CHAPTER IV

PROJECT STUDY RESULTS & APPLICATION IN INDUSTRY

4.1 Company background

4.1.1. Business info

The company under study, called NPC, manufactures and sells a complete range of olefins and related downstream petrochemical goods. With two plants on the grounds of the Map Ta Phut Industrial Estate in Rayong province, the Company has combined annual production capabilities of 1,523,000 tons, making it Thailand's largest olefins producer and the third largest in all of Asia.

Since production of the company's major products (Ethylene, Propylene and Polyethylene) is continuous process and demand is rather steady and predictable, hence, the most critical issue for production is *Asset Utilization* for minimizing cost. Unplanned production interruption could be major threat for profitability because of its impact on plant availability and off-spec product losses. However, Inventory is not much concerned as product lead time is so short like 30 minutes or so and the products are delivered directly via pipelines to customers.

4.1.2. Process & major equipment description

The production unit included nine cracking furnaces are provided for the expanded plant capacity. Eight furnaces are normally in service with the remaining furnace serving as a spare. The feedstock and dilution steam are preheated to the desired crossover temperature before entering the radiant section and being cracked by pyrolysis process. The effluent from the four radiant coils is combined in pairs to feed two primary Transfer Line Exchanger [TLE]'s. The total effluent of each furnace is further cooled in a secondary TLE and sent to the quench tower as next process. Since the Cracking unit does primary control of both production throughput and yield, then, total production performance is mostly depending on the unit's reliability.

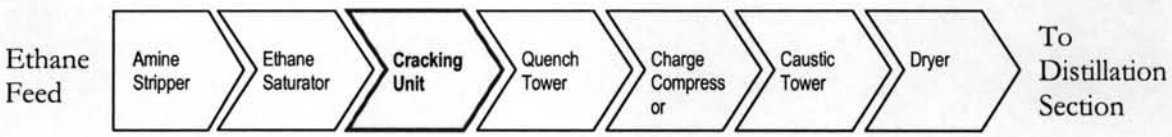

Figure 4: Early stage of Ethylene production processes

4.1.3. Organization

Olefins Production Department is in charge of olefins production. There are 3 divisions in the department as show in Figure 6; Olefins Operation Division does plant operation activities, Olefins Technical Division provides process technical support, and Olefins Maintenance Division takes care of plant equipments and reliability. Department director and division managers form steering committee and review KPI once a month. Engineers from Olefins Maintenance Division are assigned to be area focal point for each process area, facilitate SDWT, and coordinate ORMS activities.

This organization structure has been used since 2005. Before that, the structure was functional-based and there were only operation divisions in the department (Fig.5).

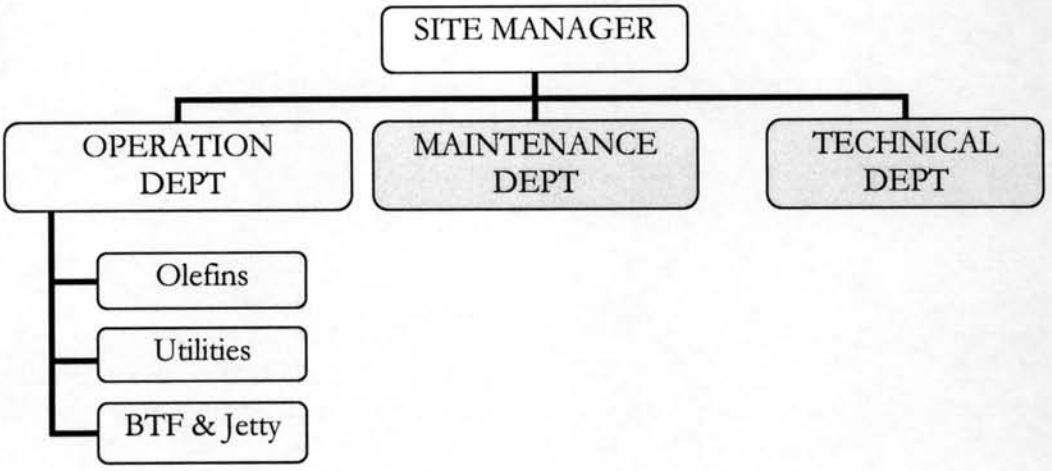

Figure 5 : NPC Organization before 2005

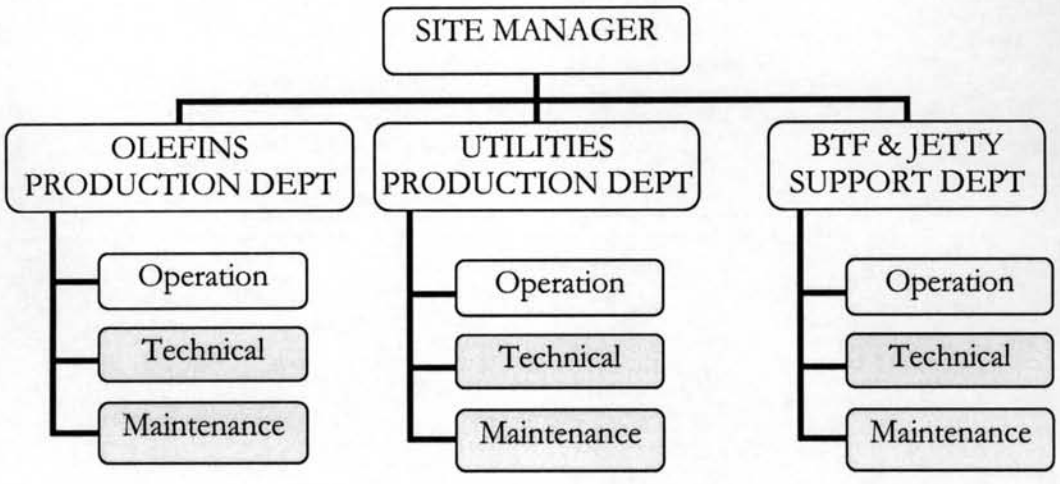

Figure 6 : Current NPC Organization since 2005

4.2 ORMS process requirements

As it is author's responsibility for planning and managing for reliability management implementation in NPC as part of the job, therefore, most of strategic information is real and has been distributed through organization and used for analysing in this case study.

4.2.1. Production requirement

Since production of NPC's major products (Ethylene, Propylene and Polyethylene) is continuous process and demand is rather steady and predictable, hence, the most critical issue for production is *Asset Utilization* for minimising cost. Unplanned production interruption could be major threat for profitability because of its impact on plant availability and off-spec product losses. However, Inventory is not much concerned as product lead time is so short like 30 minutes or so and the products are delivered directly via pipelines to customers.

For reference, NPC Olefins plant (produces Ethylene and Propylene) currently uses Key Performance Index (KPI) show in Table 5.

Table 5: NPC Olefins Plant KPI (Source: NPC)

KPI	Unit	Y2005 Target
Utilization of Cracker (Ethylene) Unit	%	88.20
Utilization of Oleflex Unit	%	94.56
Yield (Ethylene from Ethane Crack)	%	73.45
Yield (Propylene from Oleflex)	%	79.30
Flare Loss (Olefins)	Ton	2,056
Energy Consumption (Cracking Heater)	BTU / Pound	7,410
Production Plan Accuracy (Olefins)	%	-2.00

Definitions of each KPI are clarified as follow;

Production Utilization

Production Utilization is calculated by using formula; *Actual Products Volume / Designed Capacity*. The target for production volume would be set at beginning of the year to conform sales target, and then used for calculating Utilization for each product. The major factors that contribute to Utilization are: *Availability (represents actual production time),* and *Production Rate (represents actual production rate).* Production manager needs to manage production plan to comply with budget, and minimise unplanned down-time / de-rate. Equipment reliability is considered as critical success factor for achieving the target.

NPC has developed IT system for tracking "Unbudgeted Unutilized Events" called *Plant Incident Information System* for recording events that production be interrupted or de-rated unintentionally. The record consists of event description, investigation for root cause, countermeasure, and losses in term of production hours and product volume. The system is not only used for reporting production losses, but also used for improving plant reliability through preventive action assigned by root cause analysis investigation.

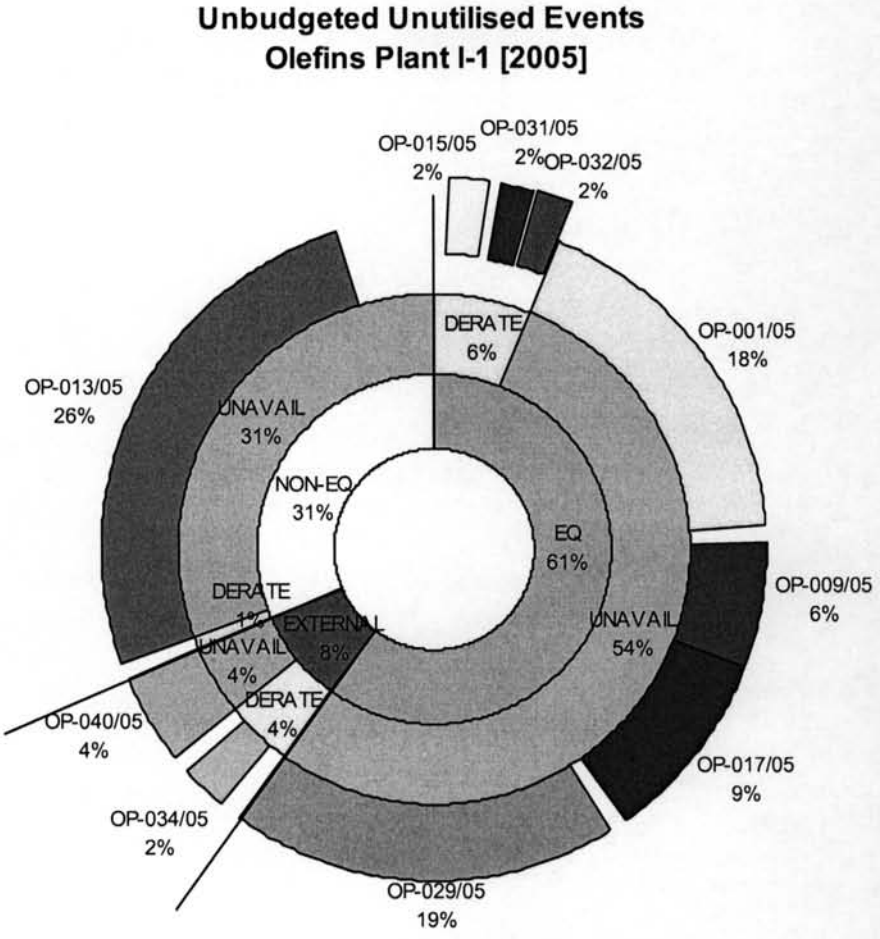

Figure 7: NPC Olefins Plant Unutilization Breakdown (source: NPC)

The data is used for reporting and analysing how production cannot achieve target. Figure 7 shows losses breakdown for unbudgeted unutilized events in 2005, total of 11 Million $. Almost two-third of losses are from equipment related problems, consist of several major incidents. However, main loss came from OP-013/05, which is 8-days production loss from plant modification delays.

Another less-critical factor that affects Utilization is *Planned Shutdown*, which is budgeted prior to production period. Effective planning and scheduling preparation could challenge maintenance process and optimize production down-time for profiting

availability as well. Along with capable maintenance ability or *Maintainability*, the production plan could be managed and controlled confidently.

Yield

Yield is calculated by using formula; *Actual Products Volume / Actual Feedstock Volume*, which is ability to convert Ethane/Propane to Ethylene/Propylene. The target for yield is also set to comply with sales target, though it is more strategic. Yield represents *Quality Rate* for olefins production and could be varied by changing production modes. Due to process characteristic, which higher throughput causes lower yield but obtains higher production rate, yield target is more likely to be directed by product market price. During high price season, lower yield might be allowed and production rate is preferred for maximise profit. In low price season, high yield mode might helps increase cost margin and contributes more for profitability.

Flare Loss

"Flare" means off-spec products which need to be eliminated (same meaning as "scraps"). Typically, unbudgeted flare losses are mainly from unplanned shutdown; therefore, this measure is also used for indicating *Production Reliability*. Regarding to Utilization topic, flare loss also contributes to Utilization as part of *Unavailability* and typically budgeted around 0.5% of planned production.

Energy Consumption

Energy consumption measure is mainly used for benchmarking in industry as *Balanced Energy Consumption / Product Volume*. Since the measure gets high effect from process technology, capacity, plant age, etc. therefore it is not very effective for comparing plants from different technologies. NPC energy index is in good position relatively, which could be translated to be around 4% of product cost.

Planning Accuracy

Planning accuracy is more like *Quality Target* and used as intermediate controlled for commercial department. Monthly production is expected not be missing more than 2% of budgeted plan.

4.2.2. Strategy deployment

Even NPC's Operational KPI is conformed to business objective of cost leadership. Hence, the only difficulty is how to deploy the KPI to shop floor effectively. These days, the objective of KPI is barely link to operational activities and middle managements do not clearly understand how their works add value to the products.

Since then, Kaplan's Balance Scorecard & Strategy Map technique has been chosen to clarify the relationship. Adapted from Meridium's article, the relationship for each perspective has been reviewed and shows in Figure 8. In Process perspective, there are opportunities for improving performance at operational level and create effects on plant level, for example; improving material procurement would help for work effectiveness, then lead to lower downtime and improving availability, eventually. With strategy map linkage, top-level objectives are assured to be met and business strategy is properly deployed.

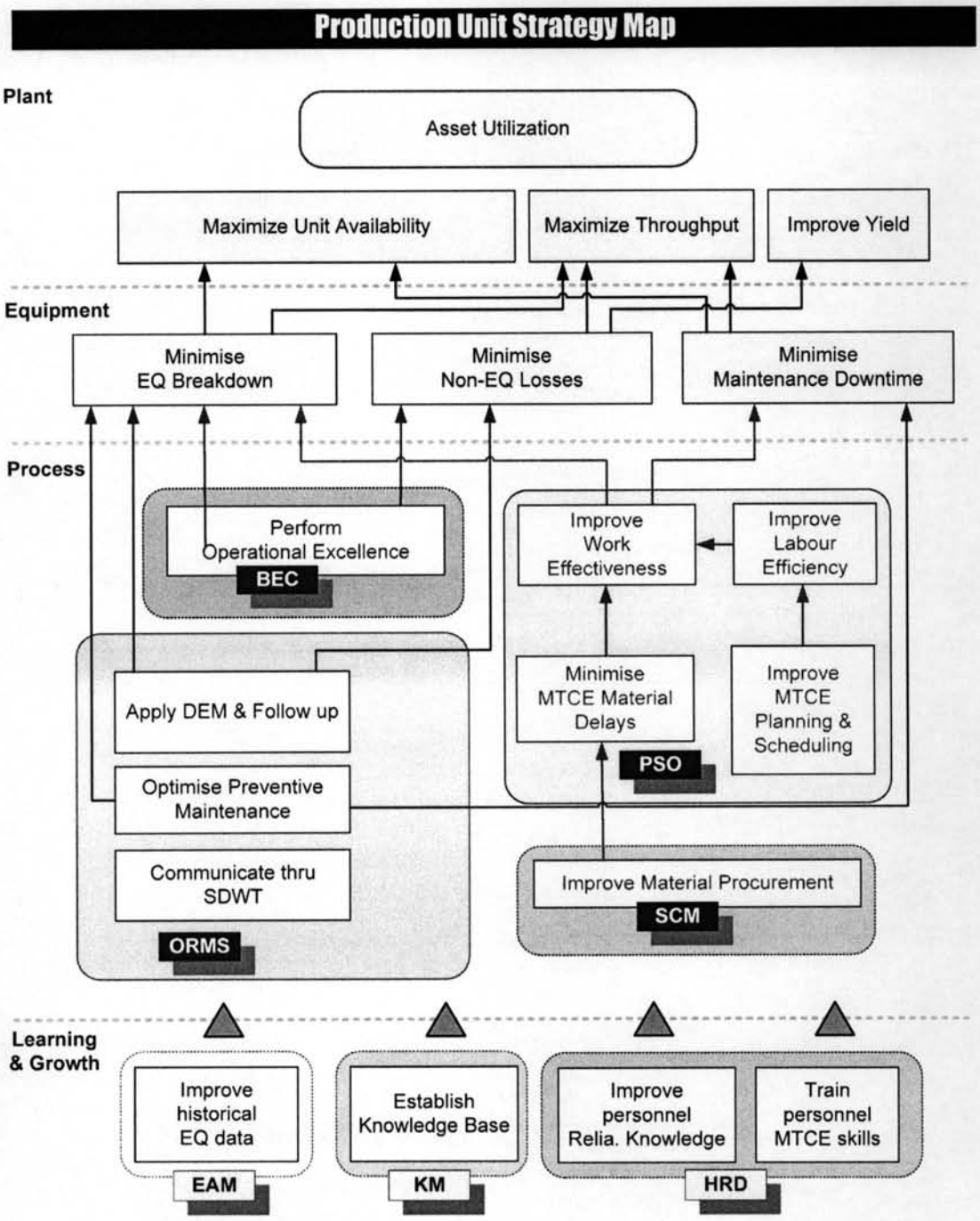

Figure 8: NPC Production Strategy Map (source: adapted from Meridium's article)

Asset Utilization, as the top level objective in Plant level, could be broken down in to three elements; Availability, Throughput, and Yield. Availability represents operating hours that the production unit actually runs. Throughput indicates actual production rate in certain period. And Yield means ability to convert feedstock into product, or Ethane to Ethylene in this case. In other word, it could be called as Overall Equipment Effectiveness (OEE) of the process.

By drilling down into Equipment level, there are three elements related to upper level objectives; Equipment Breakdown is about how often the process is interrupted because of the un-reliability of equipments running in the production unit. Non-equipment Loss shown outages which are not by equipment-related factors, such as operation errors or process-related problems. Then Maintenance Downtime shows how long machines are out-of-service due to maintenance needs. This level breakdown illustrates how equipments contribute to production requirements in top level.

In Process level, there are numbers of strategies to perform for achieving upper level's objectives. Most of strategies in this Process level are adapted from elements in literatures about Quality Management., Asset Management, and various Reliability Management tools. The strategies are categorized into 5 groups as;

ORMS

ORMS is considered as main strategy for improving plant reliability. As discuss earlier about concept of ORMS, combination of using systematic decision making process, such as RCM, RBI, and SIF, to develop *Optimum Preventive Maintenance Program* to maintain equipment proactively, and using RCA techniques for creating *Effective DEM Solution* to solve reactive problems permanently. These actions are crucial for reliability and could be sustained by *SDWT deployment*, by helping improve communication among departments and enforce ownership in work process for people involved in plant operation.

PSO

Maintenance Work Management is more about resource management; consists of works optimization, material controls, and labour controls. Works optimization could be done through *Planning & Scheduling Optimization (PSO) process*, while material and labour required for works need to be strictly controlled to ensure that preventive maintenance program and requested works are done properly and efficiently.

BEC

Basic Equipment Care (BEC) focuses on optimizing operator's activities to prioritize their works. With *Structured Round* reviewed and used, operators could focus on work necessity and optimized their routine inspection routes. This would save time and resource for implementing *BEC initiatives* on equipments; such as cleaning, lubricating, or basic inspection. Similar to TPM concept as focusing on operators who work closely with the equipments, BEC would help on detecting problems early and they could correct most of the basic problems before failure occurred.

SCM

Supply Chain Management (SCM) is one of major foundation of facilities management. To ensure that spare parts and maintenance materials are delivered right and on time, purchase requisitions are prioritized by considering on both purchasing value and impacts on production, then *Sourcing Strategy* are developed and used for focusing on more important items. For high-value, high-impact items, it may require to develop *Supplier Relationship Management* to extend value of both and ensure sustainability of the supply.

Learning & Growth

As support level, shows aspect of *Information management*, *Knowledge management*, and *Competency management* which required for support the operations in upper level. As these management systems have been developed in company already, hence, it needs to review only additional relevant items which related to above strategies.

The strategy map could be converted into MBNQA view by showing that the two top levels of Plant and Equipment are considered as desired outcomes or "Result" from performing strategies in "Process" level, which supported by "Enabler" systems. Then, the strategy map could be broken down into elements and categorized as shown in Table 6. Each element is numbered for further reference.

Table 6 : MBNQA view of production strategy map

"Result"	***Production objectives***			
	Asset Utilization (A1)			
	Availability (A2.1), Throughput (A2.2), Yield (A2.3)			
	EQ Breakdown (A3.1), Non-EQ Losses (A3.2), Maintenance Downtime (A3.3)			
"Process"	***ORMS***	***PSO***	***BEC***	***SCM***
	Effective DEM solutions (B1.1)	Effective maintenance works (B2.1)	Operation excellence (B3.1)	Improved Material procurement (B4.1)
	Optimized PM (B1.2)	Manpower management (B2.2)		
	Clearly communication thru SDWT meeting (B1.3)	Maintenance planning & scheduling (B2.3)		
"Enabler"	***EAM***: Historical Data (C1.1)			
	KM: Knowledge based system (C2.1)			
	HRD:RM Competency (C3.1)			

This above relationship clearly illustrates how strategy map could be used for communicating strategy to operation level, and help people involved in operation focus on same target. However, since this study would focus on how ORMS contribute to production improvement, then, only detailed activities of ORMS would be discussed and shown in later section.

4.2.3. ORMS Deliverables breakdown

Taking closer look at ORMS deliverables (B1.1, B1.2 and B1.3), which are objectives for front-lined operation staffs whom involved in ORMS as well. These objectives are used for developing related actions or initiatives, lead by asking question like "How could we possibly make this desired objective happen?" to describe action plan to do.

Effective DEM Solutions

To prevent recurrence failure, systematic problem solving and solution development methodology must be in place and use by operational culture. The company has implemented and deployed usage of DEM methodology developed by Shell Global Solutions. The methodology is based on RCA technique, Kepnor & Tregor's Problem Solving and Decision Making technique, and several other quality tools fit together, to ensure that the problem would be properly solved with being stated correctly, all relevant facts reviewed, root causes identified based on facts, and solutions developed properly. To sustain the methodology, the company develop DEM procedure as part of ISO9000. The procedure covers following steps;

- Define what is counted as production problem and require further investigation.
- Assess criticality of the problem, based on risk, to determine proper depth of investigation.
- Provide guideline for DEM methodology.
- Follow up and control progress of investigation and deployed solutions.
- Control related investigation documents.

However, the procedure alone could not enforce effectiveness of the investigation; it also requires good communication and commitment from people involved, which might get supported by SDWT fortunately.

Optimized PM

Not enough or too many PM programs could effect equipment reliability and production utilization. There are best practices in the industry suggested using structured work identification tools to assess equipment criticality and determine proper maintenance actions by optimizing risk and effort, consist of;

- Reliability Centred Maintenance (RCM): RCM focuses on how to assess equipment criticality and maintain equipment function by set up appropriate preventive maintenance programs to cover its failure modes as need. Hence, RCM is chosen for both initiating PM for new equipments and reviewing PM for existing ones.
- Reliability Bases Inspection (RBI): RBI focuses on assessing expected life of equipments and set up appropriate inspection programs to cover ensure that equipment would not fail before sign of failure be detected. RBI is mainly used for determining inspection method and interval to ensure that mechanical integrity would be properly maintained.
- Safety Instrumented Functions (SIF): SIF focuses on how to assess effectiveness of instrumentation system that protects the equipment, and develop initiatives as

need, including maintenance and testing programs, to ensure the equipment is protected properly in any operating scenario.

These tools are proven and widely used in the industry as part of work identification and maintenance policy development in Asset Management.

Clearly Communications

One of major key success factors for ORMS is *Communication* within multi-disciplinary team (so called Self-Directed Work Team [SDWT]). SDWT consists of front-lined operating staffs from various departments managing their works together by themselves. The concept of SDWT had been introduced earlier in the company once in year 2000 and shown partial success in that time; even they were disbanded due to lack of management support.

Since every SDWT's members are ones who work in production process, therefore, they are expected to take responsibility in equipment reliability as well. Though the concept is good in papers, SDWT implementation needs patience, and would not show much progress or benefit in early stage. Some practitioner said just keep SDWT exist is good enough for first few years of implementation and they would roll by themselves after that.

SDWT is expected to have meeting in regular basis for following up assigned work progress, discussing about production problems and opportunities, communicating production-related information and sharing knowledge from their expertise.

4.3 KPI Development

KPI for ORMS would be developed in 2 aspects; Lagging KPI for measuring Result, and Leading KPI for measuring Process. Summary of these KPI is listed in Table 7.

4.3.1. Lagging KPI

From previous discussion, it is rather clear that the expected Results of ORMS are equipment's Reliability. However, another expectation for maintaining system utilization is to operate safely and comply with environmental regulations, so called Integrity. Typically, Reliability represents ability to perform primary assigned function during certain period of time, which often applies to rotating equipments, while Integrity mainly focuses on equipment's secondary function related to hazardous risk exposures, mostly applies to material handling system (pressure vessels and piping), and protective devices.

Reliability

Hence, a well-known, widely-used metric for Reliability is *Mean Time Between Failure (MTBF)*. Fundamentally, MTBF is the reciprocal of the Failure Rate (λ) for repairable system which might be varied by time, and needs to be statistically derived from Probability Density Function (PDF) of the failure to identify the distribution pattern. However, to make the measure less complicated and be practical for routine reporting, MTBF could be calculated based on assumption of constant failure rates. Thus, the MTBF formula would be;

MTBF = Operating time (hours) / Number of Failures

Typically, period of 1 year to measuring date has been suggested to be used for MTBF calculation.

In this case, MTBF would be measured separately by equipment type, since each equipment type has different failure mode and could not be compared or grouped together. Equipment types are classified into; Pump (Centrifugal, Injection, Other), Motor, Steam Turbine, Compressor, and Fan. Failure definition for each equipment type is pre-determined for information consistency, by reviewing equipment type failure modes. Failure history could be extracted from maintenance notification records in the computerized maintenance management system. To calculate MTBF for specific equipment type, total operating hours of every equipments are summarized, then divided by total numbers of failures in that period (particularly year-to-date).

For example; there are 10 centrifugal pumps in the area, and failures happened 2 times in past 365 days.

MTBF = (10 pumps x 365 days x 24 hours) / 2 failures

= 43,800 hours (or 5 years)

MTBF target has been suggested by "World Class" practice, and would be reviewed annually. If MTBF could not reach expected target, it would be acknowledged by SDWT whom take care of the area. Further quality tools would be used to determine problematic "Bad Actor" equipment and perform investigation for improving its reliability by using RCM and DEM methodology to adjust PM program, or redesign if necessary.

Integrity

Integrity issues have been discussed in several safety management systems; such as ISRS and PSM, and used as a major requirement in various regulations. Integrity is contributed by design and inspection (included testing) program, and usually measured by detecting failure of vessels, piping, or protective devices found during inspection or testing. With proper inspection program, acceptable defect would be found early and corrected before it would grow and become failure. This kind of failure (often called Hidden Failure or Unrevealed Failure) would not be detected under normal operation, but if another failure occurs and the protection system does not work as expected, the consequence is far worse and may causes fatal losses.

However, to measure "fail-to-protect" defects, the equipments have to be at least covered by some inspection or testing program. If there is no any inspection at first place, the failure could not be found unless multiple failures occur and hazardous consequence exposes. Most inspection/testing programs are suggested by manufacturers and past experiences of knowledgeable people. Modern systematic reliability tools such as RBI and SIF are also recognized in the industry for determining optimized inspection interval based on risks.

The result of Integrity is measured directly from *percentage of Unrevealed Failure found* in certain period of time, which expected to be zero. Similar to MTBF, each protection system has different inspection philosophies and needs to be analyzed separately. Hence, they are classified into; Piping, Mechanical protective device (Pressure relief valve, Over-speed protection device), Electrical protective device (Electrical protective relay), Instrumentation protective device (Instrument safeguarding system, Gas detector). Variation from inspection/testing that is out of acceptable range is considered as failure and would be reviewed by SDWT.

4.3.2. Leading KPI

Refer to ORMS Deliverables breakdown (4.1.3); since the expectations are mostly qualitative, thus it would be difficult to make direct measurement to quantify effectiveness of the action. Feedback survey questionnaire is planned to be used once a year to analyze qualitative data from stakeholders' opinions. However, there are some indirect metrics that is still useful for tracking and controlling ORMS process during implementation phase.

Since DEM process has already develop procedure for controlling quality of incident investigation, it seems sensible to assume that the process performance could be represented by compliance of DEM procedure, or *DEM Compliance*. DEM compliance is defined as percentage of numbers of conformed incident investigation by total number of incidents in particular period, and expected to be 100%.

On the other hand, PM identification process is more subjective and hard to get evidence to tell how good the PM is. Therefore, the assumption is made as; the technical object which be reviewed by structured PM identification methodology, such as RCM, RBI, or SIF, is qualified as *RCM/RBI/SIF Compliance* and its PM should be effective. RCM/RBI/SIF compliance is defined as percentage of numbers of technical objects which conformed with RCM/RBI/SIF analysis by total number of technical objects in particular methodology, and expected to be 100%. Though, while ORMS process is under implementation, the RCM/RBI/SIF compliance is used for measuring and controlling against their progress.

To ensure that SDWT would communicate effectively, they must be in the structured meeting in regular basis. The meeting agenda are set into 2 approaches; Reactive and Proactive. Reactive issues are about current production problem that required immediate attention, including incident investigation and DEM, while Proactive issues are about initiatives for potential problems or opportunities related to production, and PM identification. *Number of SDWT meeting* is enforced to be at least twice a month, more is better.

Table 7 : Summary of KPI definition

KPI	Definition	Objectives	Formula	Qualifications
MTBF by equipment type	Mean Time Between Failures (MTBF) is the average length of time between one failure and another failure for an asset or component. MTBF is the reciprocal of the Failure Rate (λ), at constant failure rates.	This metric is used to assess the reliability of an asset. Reliability is usually expressed as the probability that an item or asset will perform its intended function without failure for a specified time period under specified conditions. An increasing MTBF indicates improved asset reliability	MTBF = Operating time (hours) / Number of Failures Sample: If an asset had 10 failures in 1000 hours of operation, then the Mean Time Between Failures is MTBF = 1000 hours / 10 failures = 100 hours	**1.** Indicator type : Lagging **2.** To be used by: maintenance personnel and reliability engineers **3.** Best when used at asset or component level. **4.** This metric should be performed on critical assets and trended over time. **5.** Can be used to compare reliability of similar equipment types. **6.** For low MTBF numbers, analysis should be performed (i.e., root cause failure analysis (RCFA), failure mode and effects analysis (FMEA), defect elimination method (DEM)) in order to determine how the asset's reliability can be improved. **7.** Equipment types are classified into; Pump (Centrifugal, Injection, Other), Motor, Steam Turbine, Compressor, and Fan
Unrevealed Failure by equipment type	Unrevealed Failure is failure that found during inspection or testing, and unable to be detected under normal operation, but if another failure occurs and the protection system does not work as expected, the consequence is far worse and may cause fatal losses.	This metric is used to assess the integrity of an asset. Integrity is usually expressed as the ability that an item or asset will perform its secondary function mainly focuses on equipment's secondary function related to hazardous risk exposures, mostly applies to material handling system (pressure vessels and piping), and protective devices. Unrevealed Failure is expected to be zero.	Unrevealed Failure = Percentage of unrevealed failures found in particular period (monthly)	**1.** Indicator type : Lagging **2.** To be used by: maintenance personnel and reliability engineers **3.** Best when used at asset or component level. **4.** This metric should be performed on critical assets and trended over time. **5.** Can be used to compare integrity of similar equipment types. **6.** If unrevealed failure keep happening, analysis should be performed (i.e., root cause failure analysis (RCFA), failure

Table 7 : Summary of KPI definition (Cont.)

KPI	Definition	Objectives	Formula	Qualifications
				mode and effects analysis (FMEA), risk based inspection (RBI), safety integrity function (SIF)) in order to determine how the asset's integrity can be improved. 7. Equipment types are classified into; Piping, Mechanical protective device (Pressure relief valve, Over-speed protection device), Electrical protective device (Electrical protective relay), Instrumentation protective device (Instrument safeguarding system, Gas detector).
DEM Compliance	The metric is defined as percentage of numbers of conformed incident investigation by total number of incidents in particular period. Typically use as year accumulative.	This metric allows one to track how DEM procedure has been implemented and used effectively in routine operation. DEM compliance is expected to be 100%	DEM Compliance (%) = (Total numbers of incidents occurred – Number of DEM non-conformance)/ Total numbers of incidents occurred X 100 Sample: If there have been 10 incidents reported since the beginning of this year, and 1 of them had not been investigated properly as per DEM procedure and issued as non-conformance. DEM Compliance = (10 total incidents – 1 non-conformance) / 10 total incidents x100% = 90%	1. This is a leading indicator. 2. To be used by operation manager (as process owner) to control quality of DEM. 3. This metric should be performed as control parameter for SDWT.

Table 7 : Summary of KPI definition (Cont.)

KPI	Definition	Objectives	Formula	Qualifications
RCM Compliance	The metric is defined as percentage of accumulative numbers of equipments that conformed RCM analysis by total number of equipment.	This metric allows one to track how RCM progress has been implemented. RCM compliance is expected to be as planned.	RCM Compliance (%) = Accumulative numbers of equipments analyzed with RCM/ Total numbers of equipment X 100 Sample: If there are 2,000 equipments in plant, 1,200 equipments already been analyzed with RCM, and 100 equipments analyzed with RCM added this month RCM Compliance = (1,400 analyzed equipments + 100 newly analyzed equipments) / 2,000 total equipments x100% = 75%	1.This is a leading indicator. 2.To be used by reliability manager (as process owner) to control implementation progress of RCM. 3.This metric should be performed as control parameter for RCM facilitators.
RBI Compliance	The metric is defined as percentage of accumulative numbers of corrosion loops that conformed RBI analysis by total number of corrosion loops.	This metric allows one to track how RBI progress has been implemented. RBI compliance is expected to be as planned.	RBI Compliance (%) = Accumulative numbers of corrosion loops analyzed with RBO/ Total numbers of corrosion loops X 100 Sample: If there are 600 corrosion loops in plant, 320 corrosion loops already been analyzed with RBI, and 40 corrosion loops analyzed with RBI added this month	1. This is a leading indicator. 2. To be used by reliability manager (as process owner) to control implementation progress of RBI. 3. This metric should be performed as control parameter for RBI facilitators.

Table 7 : Summary of KPI definition (Cont.)

KPI	Definition	Objectives	Formula	Qualifications
			RBI Compliance = (320 analyzed corrosion loops + 40 newly analyzed corrosion loops) / 600 total equipments x100% = 60%	
SIF Compliance	The metric is defined as percentage of accumulative numbers of control loops that conformed SIF analysis by total number of control loops.	This metric allows one to track how SIF progress has been implemented. SIF compliance is expected to be as planned.	SIF Compliance (%) = Accumulative numbers of control loops analyzed with SIF/ Total numbers of control loops X 100 Sample: If there are 1,200 control loops in plant, 870 control loops already been analyzed with SIF, and 90 control loops analyzed with SIF added this month SIF Compliance = (870 analyzed equipments + 90 newly analyzed equipments) / 1,200 total equipments x100% = 80%	1.This is a leading indicator. 2.To be used by reliability manager (as process owner) to control implementation progress of SIF. 3.This metric should be performed as control parameter for SIF facilitators.
No. of SDWT Meeting	Numbers of SDWT meeting is counted monthly.	To ensure that SDWT would communicate effectively, they must be in the structured meeting in regular basis. Number of SDWT meeting is enforced to be at least twice a month, more is better.	Numbers of SDWT meeting	1. This is a leading indicator. 2. To be used by reliability manager (as process owner) to control effectiveness of SDWT. 3. This metric should be performed as control parameter for SDWT facilitators.

4.4 KPI Effectiveness Test

Proposed KPI is tested using Neely et al.(2002) Ten Test Model to verify if they are good measures. The test is more like *checklist* for ensuring that every aspect is concerned.

4.4.1. MTBF

The Truth Test	*Are we really measure what we set out to measure?* Yes. MTBF show how often failure occurs, which is defined as reliability. Result: Pass
The Focus Test	*Are we only measure what we set out to measure?* Yes, refer to industrial practices. Result: Pass
The Relevance Test	*Are we measure the right thing?* Yes, refer to industrial practices. Result: Pass
The Consistency Test	*Will the measurement be same whoever make the measurement and whenever it done?* Key success factor is making definition of "Failure" consistent and understandable. Result: Pass
The Access Test	*Can the data be easily accessed and understood?* Failure event data is recorded electronically in CMMS. Therefore it is convenient to calculate by spreadsheet software. Result: Pass
The Charity Test	*Is there any possible ambiguity in the interpretation of the results?* No. Result: Pass
The So-What Test	*Can and will the measure be acted upon?* Yes. The measure would be used for trigger attention for determining frequent failed "bad actors" equipments, and improving them, by SDWT. Result: Pass
The Timeliness Test	*Can the data be accessed and analyzed rapidly enough to allow action to be taken or trend to become apparent?* Yes, as ORMS is on-going process. Result: Pass
The Cost Test	*Is the measure worth the cost of measurement?* Cost of measuring is negligible since it is part of routine works. Result: Pass
The Gaming Test	*What behaviours will the measure actually encourage?* Since MTBF is the reciprocal of the Failure Rate, it is critical to make definition of "Failure" be very clear and understandable for maintenance staffs, or maintenance record data may be manipulated to make results look good. Result: Unconfirmed

MTBF is standard KPI and widely used for reliability measurement. However, failure data need to be clearly defined and recorded to precisely calculate MTBF, or it will be manipulated easily.

4.4.2. Unrevealed Failure

The Truth Test	*Are we really measure what we set out to measure?* Yes. Unrevealed Failure show how often failure occurs, even there is no consequence at the time. Result: Pass
The Focus Test	*Are we only measure what we set out to measure?* Yes, refer to industrial practices. Result: Pass
The Relevance Test	*Are we measure the right thing?* Yes, refer to industrial practices. Result: Pass
The Consistency Test	*Will the measurement be same whoever make the measurement and whenever it done?* Yes. Result: Pass
The Access Test	*Can the data be easily accessed and understood?* Failure event data is recorded electronically in CMMS. Therefore it is convenient to calculate by spreadsheet software. Result: Pass
The Charity Test	*Is there any possible ambiguity in the interpretation of the results?* No. Result: Pass
The So-What Test	*Can and will the measure be acted upon?* Yes. The measure would be used for trigger attention for determining frequent failed "bad actors" equipments, and improving them, by SDWT. Result: Pass
The Timeliness Test	*Can the data be accessed and analyzed rapidly enough to allow action to be taken or trend to become apparent?* Yes, as ORMS is on-going process. Result: Pass
The Cost Test	*Is the measure worth the cost of measurement?* Cost of measuring is negligible since it is part of routine works. Result: Pass
The Gaming Test	*What behaviours will the measure actually encourage?* Since Unrevealed Failure is also depend on how often equipment to be tested or inspected. The result could be mis-led if some equipment has no testing program installed. Result: Unconfirmed

Similar to MTBF, unrevealed failure is also widely used in industry. But still, since unrevealed failure is also depend on how often equipment to be tested or inspected. The result could be mis-led if some equipment has no testing program installed.

4.4.3. DEM Compliance

The Truth Test	*Are we really measure what we set out to measure?* Yes. Result: Pass
The Focus Test	*Are we only measure what we set out to measure?* Yes. Result: Pass
The Relevance Test	*Are we measure the right thing?* Yes. Result: Pass
The Consistency Test	*Will the measurement be same whoever make the measurement and whenever it done?* Yes. Refer to ISO9000 audit result. Result: Pass
The Access Test	*Can the data be easily accessed and understood?* The data could be accessed easily ISO9000 audit result is published in department. Result: Pass
The Charity Test	*Is there any possible ambiguity in the interpretation of the results?* No. Result: Pass
The So-What Test	*Can and will the measure be acted upon?* Yes. Refer to ISO9000 control procedure. Result: Pass
The Timeliness Test	*Can the data be accessed and analyzed rapidly enough to allow action to be taken or trend to become apparent?* Yes, as long as the procedure existed. Result: Pass
The Cost Test	*Is the measure worth the cost of measurement?* Cost of measuring is negligible since it is part of routine works. Result: Pass
The Gaming Test	*What behaviours will the measure actually encourage?* The procedure clearly states work process and responsibility. The result would be as intended. Result: Pass

DEM Compliance passes all tests and considers as good metric.

4.4.4. RCM/RBI/SIF Compliance

The Truth Test	*Are we really measure what we set out to measure?* Yes, with previous stated assumption in 4.3.2 Result: Pass
The Focus Test	*Are we only measure what we set out to measure?* Yes. Result: Pass
The Relevance Test	*Are we measure the right thing?* Yes, with previous stated assumption in 4.3.2 Result: Pass
The Consistency Test	*Will the measurement be same whoever make the measurement and whenever it done?* Sort of. It depends on RCM/RBI/SIF project definition. Result: Pass
The Access Test	*Can the data be easily accessed and understood?* Yes, data is monthly reported by RCM/RBI/SIF team leader. Result: Pass
The Charity Test	*Is there any possible ambiguity in the interpretation of the results?* No. Result: Pass
The So-What Test	*Can and will the measure be acted upon?* Yes. The measure would be monitored against plan and controlled by RCM/RBI/SIF team leader. Result: Pass
The Timeliness Test	*Can the data be accessed and analyzed rapidly enough to allow action to be taken or trend to become apparent?* Yes, as monthly basis. Result: Pass
The Cost Test	*Is the measure worth the cost of measurement?* Cost of measuring is negligible since it is part of project implementation works. Result: Pass
The Gaming Test	*What behaviours will the measure actually encourage?* Since the result is calculated based on committed project scope, not total number of equipments in plant, therefore it might be mis-interpreted by project team. Result: Unconfirmed

RCM/RBI/SIF Compliance is about project implementation progress, which is not direct objective of production. However it may be considered as "Strategy" to achieve reliability and integrity at last.

4.4.5. SDWT Meeting Number

The Truth Test	*Are we really measure what we set out to measure?* Yes. Result: Pass
The Focus Test	*Are we only measure what we set out to measure?* Yes. Result: Pass
The Relevance Test	*Are we measure the right thing?* Yes. Result: Pass
The Consistency Test	*Will the measurement be same whoever make the measurement and whenever it done?* Yes. Result: Pass
The Access Test	*Can the data be easily accessed and understood?* Yes. Minute of meeting would be distributed among team members. Result: Pass
The Charity Test	*Is there any possible ambiguity in the interpretation of the results?* No. Result: Pass
The So-What Test	*Can and will the measure be acted upon?* Yes, by SDWT facilitators. Result: Pass
The Timeliness Test	*Can the data be accessed and analyzed rapidly enough to allow action to be taken or trend to become apparent?* Yes, as ORMS is on-going process. Result: Pass
The Cost Test	*Is the measure worth the cost of measurement?* Cost of measuring is negligible since it is part of routine works. Result: Pass
The Gaming Test	*What behaviours will the measure actually encourage?* Since this measure is defined as "more is better" so it could not go wrong. Result: Pass

Numbers of SDWT meeting is simple, yet important metric to improve communication and promote team-building culture.

4.5 Performance Monitoring & Controlling Process

Process for monitoring and controlling performance of ORMS had been discussed with Steering Committee, whom in charge of the production and considered as ORMS process owner. Roles and responsibilities for managing performance of ORMS in the organization have been clarified. The assignment for reporting lagging KPI is taken by Reliability Engineer, while leading KPI is reported by people whom take care of each initiative. Summary of the assignment shows in Table 8.

Table 8: Roles & Responsibilities in performance management process

KPI	Owner	Reporter	Acting Person
MTBF	Steering Committee	Reliability Engineer	SDWT
Unrevealed Failures	Steering Committee	Reliability Engineer	SDWT
DEM Compliance	Steering Committee	Operation Manager	Operation Manager
RCM/RBI/SIF Compliance	Steering Committee	RCM/RBI/SIF Facilitator	RCM/RBI/SIF Team Leader
SDWT Meeting No.	Steering Committee	Area Focal Point	SDWT

The performance management process is integrated into ORMS process by setting up agenda for KPI reporting in both Steering Committee meeting and SDWT meeting. The KPI report is prepared by Reliability Champion every month and used for communication in the meeting. The results are reviewed together in team and discussed for improvement.

4.6 *Study results*

The KPI has been set and measured following guideline in chapter 4.2, while targets are set based on benchmarking information and industry standards. The results have been reviewed in steering team once a month and then feedback to SDWT. Actual data measured in 2007 is shown in Table 9.

Table 9 : NPC KPI results between Jan - May 2007

Performance Indicator	Unit	Frequency	Target	Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07
Reliability															
MTBF of equipment															
Motor	Month	Month	>120	>240	>240	>240	>240	>240							
Compressor	Month	Month	>48	> 48	> 48	> 48	> 48	> 48							
Fan	Month	Month	>48	> 60	> 60	> 60	> 60	> 60							
Steam Turbine	Month	Month	>48	> 132	> 132	> 132	> 132	> 132							
Centrifugal Pump	Month	Month	>48	55.5	55.5	63.4	74	88.8							
Injection Pump	Month	Month	>48	20.3	22	29.3	66	132							
Other Pump	Month	Month	>48	> 120	> 120	> 120	> 120	> 120							
Integrity															
Unrevealed Failures of Relief Valves	%	Month	0	0.0%	33.3%	0.0%	16.7%	0.0%							
Unrevealed Failures of number tested Safeguarding Systems (Instrument)	%	Month	0	0.0%	0.0%	0.0%	No testing	0.0%							
Unrevealed Failures of number tested Electrical Protective Relays	%	Month	0	14.3%	0.0%	17.7%	0.0%	17.7%							
Unrevealed Failures of number tested Over Speed Trip system	%	Month	0	25.0%	0.0%	0.0%	0.0%	0.0%							
Unrevealed Failures of number tested Gas Detectors	%	Month	0	no data	no data	no data	0.0%	0.0%							
Leading															
DEM Compliance	%	Month	100%	100%	100%	100%	100%	100%							
RCM Compliance	%	Month	*Planned*	*16.0%*	*23.0%*	*33.0%*	*43.0%*	*50.5%*							
			Actual	14.6%	18.3%	21.5%	26.9%	27.3%							
RBI Compliance	%	Month	*Planned*	*95.0%*	*95.0%*	*95.0%*	*95.0%*	*95.0%*							
			Actual	95.0%	95.0%	95.0%	95.0%	100.0%							
SIF Compliance	%	Month	*Planned*	*42.0%*	*42.0%*	*42.0%*	*50.0%*	*60.0%*							
			Actual	42.0%	47.0%	47.0%	47.0%	47.0%							
SDWT Meeting No.	Event no.	Month	2	2	2	2	1	1							

4.7 *KPI results review*

Metrics from Table 9 are interpreted and summarized as shown in Table 10. Outstanding issues are clarified by SDWT and highlighted as Notes for reference.

Table 10 : Summary of KPI results review

Performance Indicator	Interpretation	Notes
Reliability		
MTBF of equipment		
Motor	Continuous achieve target; No failure	Keep monitoring
Compressor	Continuous achieve target; No failure	Keep monitoring
Fan	Continuous achieve target; No failure	Keep monitoring
Steam Turbine	Continuous achieve target; No failure	Keep monitoring
Centrifugal Pump	Continuous achieve target; Number of failure decreased	Most "Bad Actor" are identified and corrected at root cause.
Injection Pump	Achieve target; Number of failure decreased	Most "Bad Actor" are identified and corrected at root cause.
Other Pump	Continuous achieve target; No failure	Keep monitoring
Integrity		
Unrevealed Failures of Relief Valves	Unrevealed failures are randomly found during inspection	The problem is acknowledged and under investigation by SDWT.
Unrevealed Failures of number tested Safeguarding Systems (Instrument)	Continuous achieve target; No failure	The system has been prioritized and set up monitoring long time ago. Most potential problems have been solved already.
Unrevealed Failures of number tested Electrical Protective Relays	Unrevealed failures are randomly found during inspection	The problem is acknowledged and under investigation by SDWT.
Unrevealed Failures of number tested Over Speed Trip system	Achieve target; Number of failure decreased	The issue has been discussed in SDWT and corrective actions have been implemented.
Unrevealed Failures of number tested Gas Detectors	No failure	It has just start to measure and still monitoring.
Leading		
DEM Compliance	Continuous achieve target	The process is complied with ISO9000 procedure.
RCM Compliance	Fail to achieve target	Significantly delayed from implementation plan.
RBI Compliance	Continuous achieve target	Keep on implementation schedule.
SIF Compliance	Fail to achieve target	Slightly delayed from implementation plan.
SDWT Meeting No.	Continuous achieve target till March 2007, then less meeting organized	The process has been working in quarter 1, but failed in quarter 2 because some of team members are interrupted by plant problem urgency.

Regarding to KPI report in table 9, it is clearly visible that Reliability results are improving for every kinds of equipment type (MTBF increased means less failure occurred). Especially Injection Pump which was "bad actor" but it is able to achieve target now. By interviewing with SDWT members, they agree that many recurring problems have been discussed. Then proper solutions have been developed and managed through

structural problem solving & decision making process of DEM. Another major contribution is; SDWT close communication makes equipment problems being detected earlier, then defects are corrected before they become failures.

The Integrity results, in other hand, are still not able to reach target consistently. Unrevealed failures are randomly found during inspection in most systems. Even there is no viable loss yet, it is a signal that risk of catastrophic failures is still there. Both Steering Team and SDWT have acknowledged this issue and set up working plan on it. Part of them have been deployed already and shown in progress of some leading KPI. However, the difficulty of managing integrity is; highly technical expertise is required for understanding the system and precisely predicting the potential problem via task identification methodology. Hence, each production facility has its own characteristics; therefore, most inspection practices are not able to be replicated directly and need to be developed by their own, which would take a lot of time and resources.

From process point of view, leading KPI show how strategic activities are going. Since leading KPI metrics are developed from the strategies that aligned to production objectives. Therefore, with properly usage, leading KPI would enforce strategy deployment and show up operational response to the management. In this case, there are some messages from the KPI as;

- DEM process is still complying with ISO9000. In fact, this metric may be no longer required since ISO9000 would take care of controlling this procedure by itself.
- While RBI implementation is done as scheduled, SIF implementation is slightly delayed but closely monitoring might be sufficient. Unlike RCM implementation, which is quite delayed from plan, management attention is probably required for getting it back on track.
- SDWT is not fully supported and still based on persons. The team resources are limited and very sensitive to interfering activities and often being placed as lower priority job.

However, there are positive feedbacks from ORMS team that leading KPI help them realize problematic area easily and can promptly take action on it. After ORMS implementation finish, these leading KPI might need to be reviewed to focus more on PM task effectiveness in order to project implementation progress.