

Maintenance Strategy Selection Theory & Practices in Natural Gas

Industry: A Case Study of an Indian Gas Utility Company

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ABSTRACT

The natural gas industry is characterized by expensive specialized equipment and stringent environmental consideration. It is also evident that industrial maintenance function has gained high recognition over the last few decades in the natural gas industry. Consequently, over the years, many different strategies have been developed to support maintenance management implementation in the industry. With increasing automation and mechanization in natural gas/petrochemical process, production processes are becoming highly sensitive to machines and people. Therefore, the role of equipment maintenance in controlling quality, quantity and reducing costs is more evident and important than ever for any organization in the gas industry. In this context, the operation process is continuous in a gas utility company and any abrupt stop of the process causes delay and reduction in output. Although organization follows various maintenance strategies and practices, the cost and impact of sudden failure of equipment is found to be huge. Despite the best efforts of maintenance managers, equipment still fails, and plants are vulnerable to failures. The implications in production and maintenance suggest the need to change the focus of maintenance policies & maintenance methodology adopted. The research problem is that how the maintenance managers in a gas utility company in India formulate the maintenance strategies and how they practice these formulated maintenance strategies? This research study investigates the maintenance strategy formulation and practices adopted by maintenance managers in a large Indian gas utility company. The purpose of this research is to understand & describe the formulation of maintenance strategy in a large Indian gas utility company. Further, to understand why the particular maintenance strategy has been chosen and how these formulated strategies are being practiced in the company. This research employs the case study based qualitative research method (multi case holistic design) for the study of maintenance practices in the business verticals such as natural gas pipelines (case 1) and petrochemicals (case 2) of a large gas utility company in India. GAIL (India) Limited 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. A literature review has been carried out to identify the initial conceptual constructs and the sub-constructs which affect the maintenance strategy selection of the firm in the manufacturing industry. Further, the primary data were collected from the Maintenance Managers of GAIL using the Case study protocol. Data Analysis has been carried out with the Textual Analysis with the help of Atlas TI software and network diagrams formulated with the necessary quotation and frequency analysis. The outcome of this research study is a process model for maintenance strategies & practices formulation and implementation which presents the comparison between the theory in maintenance strategy selection & actual practice in the gas utility company. The model provided will help maintenance managers to assess, develop & select suitable maintenance strategy for their firm. This paper provides thorough study which will be useful to researchers, maintenance managers and other professionals in the gas industry to understand maintenance strategy selection problem and its implementation.

Keywords: *Maintenance Strategy, Maintenance Practices, Maintenance Strategy Selection*

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INTRODUCTION

Industries are facing a lot of challenges such as optimization of operation & maintenance function due to the continual evolving world of technologies, global competitiveness, environmental and safety requirements. The concern towards total quality and profitability of an organization are crucial factors in the business. It is evident that industrial maintenance function has gained high recognition over the last few decades in various industries. Consequently, over the years, many different strategies have been developed to support maintenance management implementation in the industry (Swanson, 2003). With increasing automation and mechanization, production processes in any industry is becoming highly sensitive to equipment and people. Further, the role of equipment maintenance in controlling quality, quantity and reducing costs is more evident and important than ever (Jay et al., 2006).

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 and 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 and 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 and Sadorsky, 1999). Ensuring cost effective plant operation such as efficient & quality production, equipment availability and employee & environmental safety depends on how the organizations are able to effectively integrate maintenance function with other functions in the organization. Therefore, for organization to survive in the present industrial environment, healthiness of equipment with sustainable operations should be ensured (Ben-daya and Duffuaa, 1995, Al-Najjar, 2001; Bennett, 2006).

Maintenance is not just ensuring healthiness of equipment in a facility but it also plays a crucial role in achieving organization's goals and objectives with optimum maintenance cost

and maximum production. Traditionally, maintenance management was dealt with the short term issues like resources, cost, man power etc. Recent past, maintenance management has changed its concerns towards the consideration of long-term goals like competitive, sustainability and strategy (Duffuaa et al., 2002). Therefore, maintenance management needs to be viewed in a strategic perspective.

Maintenance strategy is 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 (Kelly, 1997) and is concerned with formulating the best life plan for each unit of the plant, in coordination with production and other functions concerned. It describes what events (e.g. failure, passing of time, condition) trigger what type of maintenance action (inspection, repair, or replacement).

It is also evident that industrial maintenance function has gained high recognition over the last few decades and same is case with natural gas industry. Consequently, over the years, many different strategies have developed to support maintenance management implementation in natural gas industry. With increasing automation and mechanization in natural gas/petrochemical process, production processes are becoming highly sensitive to machines and people. Consequently, the role of equipment maintenance in controlling quality, quantity and reducing costs is more evident and important than ever. The natural gas industry is also characterized by expensive specialized equipment and stringent environmental consideration. A large gas utility company in India has been chosen for the study since it is having major market share in natural gas industry.

The business problem formulated from the above background is given under:-

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

A detailed literature review was carried out to understand the processes of maintenance strategy formulation, selection of maintenance strategies, and maintenance practices in various industries and the same is presented in next section.

LITERATURE REVIEW

A lot of literature is available from various resources in the field of maintenance management. In this literature review, published research papers related to maintenance strategy, maintenance management, maintenance practices, performance in maintenance management, e-maintenance, maintenance decision support system etc. were studied in order to understand the strategic level of maintenance and the maintenance management's role. The main objective of the literature review was to create a strong foundation of which the result is to be based upon. Therefore, maintenance strategy is first conceptualized from existing research, and then a conceptual framework for maintenance strategy formulation, selection and implementation was developed.

In early literatures, several maintenance approaches i.e., strategies and concepts, have been discussed by various authors (Dekker, 1996; Moubray, 1997; Mckone and Elliott, 1998; Sherwin, 2000; Swanson 2001). 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 and Reyes-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 and 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.

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 (Marquez and Gupta, 2006).

To select/choose the 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 and Braglia, 2000; Kodali and Chandra, 2001; Bertolini and Bevilacqua, 2005; Ling et al., 2006; Lin, Ambani, and Jun, 2009; Rolando et al., 2009).

Implementation of maintenance strategy is the great challenge for the maintenance managers in the organization. Every organization has its own challenges and face different problem depends on its maintenance philosophy. Further, organization puts best efforts to follow maintenance standards but it is difficult due to the environment exists in maintenance function (Alsyouf, 2007).

Further, from the literatures initial conceptual constructs and sub-constructs corresponding to each conceptual construct have also been identified which contribute to maintenance strategy formulation, selection and implementation and also these constructs can also be used to assess the maintenance strategy implementation. Corresponding literatures/authors along with inferences from literatures for all the conceptual constructs are presented in Table 1.

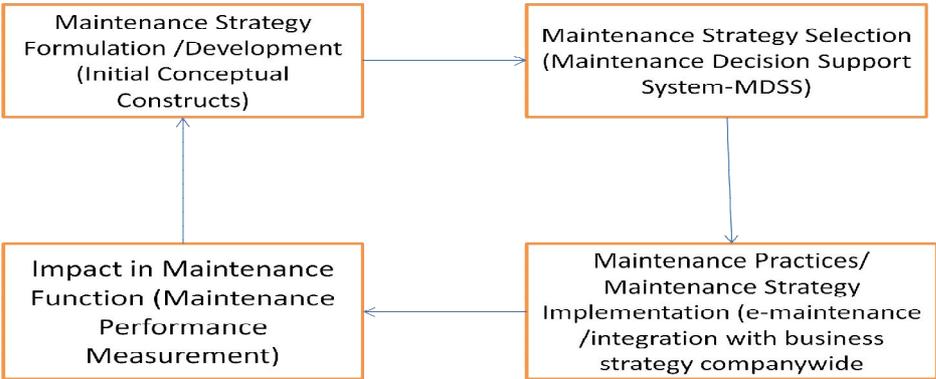
Table 1 – Constructs and literature references

Constructs	Literature Reference
Maintenance Tactics	Jonson, Patrik (1999); Carnero, M C (2006); Wang, Ling., Chu, Jian (2007)
Reliability Analysis	Bevilacqua, M; Braglia, M (2000) ; Wang , Hongzhou (2001); Brammer, C., & Bagajewicz, M (2008)
Performance Measures/ Benchmarking	Marco Machi, & Marco Garetti (2006); Swanson, Laura (2001); Gokiene, Ruta (2010)
Planning & Scheduling	Pophaley, Mahesh, Vyas, R. K (2010); Ashayeri, J., Teelen, A., & Selen, W. (1996); Jin Z, Li L, & Ni J (2009)
Materials Management	Garg ,Amik, & Desmukh S. G (2009); Jafari A, Jafarian M, Zareei, A, & Zaerpour F (2008)
Organization/Human Resources	Eti, M. C., Ogaji, S. O. T., & Probert, S.D. (2006); Marquez , Adolfo Crespo, & Gupta , Jatinder N D (2005)

Employee Empowerment	Campbell, John D., Andrew K S Jardine, & Marshall Decker AG (2001)
Information Technology	Jay, Lee , Ni, Jun Dragan Djurdjanovic, Hai Qiu, & Haitao Liao (2006); Swanson, Laura (2003)
Maintenance Policies/ Budget	Wang , Hongzhou (2001); Carnero, M C (2006); Pintelon, L.M. & Gelders, L.F. (1992)

Maintenance Strategy related frameworks have been discussed by various authors in published literatures (McAllister et al., 1999; Kelly, 2006; Salonen, 2011; Pintelon and Gelders, 2002; Eti M C et al., 2006; Muchiri et al., 2011; Pintelon and Parodi, 2008; Umar A Turki, 2011). A common thread in all these frameworks is alignment between business strategies and maintenance strategies. Few gaps in these frameworks are what are the outcomes of maintenance strategy formulation?; How to select the best among the maintenance strategy methods/approaches formulated? ; How to optimize 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 the same is not discussed in a holistic manner. Based on literature study on maintenance strategy frameworks, from existing available theories a conceptual framework developed for maintenance strategies & maintenance practices in maintenance function. A conceptual lens (framework) is shown in Figure 1.

Figure 1: Conceptual Framework for Maintenance Strategy Selection



The detailed literature survey also found few gaps in literatures such as maintenance processes describing formulation of maintenance strategies & maintenance practices related

to Indian gas utility company is not available; using multiple maintenance methods for a gas utility company is also found no references, and lacking in literature related to study of tacit knowledge & implicit knowledge available with the maintenance managers.

Problem Statement

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?

Research Question (RQ):

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?

Objective:

The specific objective of this research study is to understand and model the existing maintenance strategy formulation & maintenance practices in a large gas utility company in India.

With above Research Question and objective as a basis for this research study, the next section describes about research methodology used in this research study by presenting case study design, sampling and data collection methods, data analysis strategy, results from data analysis and summary of findings.

RESEARCH METHODOLOGY

In a maintenance function of a gas utility company in India, the tacit and explicit knowledge in the field of best practices in maintenance management are available with maintenance managers & engineers working in the company. Thus, the need is to gather an in-depth understanding of this knowledge in formulation of maintenance strategy & practices in the gas utility company. 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 company studied.

The purpose of this research work is to understand & describe the formulation of maintenance strategy in a 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 company. 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)

GAIL (India) Limited 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. 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.

These business verticals are having unique operation processes in the petrochemical process plant and gas transmission pipeline networks. Therefore, multi case holistic design (Type 3; Yin 2003) of case study research design will be used 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.

The structure of case design is detailed as given under:-

Case 1: Maintenance strategy & practices for Petrochemical processing plant;

Unit of Analysis: Plant

Case 2: Maintenance strategy & practices for Natural Gas Pipeline network;

Unit of Analysis: Plant

Level of Analysis for both the case studies (Case 1 & 2)

- 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)

The case study method focused on a maintenance strategy selection and practices on a plant i.e., petrochemicals and Natural Gas pipelines as a single holistic unit of analysis. The plant is having an Operation & Maintenance team with complementary skills assembled together for doing maintenance function and operation function. In plant, 3 levels such as junior, middle, and top level maintenance managers have been considered to understand their view on maintenance strategy selection and implementation in their plant (petrochemicals/NG pipelines).

The single case study is an appropriate design when the case represents the critical case in testing a well formulated theory, or an extreme or unique case or a revelatory case (Yin, 2003). Neither of these conditions is applicable to this research. Therefore, a multiple case design was chosen. Above two cases have been done separately and then Cross-Case analysis of Maintenance strategies & practices in Petrochemical plant & Natural Gas Pipeline network are conducted. 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 framework of maintenance strategies & maintenance practices for the selected gas utility company is developed.

Theoretical sampling method was employed for this study. For data sample, GAIL's petrochemical complex & compressor stations, Gas Terminals, Radio Repeater (RR) Stations and Sectionalizing Valve (SV) Stations of NG pipeline network were considered. The plants/terminals/stations are 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 12 maintenance managers/engineers including both the case studies Case Study 1 & Case Study 2. The data was collected from the Maintenance Managers of GAIL using the case study protocol. 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.

The interview was conducted in three levels to collect the data for the study of maintenance strategy & practices in the gas utility company. The three levels are such as Senior Management (Maintenance Heads in corporate level or unit level), Middle Management (Departmental Heads at unit level), and Junior Management (Sectional Heads/Engineers/supervisors at unit level).

The above interviews lasted between 30 to 60 minutes. The interviews were recorded and fully transcribed. Typed interview scripts were shown to the interviewees, along with follow-up questions. The main steps of data collection for the above case studies are:-

1. Development of Case Study Protocol (CSP), Review and final CSP development
2. Initial Contact and Arrangements
3. Data Collection and Interviews
4. Site visits for field observations
5. Review of case report for internal validity
6. Additional Data Collection

Data analysis aimed to identify describing maintenance strategies formulation & selection and maintenance practices of gas utility company. There were two major steps involved in data analysis: within-case analysis and cross-case analysis. Within-case analysis entailed becoming intimately familiar with each case individually and documenting it thoroughly. In cross-case analysis, similarities and differences across cases were explored.

Data Analysis was done with the Textual Analysis and cross case synthesis. Textual analysis was done with the help of Atlas TI software; network diagrams have been formulated with the necessary quotation and frequency analysis. The data analysis using grounded theory is a highly iterative process involving moving between interview data, existing theory, and observation data (Charmaz, 2006). Three steps such as Open Coding, Focused/Selective Coding, and Identifying patterns of relationship among conceptual categories were used iteratively for conducting data analysis.

At first, input data was selected, categorized and combined to understand main concepts and identify the relevant constructs. Part of the text which are sentences or paragraphs (Strauss and Corbin, 1990) describing (i) maintenance strategies formulation & selection and (ii)

maintenance practices, assigned labels for easy retrieval and categorization (Miles and Huberman, 1994) using open code technique (Strauss and Corbin, 1990; Charmaz, 2006). The coding of interview scripts was done in Qualitative Analysis software Atlas-Ti. This software facilitated the analysis process by helping with coding, linking codes, and text segments, creating memos, searching, editing and reorganizing, and for visual display of data and findings (Miles and Huberman, 1994; Weitzman, 2000; Creswell, 2007). In focused/selective coding, similar codes, codes with some common attributes were merged to create conceptual categories and abstractions from the empirical data (Strauss and Corbin, 1990).

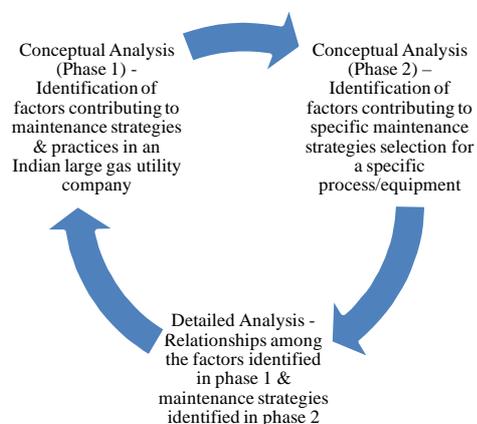
Codes illustrating maintenance strategies and maintenance practices of a large gas utility company and selection of maintenance strategies were discovered from the empirical data during the open coding, were consolidated into broader categories and categories were classified into concepts/themes are the basic units of analysis in grounded theory since these are from conceptualizations of data.

Open and focused coding resulted in labeling of all the interview data in codes, categories and concepts. Here the relationships between codes and categories were compositional in nature i.e., relationships between codes, categories and concepts identified and defined the composition of a particular concept or category. The relationships were generally of 'is part of', 'is a', 'is associated with'. In third step, an effort was made to identify the underlying relationships between codes, categories and concepts. Here the relationships identified are causal ('is part of', 'is associated of') and associative in nature. Activities mentioned by interviewees leading to the maintenance strategy processes were identified by creating appropriate codes in Atlas Ti software.

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 verticals such as pipeline systems (NG transmission) and why the specific maintenance strategy has been selected for a particular operation process/equipment?. This led to the identification of various factors forms the basis for maintenance strategy formulation and maintenance practices in a large Indian gas utility company. Further, specific maintenance strategies being adopted for a particular operation process/equipment in the organization were identified. Then, the relationship between among the identified factors and selection of maintenance strategies was analyzed.

The data analysis was done at two levels, conceptual and detailed. The phases in within case analysis are shown in Figure 4. The findings from the conceptual analysis are of descriptive nature, these describe the nature of maintenance strategy formulation and maintenance practices. The findings from the detailed analysis are perspective in nature (Tsang, 1997); they describe the relationships among the factors contributing to maintenance strategies and practices & selection of specific maintenance strategy for a particular operation process/equipment. This two level analysis also helped increasing the internal validity of the research by triangulation of perspectives on the same data set (Theory triangulation) (Patton, 1990).

Figure 2: Phases within case analysis



The results of within case analysis are displayed in the form of “qualitative associative networks”. The network diagrams for case study 1(NG Pipelines) and case study 2 (petrochemicals) are shown in Figure 3 and Figure 4 respectively. Associative networks have node linked to each other by association and allows for fuzzy, intuitive and subconscious relations between concepts to be presented visually. The qualitative associative networks created in this study show maintenance strategy selection and maintenance practices for NG Pipelines and petrochemicals.

The key findings of the above case studies are presented below.

Case Study -1 NG Pipelines Findings (Within Case Analysis- Refer Figure 3)

- Constructs emerged out from this study are Maintenance Tactics, Reliability Analysis, Performance Measures/ Benchmarking, Planning & Execution, Information Technology, Human Resources, Maintenance Policy/Budget, Material Management and Employee Empowerment

- Constructs emerged out from the study are matching with the initial conceptual constructs
- Additionally, two new constructs have been identified such as Maintenance Challenges & Specific Maintenance Strategy for NG Pipelines

Figure 3: Qualitative Associative Network for Case Study 1 (NG Pipelines)

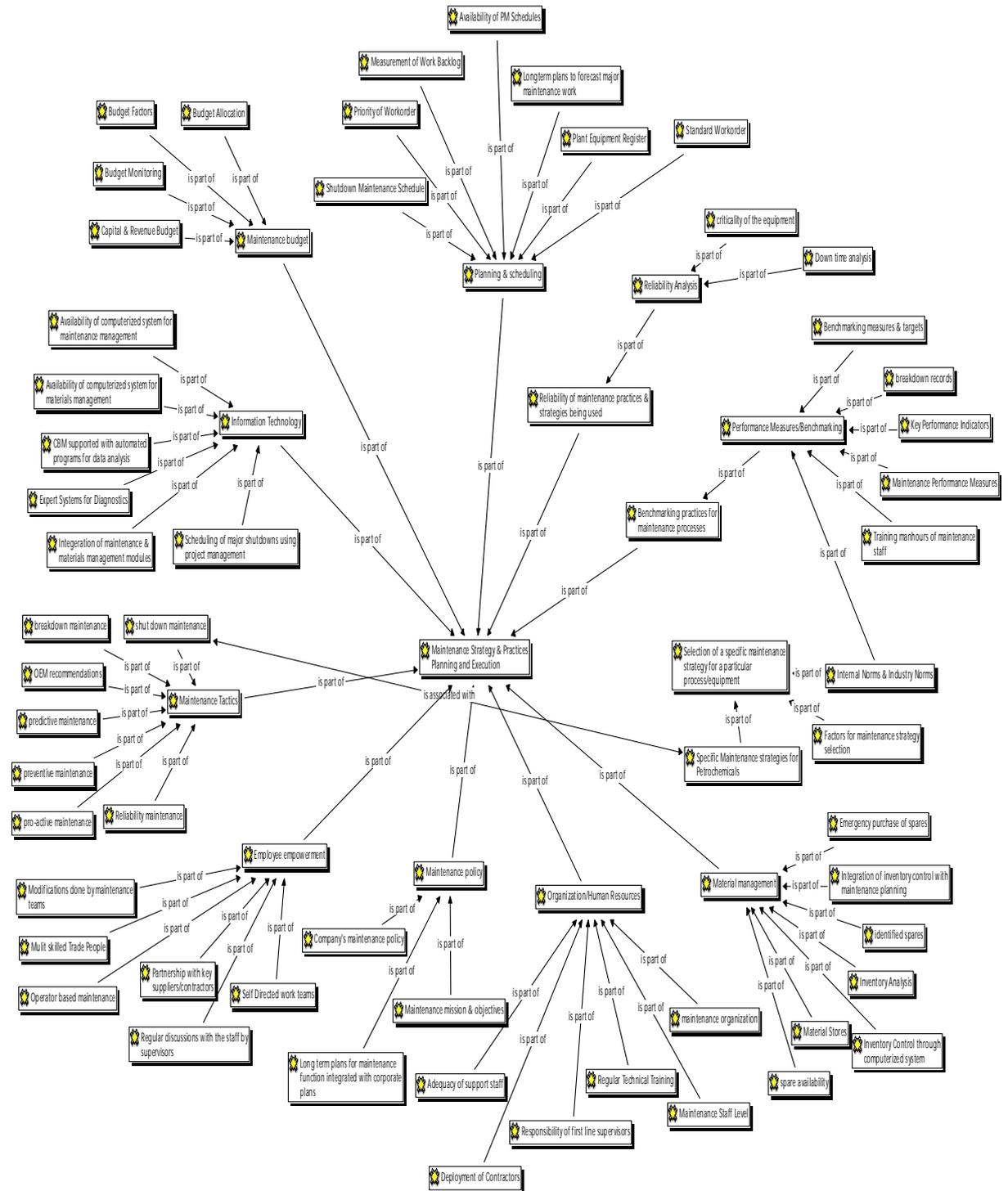
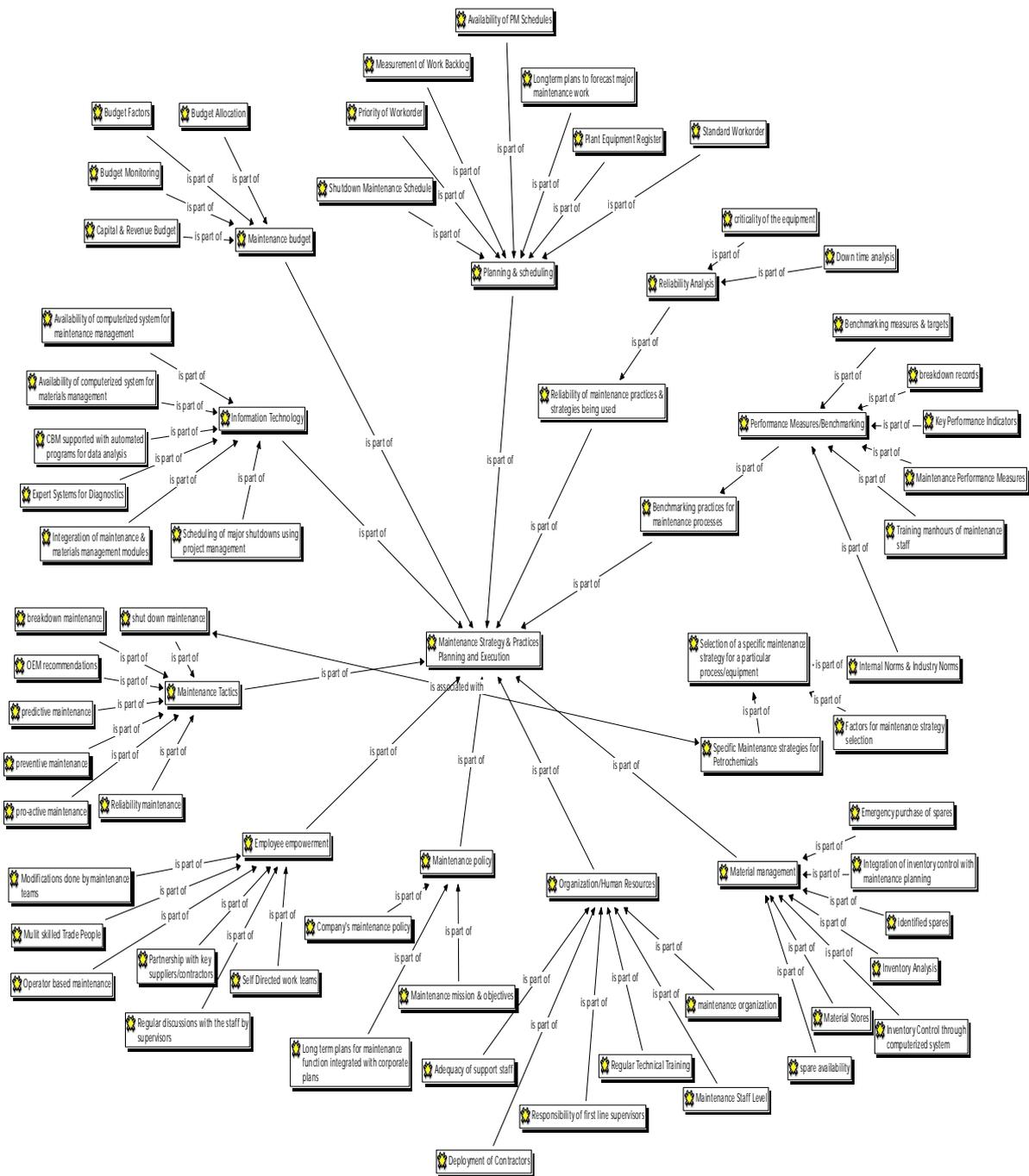


Figure 4: Qualitative Associative Network (QAN) for Case Study 2 (Petrochemicals)



Case Study -2 Petrochemicals Findings (Within Case Analysis- Refer Figure 4)

- Constructs emerged out from this study are Maintenance Tactics, Reliability Analysis, Performance Measures/ Benchmarking, Planning & Execution, Information Technology, Human Resources, Maintenance Policy/Budget, Material Management and Employee Empowerment

- Constructs emerged out from the study are matching with the initial conceptual constructs
- Additionally, two new constructs have been identified such as Maintenance Challenges & Specific Maintenance Strategy for NG Pipelines
- One new type of maintenance tactics was emerged out from the study i.e., Proactive Maintenance

RESULTS

Data has been analyzed 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 theoretical framework discussed above in literature review section of this study consists of Initial Conceptual Constructs such as Maintenance Tactics, Reliability Analysis, Performance Measures, Planning & Scheduling, Materials Management, Human Resources, Information Technology, and Maintenance Policy with the functions e-Maintenance, Maintenance Decision Support System, and Companywide Integration. This framework will be used as a template for comparing and generalizing the empirical results of the above two case studies. Studying multiple cases makes it possible to build a logical chain of evidence (Yin 1994; Miles and 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.

The relevant issues concerning formulation of maintenance strategies & maintenance practices relate to Research Questions have been formulated as propositions and they are discussed in detail with reference to the model developed for maintenance strategies and practices planning & execution in maintenance function. A model for maintenance strategies and practices planning & execution in maintenance function is presented in Figure 5.

P1: How the Initial Conceptual Constructs (ICC1 to ICC8) is being used in formulating maintenance strategies in the gas utility company? How the maintenance managers planning & executing these maintenance strategies & practices to ensure smooth operation process?

The constructs identified from the empirical data are found similar with the Initial Conceptual Constructs. But, the extent of application of the constructs varies in both the cases i.e., Petrochemicals & NG Pipelines. The detailed findings of Case Study 1 & 2 and Cross-case analysis are discussed above in previous section. However, the study indicates that develop of maintenance strategies are basically based on the constructs such as Maintenance Tactics, Reliability Analysis, Performance Measures, Planning & Scheduling, Materials Management, Human Resources, Information Technology, and Maintenance Policy. The result of this study validates the proposition P1.

Further, the above study emerges with the two new constructs like maintenance challenges & Specific maintenance strategies for Petrochemicals/NG Pipeline. This means that these new constructs are also contributing in development (or) selection of maintenance strategies of the gas utility company.

P2: What is the role of Maintenance Decision Support Systems (MDSS) in selection of optimum maintenance strategy mix (or) best maintenance strategy among the developed maintenance strategies for the particular equipment/process/operation?

There is no evidence found from the interview data that the gas utility company is using MDSS for selection of maintenance strategy. Development & formulation of maintenance strategy is being done based on corporate guidelines such as Maintenance Policy and MOU Targets, previous experience, process/operation requirements, OEM Recommendations, Criticality of Process/equipment, Internal Norms such as ISO maintenance manual, unit level guidelines, etc., Industry Norms such as OISD, PNGRB standards & guidelines and, specific maintenance strategies as recommended by equipment OEM, industry practices.

P3: How Maintenance Decision Support Systems (MDSS) helps to improve performance of maintenance function in terms of maximizing availability of equipment/operations with the appropriate maintenance strategy selection for those equipment/operations?

There is no evidence found from the interview data that the gas utility company is using MDSS for selection of maintenance strategy.

P4: How integration of organization's business strategy with maintenance strategy provides an effective implementation of maintenance strategy?

Organization'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.

P5: Why e- maintenance concepts are used for efficient implementation of a maintenance strategy in the gas utility company?

There is sufficient evidence available that both the petrochemicals & NG Pipelines are using the e-maintenance concepts for effective & efficient implementation of maintenance strategies. Few such maintenance concepts are such as Distributed Control System (DCS), Supervisory Control And Data Acquisition (SCADA) System, Vibration Monitoring System & Software, and SAP PM Module.

P6: How maintenance tactics are being integrated with e-maintenance framework for development of comprehensive model for failures? How this model could help in formulation of maintenance policy at the company level?

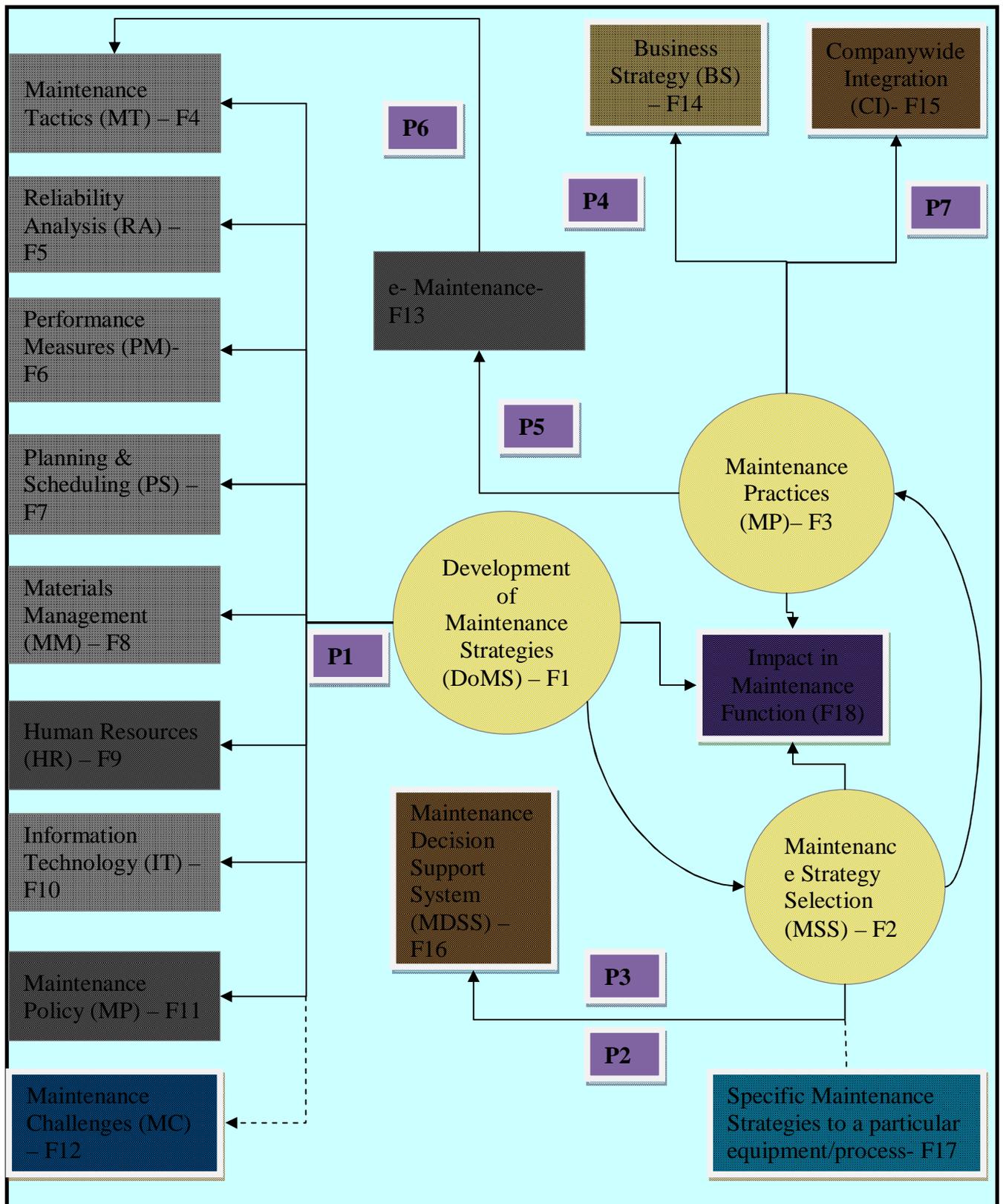
In the gas utility company, e-maintenance is being practices through SAP system. In SAP system, one specific module is available i.e., Plant Maintenance module (SAP-PM module). SAP PM Module integrate the maintenance activities such PM scheduling, planning, issuing of work permits, Equipment History, Work Instructions records etc., Further PM Module is also integrated with Material Management module (SAP –MM) 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.

P7: How the manufacturing/ production capabilities of an organization have been enhanced by integrating maintenance strategy Companywide?

Manufacturing/production capabilities of the company are getting enhanced by integrating maintenance strategy Companywide. For example, all gas processing plants 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.

This study could find evidence among relationship between the various factors related maintenance strategies & practices existing in the large gas utility company (taken for this study) and the specific maintenance strategies used in a particular equipment/process. Based on the empirical data collected through these case studies and cross-case analysis, a maintenance model which clearly depicts the sequential relationships among the factors which are contributing to maintenance strategy development or formulation of maintenance strategy and further their relation with selection of maintenance strategy and implementation of maintenance strategies i.e., maintenance practices.

Figure 5: A model for Maintenance Strategy Selection & Maintenance Practices



CONCLUSION

This research study has revisited the conceptual framework based on empirical data. A model for maintenance strategies and practices planning & execution in maintenance function has been developed with the help of conceptual lens and empirical data. Based on the detailed literature review, conceptual constructs which form the basis for maintenance strategy formulation, selection and maintenance practices were identified. These constructs were expected to be found from the empirical study. Such constructs are Maintenance Tactics, Reliability Analysis, Performance measures/Benchmarking, Planning & Scheduling, Maintenance Organization/ Human Resources, Information Technology, Maintenance Policy/Budget, Material Management, and Employee Empowerment. All these constructs have been emerged from the research study.

Additionally, two constructs such as Maintenance Challenges and Specific Maintenance Strategies for a particular equipment/process have also been emerged from the data in this research. Further, this research study uncovered maintenance strategies and practices planning and execution related to this new constructs in detail.

For a gas utility company in the Indian gas industry to manage maintenance activities more efficiently & effectively in order to operate the process/equipment smoothly. Indian Gas utility company has taken for this study needs to focus in the following:-

1. Company's maintenance strategy is to be assessed with the above identified constructs and baseline to be set.
2. 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.
3. 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.
4. 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.

5. No much emphasis is given to Labor/ material cost in the benchmarks of maintenance since the operation capacities of pipelines & process plants are being achieved excellently.
6. New construct identified i.e., Maintenance challenges influences the maintenance practices and also effect the formulation of maintenance strategy. Therefore, company has to give due priority to these issues and effective system is to be developed to mitigate these maintenance challenges and there is a need to optimize the maintenance function.
7. 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.

Theoretical contributions

Two new types of factors contributing to maintenance strategy development/formulation & maintenance practices emerged from the data such as Maintenance Challenges and Specific selection of maintenance strategies for a particular operation process/equipment. Apart from these, two types of maintenance tactics are also emerged out from the data such as Shutdown maintenance and Pro-active maintenance. Both of these maintenance tactics are very crucial for petrochemical maintenance. But, these maintenance tactics are not much useful for NG Pipelines maintenance strategy development & maintenance practices. A process model for maintenance strategies & maintenance practices has also been developed. This research contributes to the theory of maintenance strategies & practices of gas industry and in general.

Practical contribution: Implication for managers

This study would help the maintenance managers to benchmark the maintenance practices to understand the maintenance strategies development methodologies. Further, this research found evidence to formalize & improve the maintenance strategy adapted since importance attached to industry/operation/equipment specific maintenance strategies in both NG Pipelines & Petrochemicals.

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