Maintenance Spares Inventory Management-Performance Measurement using a HOMM

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Abstract— Spare parts inventory management differs from both work-in-process inventory management and finished product inventory management mainly due to its unique aspects in function with maintenance. Furthermore, its inventory management shows more complexities and the performance measurement differs from other productions' either. Studies both in theoretical research and in practice have shown that only some concrete figures had been considered in traditional KPI's for spare parts inventory management, including the total stock value, cost of keeping stock, critical spares stock-outs, operational downtime due to stock-outs, rate of circulation, etc. However, such KPI's may only reflect limited results from spares inventory management. In another word, they cannot help to find out the root causes of which aspects are the management's bottlenecks, or from which aspects it can be improved step-by-step. This paper aims to propose a new way to measure the performance of spares inventory management from the perspective of a House of Maintenance Management (HOMM). First, the HOMM-Spares with PDSA (Plan, Do, Study, Act) thinking will be promoted with the consideration of spares management. Second, management review for spares inventory using the HOMM-Spares will be discussed in details and the performance measurement will be clarified. Obviously, with the new promoted measurement system, we can not only review its performance from a more systematic standing point, but also, the continuously improvement plan with a more scientific analysis will be achieved simultaneously. How to support decision making with this spares performance measurement system is demonstrated as well with a case study.

Keywords— Spare parts, Maintenance management, Performance measurement, PDSA

I. INTRODUCTION

Spare parts inventory management differs from both work-in-process inventory management and finished product inventory management mainly due to its unique aspects in function with maintenance (Huiskonen, 2001). Furthermore, its inventory management shows more complexities and the performance measurement differs from other productions' either. Recent literatures (including Kennedy et al. 2002; Bolyan et al. 2008; Bolyan & Syntetos 2009; Syntetos et al. 2005; Syntetos et al. 2009; Eaves & Kingsman 2004; Ghodrati et al. 2007; Mccarthy et al. 2004; Kobbacy & Liang 1999; Fildes et al. 2006; and references therein) shows that achievements regarding spares inventory optimization mainly focus on four aspects: 1) spares classification optimization; 2) spares forecasting optimization; 3) spares inventory strategies optimization; and 4) spares inventory management

information system development. In addition, to measure the effectivness of such optimizations, one common thing is to focus highly on the spares inventory value improvement with some special Key Performance Indicators (KPI's), including the total stock value, cost of keeping stock, critical spares stock-outs, operational downtime due to stock-outs, rate of circulation, Inventory Record Accuracy (IRA), number of returned parts to stores, etc. Related studies can be easily found; for instance, Daniel Dewald (2011), who owns over 30 years of experience in spares management consultant, has proposed a quantitative measurements matrix chart with 24 KPI's for spares inventory management being discussed. In his stuides, he did not only list useful KPI's with the formula, but also, he ranked the importance of each KPI in four categories: critical needs, high importance, moderate needs, and low importance.

Although the KPI's for spares management are set up more and more strictly, however, complains on site are still very common which is another unneglected fact in pratice. For example, maintenance departments may complain that they do not know which kind and how many spares should be stocked ahead of time. Purchasing departments may complain that they do not know how to control the spares keeping cost, because they are not sure if some budgets can be reduced with low stock-out risk. In addition, to achieve more logically spares management, lots of efforts have been already tried. However, the effectiveness is not obvious. For instance, some spares inventory plans may be only based on the manufactures' suggestion or some limited experience set up. However, because the spares real lifetimes will be influenced by their real running conditions, the spares history data on site is also important for individual plants. Meanwhile, the spares purchasing budget might be reduced in the next accounting period if the higher management level thinks the spares inventory cost is too high; or on the contrary, the lower level's management department will be blamed if the spares stock-out happens. Although usually financial departments do not know why the gaps have been occurred, they may have the rights to control the spares budget. In addition, some spares usage feedbacks from work orders, condition monitoring and inspection tasks may be used, but most feedbacks have turned to be individual's experience which cannot be shared and applied further. Meanwhile, people do not know clearly about any exact figures to describe the spares information regarding history usage, even where to store such information. Furthermore, spares inventory management strategies may be reviewed, but only when needed; training program may be set

up, but only for storekeepers; maintenance engineers may think the spares management is isolated from other maintenance works, which is not good for accumulating spares data on site.

Obviously, reviewed from the KPI's mentioned above, we may find that such KPI's may only reflect limited results from spares inventory management. For instance, with the number of the cost for keeping stock, we may only know how much money are occupied by the spares inventory, however, the number will not let us know how much shoud be redued as well as how to reduce it. Even sometimes, we do not know if the numbers from KPI's are too high or too low. We just want them to looks better (reduced or enhanced). In another word, the number of KPI's can not help to find out the root causes of which aspects are the management's bottlenecks, or from which aspects it can be improved step-by-step. However, both theorical references and studies in practice have shown that integrated studies on how to improve above KPI's are limited. To deal with above problems, we propose a new method to measure the performance of spares inventory management from the perspective of a House of Maintenance Management (HOMM), instead of paying much more attention only to strict KPI's with concrete numbers. The rest of this paper was organized as follows. In section II, the evoluation from HOMM with PDSA (Plan, Do, Study, Act) thinking to HOMM-Spares is promoted. In section III, management review for spares inventory using the HOMM-Spares is discussed in details and the performance measurement is clarified. Obviously, with the new measurement promoted system, we can not only review its performance from a more systematic standing point, but also, the continuously improvement plan will be achieved with a more scientific analysis simultaneously. Section IV has demonstrated that how to support decision making with this spares performance measurement system with a case study. Finally, in section V, the conclusions, contributions and potential extensions of this paper is put forth.

II. FROM HOMM TO HOMM-SPARES

The House of Maintenance Management (HOMM) was firstly promoted by Lin & Ghodrati (2011), in which the improvement activities for maintenance management can be described from the following aspects: "Roof", "Ceiling", "Walls", "Floor", and "Door & Windows" (see Fig.1.).
Compared with the HOMM discussed above, maintenance pares parts inventory management, which belongs to a more concrete area, should also be incorporated in it as being reviewed. The revolution process can also be shown from below five aspects.

A. Roof of HOMM-Spares

The roof of mentioned HOMM is consisted of long/short-period business goals. All other sub-goals, such as production performance, financial profits, etc., will be focused on the central task of the overall long term business goal. Accordingly, the roof of HOMM-spares (see Fig.2.) naturally consists of long/short-period spares management goals, which should also be focused on the central task of the overall long term business goal.
The most common goal in a long period is to supply the "right item" at "right place" and "right time" with "the lowest price". For a shorter period, it can reduce/enhance some concrete numbers such as the total stock value, cost of keeping stock, critical part stock outs, operational downtime due to stock-outs, rate of circulation, etc.

B. Ceiling HOMM-Spares

At each plant, there should be some either qualified or non-qualified management systems (Lin & Ghodrati, 2011). All management systems will support to achieve the business goal and make maintenance decisions shown on the "walls". Spares management system belongs to the non-qualified category, which can be viewed as the ceiling in the HOMM-Spares.

The contents of such system should cover the spares' whole life, including spare parts' selection, purchasing, installation, operation, maintenance, quality tracking, spares obsolete, and the like. Meanwhile, different working tasks should also be considered in the system documents, including but not limited to: spares information recording, spares maintenance, lubrication, condition monitoring, and spares cost management.

C. Walls of HOMM-Spares

Following the thinking of continuous improvement, which was developed by Dr. W. Edwards Deming (1986), four pieces of load bearing wall have been considered in HOMM, with indicators of "Plan", "Do", "Study", and "Act". In addition, they are viewed as four stages which cannot be neglected in continuous improvement activities. In the HOMM-Spares, similar walls also exist.

1) Plan: Main tasks shown on this wall involve: setting up spares management goals, spares database, spares plan, as well as spares management processes. Plan is a basic stage for continuous improvement activities; and it will decide, as for spares management, what will be done, where they will be done, who will do them, as well as when and how they should be done.

2) Do: In the execution stage for spares management, work orders are still the mainline to be followed. There are four key points: spares preparation for planned/un-planned work orders execution, spares failure analysis, spares feedback, and spares business processes execution. During the Do stage, nearly all spares working plans are executed.

3) Study: Based on the belief that, our knowledge and skills are limited but improving, in the Study stage, key information will be improved. In the HOMM-spares, the KPI system for spares management should be constructed, focusing on different needs. That is to say, the KPI system should be divided into different levels (management level, operational level, etc.) and be focusing on different areas (spares reliability, spares inventory management, spares business process, spares suppliers evaluation, etc.).

Business Goal

Asset Management System

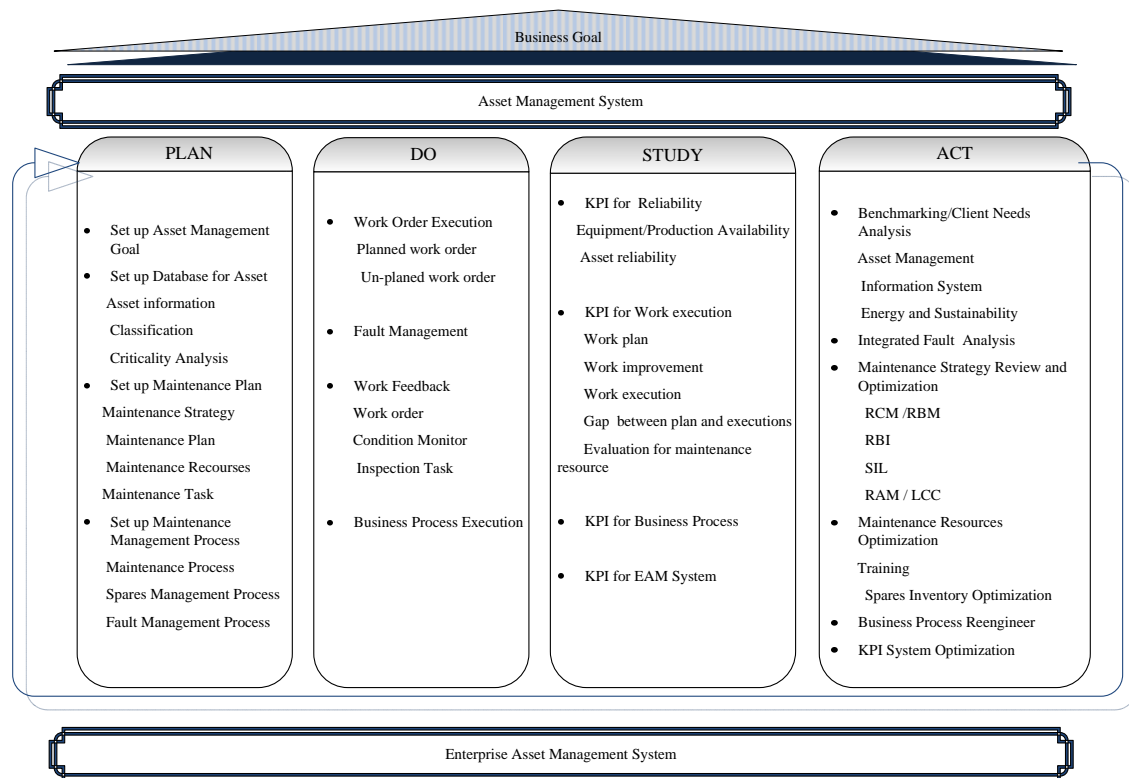| PLAN	DO	STUDY	ACT
• Set up Asset Management Goal • Set up Database for Asset Asset information Classification Criticality Analysis • Set up Maintenance Plan Maintenance Strategy Maintenance Plan Maintenance Recourses Maintenance Task • Set up Maintenance Management Process Maintenance Process Spares Management Process Fault Management Process	• Work Order Execution Planned work order Un-planed work order • Fault Management • Work Feedback Work order Condition Monitor Inspection Task • Business Process Execution	• KPI for Reliability Equipment/Production Availability Asset reliability • KPI for Work execution Work plan Work improvement Work execution Gap between plan and executions Evaluation for maintenance resource • KPI for Business Process • KPI for EAM System	• Benchmarking/Client Needs Analysis Asset Management Information System Energy and Sustainability • Integrated Fault Analysis • Maintenance Strategy Review and Optimization RCM /RBM RBI SIL RAM / LCC • Maintenance Resources Optimization Training Spares Inventory Optimization • Business Process Reengineer • KPI System Optimization

Enterprise Asset Management System

Fig.1. House of Maintenance Management (Lin & Ghodrati, 2011)

4) Act: Following the Study stage, some gaps naturally will be discovered. And then, the most important thing is to improve the performance (or to study). Benchmarking or Client Need Analysis will help us to know more clearly about the differences between one plant and others in the same segment, in a local or international level. Also, the rate of study can be measured here. Other indispensable work involves: spares lifetime analysis, spares inventory Management Strategy Review (MSR) and optimization, spares management training, spares Business Process Reengineering (BPR), as well as spares KPI system's optimization.

After a cycle, all those in the Plan stage should be reviewed and improved further. And then, a new cycle starts.

D. Floor of HOMM-Spares

Because in the HOMM-Spares, data also plays a significant role when decisions are made, so it can be counted as the foundation and thus be viewed as floor. Usually, most data related to spares management should have been recorded in several kinds of Management Information Systems (MIS), such as Enterprise Resource Planning (ERP), CMMS\EAM, special software for spares inventory management, and some other special useful tools for maintenance management. For instance, both SAP and MAXIMO are the most popular MIS where some special modules can be used for maintenance spares inventory management.

E. Door & Windows of HOMM-Spares

As discussed in the former HOMM (Lin & Ghodrati, 2011), if a start point is from the plan wall, we can imagine that a door exists. It is true that, we can start from each point in practice, when we plan to diagnosis the running conditions of the HOMM-Spares. By the same way, there should be windows, by which continuous improvement activities can be implemented through them.

III. PERFORMANCE MEASUREMENT VIA HOMM-SPARES

In practice, compared to the HOMM-Spares described above, few plants have done the cycle well. It is increasingly becoming common to set up some KPI's for its performance measurement, including the total stock value; cost of keeping stock, critical spares stock-outs, operational downtime due to stock-outs, rate of circulation, etc. However, actions for reviewing and improving them are limited.

Therefore, we propose to apply the HOMM-Spares to review the plants' spares management level in the form of a survey, to find out the effective improving ways, and make maintenance decisions as well.

F. Roof of HOMM-Spares

To make sure that all maintenance spares inventory management works will take us closer to the organization's business goal, we should review that:

If the spares management goals are striking for a long period and a short period separately?
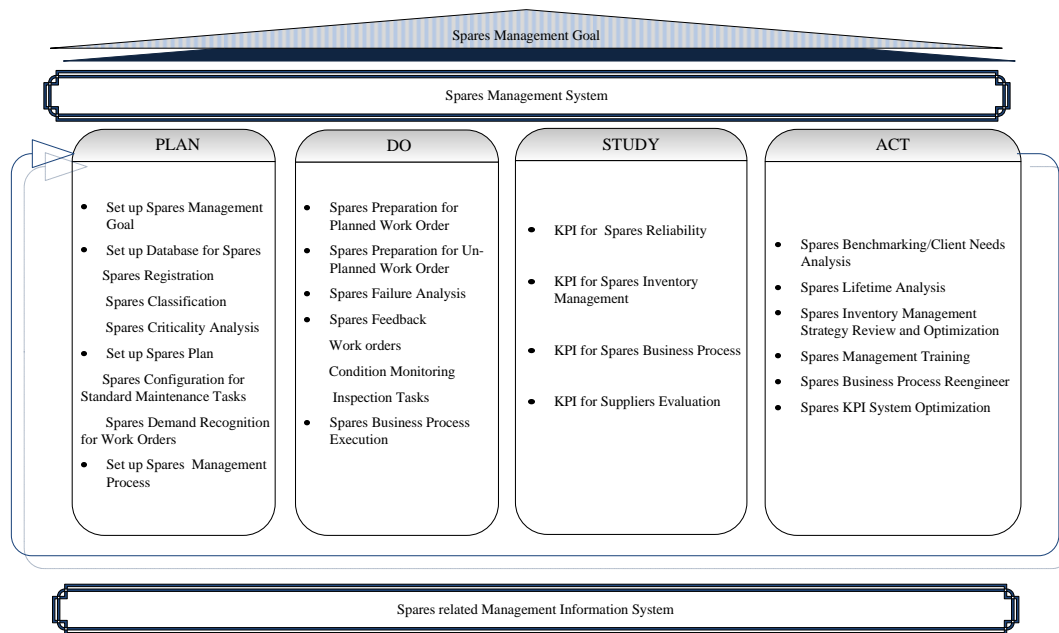
Fig.2. HOMM-Spares

If both the decision makers and operators (or other engineers) on site understand all goals?

This aim to confirm that all spares management plans and activities will support and result to one goal, and everybody knows "where to go". The tasks to construct the "roof" can also be viewed as a part of the "Plan" wall.

G. Ceiling of HOMM-Spares

Spares Management System plays a critical role in the management systems. In practice, only some plants with higher management level may already have set up one. Usually, some simple rules or business process such as spares purchasing, inventory input/output, spares suppliers' evaluation may have already been set up; however, they should be integrated as a whole management system. In other way, it can be an indicator or a milestone of the maturity of any management system. In this light, following issues must be reviewed:

If any spares management system has been set up?

If it has already been set up, whether the system documents have covered the spares' whole life, including spare parts' selection, spares purchasing, spares installation, spares operation, spares maintenance, spares quality tracking, spares obsolete, etc.?

If it has already been set up, whether the system documents have covered the spares' different management tasks, including but not be limited to spares information recording, spares maintenance, spares lubrication, spares condition monitoring, and spares cost management?

Obviously, based on the plants' different speed of study (rate of improvement in the "Study" wall), the system should be improved continuously.

H. Walls of HOMM-Spares

I. Plan

In order to know if the spares management goal is set up clearly, we need to review what have been discussed in section 3.1 with both maintenance managers and maintenance engineers on site.

The quality of the spares database is a critical foundation. To evaluate whether the dataset for spares management is satisfactory, at least three aspects need to be reviewed: the quality of spares registration, the quality of spares classification, and the quality of spares criticality analysis. Details including but not limited to:

If the dataset for spares registration is completed (how much (per cent) is registered), including spares catalogue, etc.?

If the Bill of Materials (BOM's) information in the plant is subject to the spare's level?

What percentage of all spares has accurate & up to date BOM that makes up the catalogue showing all stock items, locations, economic order quantities, (EOQ) Re-Order (RO) Points, and safety inventory levels?

How does the plant classify its spares by criticality (only by ABC analysis, by corresponding equipment' criticality, or any other criticality analysis such as RCM, etc.)?

What proportion of all spares had a criticality analysis performed?

The quality of the spares (usage) plans should also be reviewed:

What percentage of all planned spares has been derived from a standardized/recognized technical process? For example, spares Root Cause Analysis (RCA), Failure Mode & Effects Analysis (FMEA), Reliability Centred Maintenance (RCM), and Risk Based Maintenance (RBM).

How accurate (effective) are spares configuration for standard Maintenance Tasks?

How accurate (effective) are spares demand recognition for work orders?

If the operators are qualified, those who are responsible for spare parts inventory management?

Regarding the spares management process, the following aspects should not be neglected:

Have all spares management processes been set up, such as spares application, spares purchasing, spares obsolete, spares failure analysis, as well as how to set up EOQ / RO/safety inventory level for different kinds of spares, etc.?

Whether all spares management processes do satisfy all the maintenance needs or not?

II. Do

In order to know the spares real implementing situations, we need to review them from four aspects. First, reviewing the spares management with work orders' execution, which is consists of planned and un-planned work orders. Secondly, reviewing the spares failure analysis, in which the historical data should be recorded and analysed. Thirdly, the review should be taken with work feedbacks, including feedbacks from work orders, condition monitoring, and inspection tasks. Such feedbacks are easily to be neglected. Finally, reviewing the business process execution should not be neglected neither. Details include:

If the spares information has been recorded in details in work orders, including spares registration number, equipped equipment, equipped numbers, failure information, etc?

How accurate (effective) are the spares preparation for planned work orders?

How accurate (effective) are the spares preparation for unplanned work orders?

What is the percentage of spares, which are implemented with failure analysis?

If all the work feedbacks have been completed with sufficient spares information (feedbacks for work orders, condition monitoring, and inspection tasks, etc.)?

Whether the spares management processes were followed well?

III. Study

In traditional performance measurement for spares management, only some KPI's are set up to evaluate the working effectiveness. From the HOMM-Spares' view point, it is not enough.

Usually the plants in practice have set up their own simple spares management KPI's, considering various interests but often without sufficient scientific reason and support. However, the most KPI's have been so far set up only from economic viewpoints which cannot be suitable for all the levels of management. Even some completed spares management KPI systems have been set up, but most of them

are short of improvements. Therefore, when the Study stage is reviewed, we need to know the followings:

If the KPI's for spares management have been set up considering different management levels' needs, for instance the decision level, the management level, and the operation level?

If the KPI's for spares management have been set up considering different spares users, including different department, different channels, different equipment, different work orders with different maintenance strategies, and different criticality?

If the KPI's for spares management have been set up considering different time periods?

If the KPI's for spares management have been set up considering spares reliability (lifetime analysis), spares inventory management (inventory control indexes such as the cost of spares, the cost of keeping stock, etc.), spares business process, and spares suppliers' evaluation?

How accurate (effective) are the current KPI's for spares management with exact data?

What is the percentage of the KPI's for spares management have been applied when making related decisions?

IV. Act

The Act stage is another important phase in the walls of the HOMM-Spares. We have to know the situations from the following aspects:

If the differences focusing on spares inventory management between this plant and other plants in the same segment are clearly known?

What are the differences between this plant and other plants in the same segment?

By such questions and answers, we may get not only the benchmarking but also the rate of study for this plant.

It is very common that spares failure data may only be recorded and few of them were analysed for further utilization, especially for spares inventory management strategies optimization. However, they are very important for reducing the operational downtime due to spares stock-outs and the cost of keeping stock, as well as accumulate information for suppliers' performance evaluation. We should review the following aspects for spares lifetime analysis:

If the spares failure analysis data has been utilized for decision making?

How accurate (effective) are the spares lifetime data for maintenance management??

Simultaneously, spares inventory management strategies need to be reviewed:

How often the spares inventory management strategies are reviewed?

How the spares inventory management strategies optimization activities are implemented?

Human factors should not be neglected, because all rules are made for and need to be followed by people. Following aspects should be reviewed:

How many training hours per year are given on an average to a crew regarding spares management?

As for spares management, does there exist any concrete training plans for individuals with different operator levels?

How about the results from WCA (Workgroup Climate Assessment) or similar evaluations among spare related departments?

Spares management optimization should not be neglected. For this, the following reviews are essential:

If all spares have been obtained at the right place, right time, right quantity, and for right equipment?

If the structure of spares inventory is reasonable?

How often the spares catalogue, showing all stock items, locations, economic order quantities, (EOQ) Re-Order (RO) Points, safety inventory level, will be reviewed and updated?

How often the spares purchasing cost and lead time have been reviewed?

As for spares KPI's:

How often the KPI's will be reviewed and updated?

I. Floor of HOMM-Spares

Nowadays, because of enormous data for recording and analysis, computerized management programs are getting very popular. It may be embarrassing that some software has been designed perfectly but engineers who use them may be not satisfied. The root causes can be different. Besides design problems, it may be caused by operator's error, or process imperfectness, etc. Anyway, we should not evaluate the spares management level just by that if the plant has applied some advanced software, but also how such software be used in practice from the following aspects:

If all spares management tasks have been connected with MIS, or if they can be tracked from any MIS?

Whether the data is sufficient enough as making decisions related to spares management?

How about the MIS's application on site related to spares inventory management, which have already been implemented, such as ERP (e.g. SAP, Oracle), EAM/CMMS (e.g. MAXIMO, APIPRO), and any other useful modules or tools?

J. Door & Windows of HOMM-Spares

Obviously, without the continuous improvement activities, the knowledge in the plant will not be used resulting in the failure of PDSA cycle. In other way, the activities during Study and Act stage would become of little use without continuous improvement process. Without the "door" and "windows", we will not know the real running situations of the PDSA cycle. To ensure that the cycle works continuously and effectively, some classical points as below should be reviewed:

How often the spares inventory management strategies are reviewed?

If the PDSA cycle's (for spares management) running details are visible and understandable by all?

IV. CASE STUDY

Customer A develops, manufactures and markets value-added aluminium profiles, profile-based building systems and heat exchanger solutions in aluminium. Currently they have implemented SAP system as well as EAM system for several years, with which the spares inventory are managed and related information are recorded. In addition, they have set up some strict KPI's, including spares cost, spares usage, and spares cost for maximum Top 5 per week/month/ each equipment, and the like. The results are announced per month. The maintenance department adjusts the budget application based on the statistics and the purchasing department evaluates the suppliers after a while. The management processes have been set up, and it seems that they are followed well. However, they are still confused: there are more and more spares stocked in the warehouse; the spares stock-out may occur quite often; maintenance engineers have always complained that they are not sure which kinds of spares should be stocked with low stock-over risk and vice versa, etc. Therefore, they want to know that how to evaluate their spares management level, where the management bottleneck exist, and the most important is how to improve it.

TABLE I
MATRIC FOR HOMM-SPARES

House		I	II	III	IV	Total (weights)
Roof		0	0	2	0	2
Ceiling		0	2	0	0	2
Walls	Plan	8	16	0	0	24
	Do	20	8	0	0	28
	Study	8	8	0	0	16
	Act	20	4	0	0	24
Floor		0	0	2	0	2
Door & Windows		2	0	0	0	2
Total Facet		58	38	4	0	100

* I: fire fighting; II: maintaining; III: promoting; IV: innovating

The purpose of the study is to make a 3-years' development plan for Customer A's maintenance spares management, after reviewing the activities with our HOMM-Spares from all facets. The application was divided into four phases: fire fighting, maintaining, promoting, and innovating. In fire fighting phase, spares management activities are mostly reactive, unstable, and may even be chaotic. Sometimes, people even do not know why they do, what they do, or how long it takes. The costs and the historical details are not recorded. In maintaining phase, spares management activities are not optimal; however, they are now becoming stable. In other words, they are essentially functional activities. In promoting phase, the spares management activities are proactive (sub or solid optimal) and stable. People know what to do, when, why, where and how to do. They actually perform it in full and on-time. In innovating phase, spares management activities are optimal and are reliable, and future

focused. People know what is done, based on what they intended, and they deduce how to improve in the future.

TABLE II
THREE-YEAR DEVELOPMENT PLAN

House	Tasks	2010	2011	2012	2013
Roof	Spares management goal	III	III	IV	IV
Ceiling	Spares management System	II	II	III	III
Plan	Spares registration	II	II	II	III
	Spares classification	II	III	IV	IV
	Spares criticality Analysis	I	II	III	III
	Spares configuration	I	II	III	III
	Spares demand recognition	II	II	II	III
	Spares management process	II	II	III	IV
Do	Spares preparation for planned work order	I	II	III	III
	Spares preparation for unplanned work order	I	II	III	III
	Spares failure analysis	I	II	II	III
	Spares feed back from work orders	II	II	III	IV
	Spares feed back from condition monitoring	I	II	III	III
	Spares feed back from inspection tasks	I	II	III	III
	Spares business process execution	II	II	III	IV
Study	KPI for spares reliability	I	II	III	III
	KPI for spares inventory management	II	II	III	III
	KPI for spares business process	I	II	III	III
	KPI for Suppliers evaluation	II	II	III	III
Act	Spares Benchmarking/ Client Needs Analysis	I	II	III	III
	Spares lifetime analysis	I	II	III	III
	Spares inventory MSR & optimization	II	II	III	III
	Spares management training	I	II	II	III
	Spares BPR	I	II	II	III
	Spares KPI system review	I	II	III	IV
Floor	Spares related MIS review	III	III	IV	IV
D & W	PDSA implementation	I	II	III	III

As evaluated by our HOMM-Spares principles, customer A has its 58% spares management activities belonging to fire-fighting phase, 38% activities belonging to maintaining phase and 4% belong to promoting phase. Or we can say, 92% activities in the organization are in a stabilizing phase (I% + II%), and only 8% are in optimizing phase (III% + IV%). Details can be seen from table I.

Based on the results from reviewing the HOMM-Spares concept for customer A, a future development plan for maintenance management in the next three years can be made as shown in table II. Additionally, there are two PDSA processes seen from rows and columns separately.

V. CONCLUSIONS

It is natural that, after reviewing all mentioned aspects, one will get ideas on how to improve the spares inventory management level step-by-step. It means that, with the help of HOMM-Spares, spares management development plans can be made more scientific and credible. In the HOMM-Spares, PDSA cycle works not only in the whole spares management business, but also in any concrete area. When reviewing the HOMM-Spares, to get more truth, we should collect information from different sources, not only through people (from management and operator levels), but also through MIS data and by real running situations on-site observed by reviewers.

In the case studies, customer A can get the evaluation for its spares management with the HOMM-Spares, and the development plan to improve it. The weights which were set up in Table I should be adjusted further with consideration of different needs. Furthermore, in this paper, the HOMM-Spares has been described roughly, details can be different regarding different industrial segments.

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