equipment complexity, equipment availability, process severity, and complexity of the process	Mathematical modelling is not used in the gas utility company for selection of maintenance strategies; maintenance strategies selection process is based on few criteria which is of qualitative nature and depends on the previous experience of maintenance managers/engineers.
Maintenance Decision Support System (MDSS) models prove that the implementation of suitable maintenance methodology helps in improving maintenance function & optimise the operational/ maintenance costs; Reliability assessment, risk levels and failure management in maintenance can be	Specific maintenance strategies being used in NG Pipelines are intelligent pigging, integrity management system, Cathodic Protection, Vibration monitoring system, Stand-by equipment strategy, Helicopter Patrolling, Line walk, Cleaning Pigging; in petrochemicals shutdown maintenance strategy is used majorly; Gas utility company	MDSS is not being practiced in the company; Specific maintenance strategies are used based on OEM recommendations, applicable national/ international standards, and guidelines from PNGRB, OISD, etc.

effectively handled with the help of models using tools such as fuzzy Bayesian methods, fuzzy modelling, Analytical Hierarchy Processing etc.	is following industry norms such as standards of OISD, PNGRB, etc. and internal norms are such as sharing maintenance problems among work centres and maintain SAP system so that all data can be accessed by all work centres across the country. These norms help the company to implement uniform maintenance strategy selection process across the work centres in the country	

7.2.3 Relationship between Maintenance Strategies Selection Process and Maintenance Strategies & Maintenance Practices

The relationship between maintenance strategies selection process and maintenance strategies & maintenance practices are explained through various maintenance strategies related models in Chapter 2 (Section 2.7). The basic frameworks of these models are discussed and the model developed based on empirical data of this research study is presented in this section.

Maintenance strategy depends on various maintenance policy sectors & practices which consist of system elements such as asset management support, performance and strategy audits, etc. & organisation elements such as people development, planning etc. (McAlister et al., 1999). Maintenance strategy supports translation of business objectives into maintenance objectives so that formulation of maintenance strategy can be done effectively. The factors contributing to maintenance strategy formulation are life plan, preventive schedule, resources, work planning system, administrative structure, and maintenance control (Kelly, 2006). The key elements for maintenance strategies and practices are strategy alignment, performance indicators for maintenance performance, target action plan along with time frames (Salonen, 2011).

Maintenance management framework must include system design aspects such as maintenance philosophies & production control systems, planning & control aspects such as maintenance objectives, resources & performance reporting and managerial tool kit such as failure modelling techniques & computer support (Pintelon & Gelders, 2002). Key elements related to maintenance strategies & maintenance practices are such as maintenance organisation, measure of effectiveness, work control, maintenance management information system, personnel records, logistic support, maintenance tasks & maintenance engineering (Eti et al., 2006). Alignment of corporate strategy with the maintenance strategy is the key element in formulating the maintenance strategy. The leading performance indicators related to maintenance strategies selection are work execution; scheduling, planning & work identification and lagging performance indicators are performance targets, benchmarks, maintenance results like equipment performance & maintenance cost (Muchiri et al., 2011). Main focus on maintenance management is still on the tactical and operation planning. Bridging the gap between business strategy and maintenance strategy is the key challenge in maintenance (Pintelon & Parodi, 2008). Maintenance strategic planning are based on nine functions such as identification of major stakeholders, formulation mission statement, setting of the strategic objectives of maintenance, analysis of the current situation, identification of the strategic issues, strategic options, strategy selection, development of performance measures, and implementation planning (Umar, 2011).

This research study could find evidences from empirical data to the various functions described in the above models and it could find the relationships among these functions which describe holistically the maintenance strategies & maintenance practices planning and execution at an organisation level as discussed in cross case analysis chapter 6 (Section 6.4). Based on these inferences, the key functions identified from empirical data in the process of maintenance strategies & maintenance practices are maintenance strategy formulation, maintenance strategy selection, implementation of maintenance strategies, e-maintenance impact in maintenance, development of maintenance models for maintenance strategies selection, specific maintenance strategies for a particular process/equipment, companywide integration of maintenance strategies, alignment of business strategies with maintenance strategies.

Categories contributing to maintenance strategies & maintenance practices such as maintenance tactics, reliability analysis, performance measures/ benchmarking, materials management, employee empowerment, organisation/ HR, planning & scheduling, information technology, maintenance policies/ budget, maintenance challenges from the empirical data of both the case studies and key functions identified such as maintenance strategy formulation, selection of maintenance strategies, implementation of maintenance strategies, e-maintenance from the empirical data of both the case studies were used as a template for comparing and generalizing the empirical results of the two case studies NG Pipelines and Petrochemicals. Multiple cases studies help to build a logical chain of evidence (Yin 1994; Miles & Huberman, 1994). In other words, cross case analysis is used to identify a chain of evidence for the relationships studied on the basis of the framework.

A model for maintenance strategies & maintenance practices planning and execution is proposed in this research study. The model is as shown in Figure 7.3

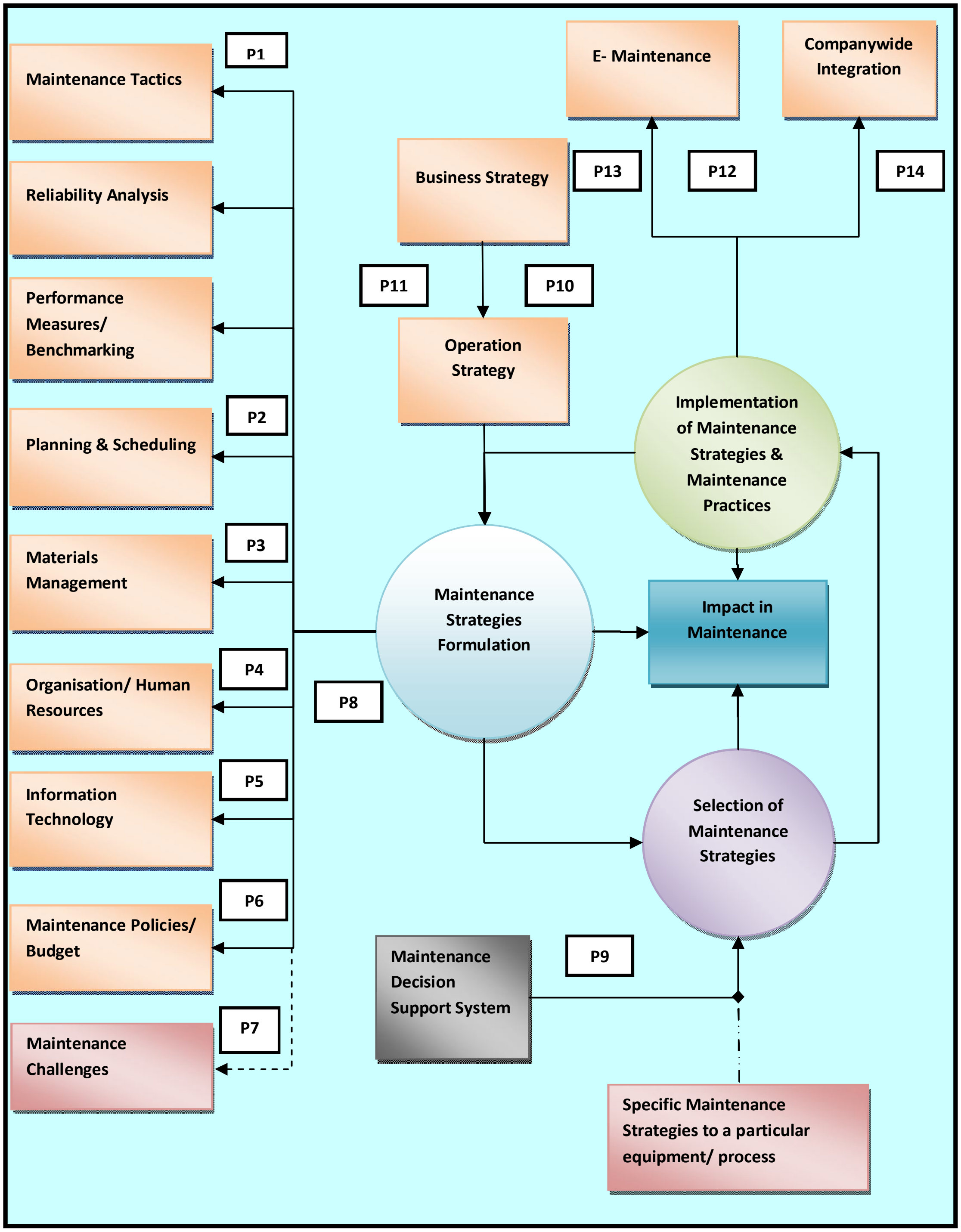

Figure 7.3 – Model for Maintenance Strategies & Maintenance Practices Planning & Execution

As shown in above Figure 7.3, maintenance strategies formulation, selection of maintenance strategies, and implementation of maintenance strategies/ maintenance practices are interlinked processes. All these processes are impacting maintenance planning & execution in an organisation. The contributing factors to these processes are the activities related to the functions such as performance measures, planning & scheduling, materials management, human resources, information technology, employee empowerment, maintenance tactics, reliability analysis, maintenance policies/maintenance budget, and maintenance challenges. Maintenance strategies selection process is based on two functions such as development of Maintenance Decision Support System (MDSS) suitable to an organisational requirement and execution of specific maintenance strategies for a particular process/equipment as recommended by equipment manufacturer or process licensor. Maintenance strategy related processes such as formulation, selection, and implementation & maintenance practices must be aligned with the business strategies and operational strategies of an organisation. Implementation of maintenance strategies & maintenance practices is followed by the formulation of maintenance strategies and selection of proper mix of maintenance strategies suitable to the process/equipment/operations. Effective implementation of maintenance strategies can be achieved by using latest e-maintenance tools, techniques, and software applications. Further, companywide integration of maintenance practices will help the organisation to implement the maintenance strategies efficiently. Total 14 propositions have been developed from cross case analysis and these propositions are incorporated in the model sequentially. This model could describe the processes of maintenance strategies & maintenance practices planning and execution at an organisation level.

7.3 FINDINGS SUMMARY INTERMS OF RESEARCH QUESTIONS

As a means to fulfil the objectives of this research study, the research questions are formulated. The findings summary for these research questions are presented below.

7.3.1 Planning & Execution of Maintenance Strategies & Maintenance Practices

CRQ: How the gas utility company is planning and executing its maintenance strategy & practices to ensure smooth operation process in the company's business verticals such as petrochemicals & pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?

The gas utility company is planning and executing its maintenance strategies & practices based on the processes such as maintenance strategies formulation, selection of maintenance strategies, and implementation of maintenance strategies. Formulation of maintenance strategies is based on the company's well-defined maintenance policies & maintenance objectives. Maintenance targets are basically based on production targets which are derived from the corporate MOU targets. The major maintenance tactics being used by the gas utility company are Preventive Maintenance, Predictive Maintenance, Shutdown Maintenance, and Emergency Maintenance. The gas utility company maintenance managers indicated the linkages of the maintenance strategy related processes with the functions such as information technology, HR, planning & scheduling, materials management, reliability analysis, and performance measures. The activities of these functions are being leveraged & integrated using advanced software applications to performance maintenance in order to ensure smooth operation in the company.

Further, maintenance strategies selection process of the company involve the following major activities (i) maintenance strategies selection based on previous experience of maintenance managers, criticality of the system/equipment, OEM recommendations, maintenance policy guidelines, equipment complexity, equipment availability, process severity, and complexity of the process, (ii) specific maintenance strategies pertaining to NG Pipelines/Petrochemicals, and (iii) internal & industry norms.

Maintenance managers/engineers of the gas utility company have raised their concerns regarding maintenance challenges. Presently, these challenges are being managed by previous experience of managers/engineers on case to case basis. The factors contributing to maintenance challenges in both the business verticals can be documented & standardised as indicated by the maintenance manager/engineer to improve maintenance strategies & maintenance practices in the organisation.

The gas utility company religiously following specific maintenance strategies pertaining to particular equipment/ process as recommended by equipment manufacturer or licensor. However, it is not using the maintenance methods such as Reliability Centred Maintenance and Total Productive Maintenance. Further, maintenance performance are not based on industry benchmarked maintenance parameters, it is based on internal/external audits performance by Subject Matter Experts and other external agencies such as OISD, PNGRB, etc.

Therefore, it can be concluded that the gas utility company is having set of procedures & polices in maintenance function for planning & execution of maintenance strategies and maintenance practices. Since the gas utility company is the public sector company, maintenance strategy related processes are having impact from Indian industry norms set by Government agencies such as OISD, PNGRB, etc. Presently, the company is not following few industry best practices such as Reliability Centred Maintenance, Benchmarking, Maintenance Decision Support System, etc.

7.3.2 Common and Different Maintenance Strategies & Maintenance Practices in the large Gas Utility Company

RQ1: What are the common and different maintenance strategies & practices to both the business verticals (and) how the maintenance strategy & practices differ with the specific assets available in one operation process/plant/pipeline network from others business verticals?

From the data analysis as shown in Figure 7.1 & Figure 7.2, the maintenance strategies formulation, selection and implementation are based on the ten categories identified from the empirical findings. However, depends on the nature of process and type of equipment the degree of maintenance varies in both petrochemicals and NG pipelines. For example, shutdown maintenance is the major maintenance strategy used in petrochemicals and it is not the case in NG Pipelines. Preventive Maintenance is more in petrochemicals. But, in NG Pipeline predictive maintenance is more. Both the business verticals are using similar enterprise resource planning system SAP for integrating its maintenance activities with the functions materials management, maintenance management and human resources.

Maintenance techniques used are specific to process/equipment in NG Pipelines & Petrochemicals. For example, cathodic protection, intelligent pigging, helicopter patrolling, etc. are the specific maintenance strategies used in NG Pipelines. However, shutdown maintenance is the specific maintenance strategy in Petrochemicals. Also, proactive maintenance is the new maintenance tactic emerged out from the case study of petrochemicals and the same is not being practiced in NG Pipelines. Proactive maintenance is based on experience of maintenance managers/engineers. Maintenance challenges are different in petrochemicals & NG Pipelines. Standardisation of maintenance practices is the major maintenance challenge in Petrochemicals.

However, natural disaster & sabotage of pipelines are the major maintenance challenges in NG Pipelines.

Therefore, it can be concluded that even empirical data analysis of both the business verticals are emerging out with the similar processes related to maintenance strategies & maintenance practices in the gas utility company, the extent of use of maintenance strategies are vary with the process/equipment/ plant. Maintenance practices are also different in NG Pipelines & Petrochemicals.

7.3.3 Reliability in Maintenance

RQ2: How the reliability of the operation process/ equipment/ assets is ensured by the maintenance strategy used for the particular operation process/ equipment/ assets?

Reliability in maintenance performance is the ultimate objective of the right selection of maintenance strategy. Reliability is the one among the factors which plays crucial role in maintenance strategy formulation and selection as evident from the literature review. A qualitative associative network is developed for reliability from interview data and the same is presented and discussed in section 4.3.8 and section 5.3.8. From the empirical data, it is evident that the company is not using any reliability metrics in assessing maintenance performance and it is also not following the Reliability Centred Maintenance (RCM). Presently, reliability of the equipment is fairly depending on the maintenance execution based on previous experiences of maintenance managers. However, OEM recommendations are being implemented in equipment maintenance in order to ensure the equipment's reliability and maintenance managers are keen in implementation of RCM method.

7.3.4 Maintenance Benchmarking

RQ3: What are the benchmarks being used in petrochemicals/ NG pipelines? What is extent of achievement of benchmark parameters in practices?

A qualitative associative network is developed for reliability from interview data and the same is presented and discussed in section 4.3.1 and section 5.3.1. It is evident from empirical data that the company is not following any benchmarks for measuring the maintenance performance. However, maintenance performance is being monitored indirectly from the operational targets such as MOU targets, IMOU targets. Since the company is market leader in the industry, few maintenance managers are of the opinion that the targets what they are achieving like 99% availability of pipeline and 95% availability of petrochemicals can be taken as benchmarks. Detailed study on gaps between maintenance strategies & maintenance practices and benchmarks in maintenance was carried out and presented in section 6.5.1. The result of this study shows that the industry maintenance benchmarks in maintenance are not being followed by the large gas utility company.

7.4 SIGNIFICANCE OF THE FINDINGS

This section discusses the significance of the findings of this research. Contributions of this research study to theory, methodology and practice are very important. Maintenance strategy related processes are discussed in literature such as formulation of maintenance strategies (McAlister, 1999; Waeyenbergh & Pintelon, 2002; Cooke, 2003), maintenance strategies selection (Bevilacqua & Braglia, 2000; Murthy, Atrens, & Eccleston, 2002; Bertolini & Bravilacqua, 2005), implementation of maintenance strategies (Pinjala, Pintelon, & Vereecke, 2006; Veldman, Klingenberg, & Wortmann, 2011), and maintenance practices (Swanson, 1997). However, these frameworks are not discussing all the maintenance strategy related processes in a holistic manner and also not incorporating the tacit & implicit knowledge available with maintenance managers/engineers based on existing practices at an organisation level in operations intensive industry like natural gas industry.

Therefore, in the area of maintenance management, there has been a need to understand and describe the maintenance strategies formulation, selection, implementation, and maintenance practices based on the existing maintenance practices at an organisation level in operations intensive industry like natural gas industry. Especially in an Indian context of the industry, this kind of study could contribute much to the industry. Accordingly, this research fills the gap by developing the multilevel framework which provides thick description of all the processes related to maintenance strategies & maintenance practices planning and execution in an organisation.

Selection of maintenance strategies is treated as Multiple Criteria Decision Making (MCDM) problem and this problem is solved with the mathematical techniques such as AHP, Fuzzy AHP, VIKOR etc. as identified in literature (Dekker, 1996; Bevilacqua & Braglia, 2000; Kodali & Chandra, 2001; Murthy, Atrens, & Eccleston, 2002; Bertolini & Bravilacqua, 2005; Li, Ambani, & Ni, 2009). This study found that the maintenance managers/ engineers are not using such mathematical techniques for maintenance strategy selection. Selection of maintenance strategy is based on the factors such as industry norms, specific maintenance methods recommended by equipment manufacturer or process licensor, and previous experiences of maintenance managers/ engineers. Standardisation of these factors contributes to the theory of maintenance management.

This research study brought out the significance findings for the large gas utility company in the Indian gas industry to manage maintenance activities more efficiently & effectively in order to operate the process/equipment smoothly. These findings will help maintenance managers/engineers to streamline processes of maintenance strategies & maintenance practices in the company. The findings are as given under:-

- Company’s maintenance strategy processes can be assessed with the categories emerged out from empirical data in this research study through survey.
- Reliability maintenance concepts are not being used by the company except root cause analysis/incident analysis report. Maintenance managers are of the opinion that these concepts are to be used for improving maintenance performances. Therefore, RCM can be implemented in the company.
- Maintenance executives of the company have not spoken about the use of Total Productive Maintenance (TPM). Either they are not aware of this maintenance method or not using the same. The possibility of implementation of TPM may also be explored by maintenance team of the company.
- Benchmarking measures are not being used by the company. Not much data is available with the company. However, they use primarily MOU targets as performance measures. Since company is market leader as a gas utility company, maintenance managers of the company feels that their present operating conditions are benchmark. So far, the company is achieving all the MOU targets successfully. The company can go for benchmarking of maintenance for both the business verticals such as NG Pipelines & Petrochemicals.
- Maintenance challenges as described by the maintenance manages/ engineers influence the maintenance practices and also affect the maintenance strategy processes. Therefore, company has to give due priority to these issues and effective system is to be developed to mitigate these maintenance challenges and further there is a need to optimise the maintenance function.
- Proactive Maintenance is the new type of maintenance tactics emerging out from this study. There is a need to work more on this maintenance tactic and apply in practice.

7.4.1 Theoretical Contributions

This research study shows that simple and non-resource demanding processes may be used in formulation & selection of maintenance strategies which can be aligned to overall strategic goals of the company. This process is based on a set of Ten (10) factors that the company regards strategically important for their maintenance.

One new type of factor contributing to maintenance strategies selection & maintenance practices emerged from the data such as Maintenance Challenges. Apart from this, two types of maintenance tactics are also emerged out from the empirical data such as Shutdown maintenance and Proactive maintenance. Both of these maintenance tactics are very crucial for maintenance strategies formulation, selection, and implementation & maintenance practices at an organisation level. Further, a process model for maintenance strategies & maintenance practices planning and execution has been developed. This research study provides rich description to the theory of maintenance strategies & practices in maintenance management at an organisation level in the operations intensive industry like gas industry and in general also.

7.4.2 Practical Contributions: Implication for Managers

The scope of this research work was well appreciated by the maintenance managers/engineers in the large gas utility company in India. There is a growing demand among the maintenance managers/engineers that there is a large improvement potential within their maintenance programs at an organisation level. Even though maintenance managers/engineers are aware about potential improvements required for betterment of maintenance performance, it could be inferred from the research study that the maintenance practices are not having strategic perspectives of maintenance management. The conducted research study could provide guidelines to assess the existing maintenance strategies & maintenance practices based on the factors and processes emerged out in this study at an organisation level. Further, this study could also suggest set of maintenance guidelines & parameters for maintenance strategy formulation, selection, implementation, and maintenance practices. Therefore, this study would help the maintenance managers to benchmark the maintenance practices in their organisation and their teams to understand the maintenance strategies development. This research study also found evidences to formalise & improve the maintenance strategy adapted since importance attached to industry/ operation/ equipment specific maintenance strategies in both NG Pipelines & Petrochemicals.

7.5 LIMITATIONS

The conclusions offered in this research are based on an in-depth study of the large gas utility company in India. The conclusions are derived by applying a qualitative interpretive approach as research methodology in this study. It is often considered as subjective and having limited generalizability (Klein and Myers, 1999). The relationship between maintenance strategies selection process and maintenance strategies & maintenance practices developed in this research are based to a large extent on the perception of interviewees, which may be subjective. To reduce the subjectivity of interview of data, evidences were also collected from internal & external documentation and observations in the case studies as suggested by Yin (2003) and Eisenhardt (1989). These evidences are considered to be more objective sources.

7.6 SCOPE FOR FUTURE RESEARCH

The results of this research study provide an insight into the processes of maintenance strategies & maintenance practices of the large gas utility company in India. A number of topics can be suggested for a future research.

- Further studies can design and conduct surveys across operations intensive industries to test the propositions developed in this research.

- There is a need to explore the relative strength of relationships between maintenance strategies selection processes and maintenance strategies & maintenance practices.
- Further studies using qualitative research approach can explore other countries / other industries / other types of business verticals
- Further studies can develop Quantitative Associative Networks, which might further enhance the understanding of maintenance strategies & maintenance practices

Researcher feels that it is worth mentioning few literature gaps related to maintenance strategy formulation and selection which could be identified from the in-depth literature review so that further research can be carried out in the area of maintenance strategies selection. The literature gaps are as given under:-

- Study on integration of real time condition monitoring methods into development of maintenance strategies so that achieving maximum availability of equipment/operations can be carried out.
- Inclusion of human model in Maintenance Decision Support System (MDSS) for making more accurate decisions in selection of optimal maintenance strategy is not done. Therefore, human model based study might able to capture efficiency of maintenance manpower in terms efficient implementation of maintenance strategy.
- Further study on Decision Support Systems (DSS) for maintenance can include the recent developments in their models such as sustainability, bottleneck resources, restoration cost, etc.
- Not much research work is available on e-maintenance implementation to integrate various approaches of condition based monitoring and development of comprehensive model for failure management in maintenance.

- Case studies that epitomise maintenance strategy implementation and further verify the relation between maintenance and manufacturing capabilities are not available.
- Study on impact of training and resources in maintenance strategies selection & maintenance practices in an industry/ organisation can provide value addition to maintenance management.

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- Research proposal on “Study of maintenance strategies & practices of a large Indian gas utility company – A case study” was awarded as best early research proposal in “Operation Research” category at Doctoral Colloquium IIM, Ahmadabad (January, 2013).
- A paper on “Sustainability approach to strategic maintenance management in Indian gas industry – A framework” was presented in ICMI, 2013 at UPES, Dehradun (February, 2013).
- A paper on “Maintain asset integrity and firm performance: A conceptual model for Indian gas industry” was presented in ICMI, 2014 at UPES, Dehradun (February, 2014).
- Maintenance strategy selection theory & practices in natural gas industry: A case study of an Indian gas utility company was presented in International Gas Research Conference (IGRC-2014) at Copenhagen, Denmark (September, 2014).
- A paper on “Maintenance strategy selection and its impact in maintenance function: A conceptual framework for manufacturing industry” has been accepted for publication in International Journal of Operations & Production Management, Emerald (October, 2014).