Research on Maintenance and Safety-Ensuring Information Platform in Refining and Chemical Enterprises Based on SOA

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Abstract: - Dynamic monitoring and risk-based management of close-loop are both proposed in this paper for equipments in refining and chemical enterprises. Research on the optimal inspection and maintenance mode on the basis of Dynamic Risk-Based Inspection (DRBI) and Dynamic Reliability-Centered Maintenance (DRCM) is carried out. Maintenance and Safety-ensuring Information Platform (MSI) is developed based on SOA, through which the Dynamic Data Platform of the Running Status is established and businesses of heterogeneous system are integrated, thus eradicating Information Island formed among condition monitoring system, fault diagnosis system, risk analysis system and engineering asset management (EAM) system. Meanwhile, combined with ERP, MSI can provide long-term technological support for the stable and economical operations of equipments, and it has been gaining increasing popularity in process industry.

Key-Words: - Safety-Ensuring; Systematic Diagnosis; Information System; Risk-Based Inspection; Reliability-Centered Maintenance; Service-Oriented Architecture

1 Introduction

Maximization, high-speed, automation and intelligence are characterizing the changing trend of modern equipments that are extensively applied in petrochemical, metallurgy, electric and other industries. Such key equipments as high-speed turbines, pumps, ventilators, compressors and centrifuges are closely related to manufacturing processes. However, once failure happens, there might be grave accidents or even breakdown, thus causing huge economic losses [1-3].

In recent years, many kinds of technologies in relation to condition monitoring, early-warning, fault diagnosis and maintenance have been developed, and it has been proved that they can greatly enhance the ability of keeping equipments under stable operation, improving their efficiency and prolonging their life-span. However, the applications of these technologies have not been effectively merged into the safety risk management process of equipments, and in the meantime, they are usually isolated from one another and it is not easy to get them integrated.

In order to resolve those problems, this paper proposes the Maintenance and Safety Ensuring Information Platform (MSI) which employs both Dynamic Risk-Based Inspection (DRBI) and Dynamic Reliability-Centered Maintenance (DRCM). MSI can perform risk-based decision-making according to practical conditions of equipments, and therefore makes previous inspection plans and maintenance measures more purposeful and effective. Furthermore, MSI realizes dynamic monitoring of data by setting up the Dynamic Data Platform of the Running Status, integrates businesses and processes among various systems through Service Bus Layer, and achieves the sharing and integration of knowledge base, case base, data bank and dynamic database by means of Database Service Layer based on SOA. Consequently, condition monitoring system, fault diagnosis system, DRCM system, DRBI system and equipment business management system are combined, which contributes to the establishment of a comprehensive management mechanism, thus effectively reducing the risk of equipment operation as well as maintenance cost.

2 Information Platform for EAM in refining and chemical enterprises

In the past few years, the management of enterprises has been faced with increasing pressures and challenges. On one hand, mandatory laws and regulations on environmental protection, safe production and public sanitation are imposed on enterprises, and on the other, they have to improve competitiveness and pursue profits by economizing on human, financial and material resources. However, those two aspects often contradict with each other, especially when it comes to EAM, for laws and regulations mentioned above usually require that enterprises should pay more attention to equipment maintenance, failure decreasing and reduction of pollution emission, while they are under high pressures of achieving best cost-effectiveness. Therefore, to address such conflicts, EAM should be emphasized.

At present, there still exist many problems in the informatization process of EAM in many domestic enterprises.

(1) Management patterns are mostly extensive while decision-makings usually lack scientific ground;

(2) Basic references are incomplete so that consultations are inconvenient;

(3) Integrations of all kinds of professional software and management software are usually difficult, which forms Information Island;

(4) Planned maintenance and spot inspection are combined together, with hard-time maintenance dominating;

(5) Condition monitoring of equipments and decision-making of maintenance are both just at the very initial stage;

(6) The informatization is driven by function rather than process;

(7) The informatization lacks effective measures for controlling and analyzing expenses of maintenance;

(8) Practitioners' qualities usually lag behind technological progresses.

The process of informatization construction of EAM in modern enterprises is somehow like the recreation of the management process. In order to resolve the present problems mentioned above, we should start with the analysis of the whole process. Currently, one of the world's most advanced safety risk management mode for enterprises is Deming Circle, which bears the core idea of PCDA (PLAN, DO, CHECK and ACT) and can enable a spiral ascending of the equipment management level.

In regard to EAM in large-scale refining and chemical enterprises, PCDA is also extremely crucial, with each step consisting of several systems with independent functions. Meanwhile, as safety risk management process requires, there has been developed a comprehensive series of sophisticated techniques in support of the interactions-not only interactions of data, but also the integrations of information and knowledge-among those systems, just as shown in Fig.1.

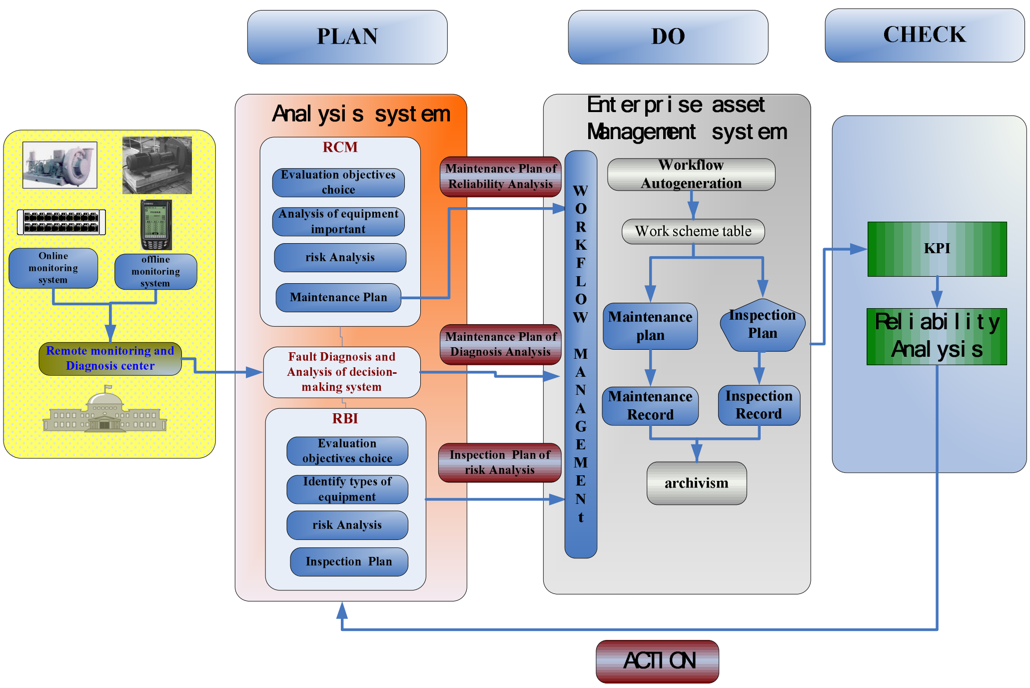

Fig.1 Safety Risk Management Mode for Engineering Asset in Process Industry

The four important steps of PDCA are illustrated as follows:

(1) PLAN

This step mainly deals with issues on how to purposefully finalize inspection plans or maintenance measures for rotary or static equipments. The task of risk identification and risk rating for equipments can be conducted in light of various professional fields, so that equipments can be managed according to their respective risk grades. Furthermore, specific measures to reduce risk are proposed systematically, and the content, methods, criterion of both maintenance and inspection are clearly defined, which can not only effectively tackle the problem of “to maintain or not”, but also eradicate the conflicts between the running cycle and maintenance cycle of equipments, thus achieving the balance between lowering the cost of maintenance and extending the its depth and width.

(2) DO

Usually accomplished by either the plant management module of ERP or the traditional EAM system, The step of DO not only completes the implementation and management of workflow, but also strengthens the management ideology of cost accounting based on assets model and equipment account. With the sequence of establishment, verification, implementation and closure of worksheet as the main line, this step can optimally arrange related human, financial and material resources.

(3) CHECK and ACTION

Rome is not built in one day, so it is with any safety risk management system, which requires a sustained close-loop optimization and improvement. In the step of CHECK, various factors in manufacturing and operation process are analyzed through key performance indicators (KPI) system, which aims at safety measures. Besides, visualized analysis tools applied in safety supervision module are developed due to inspirations from the Management Principle, and they can dynamically optimize the systems in the step of PLAN through feedback from the step of ACTION.

3 Architecture of MSI

Given the characteristics of safety risk management in process industry, in order to satisfy the needs of PDCA, MSI integrates various online monitoring and spot inspection systems, establishes a dynamic data platform on the basis of SOA, brings in the concept of safety risk management, and combines varieties of professional software and management software, thus achieving information sharing and interconnection with EAM. Therefore, such functions as basic equipment management, operation management, inspection management and maintenance management can be realized, thus improving equipment management capability.

MSI mainly consists of three subsystems as shown in Fig.2.

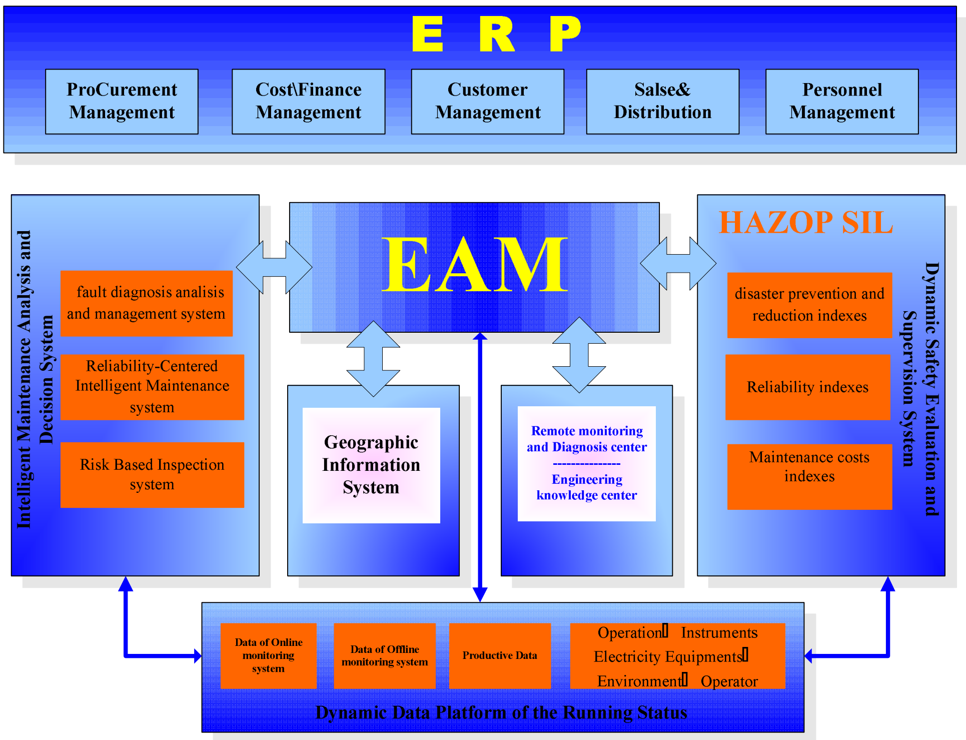

Fig.2 Architecture of MSI

(1) Dynamic Data Platform of the Running Status (bottom);

(2) Intelligent Maintenance Analysis and Decision System (middle left);

(3) Dynamic Safety Evaluation and Supervision System (middle right).

3.1 Dynamic Data Platform of the Running Status

With the development of condition monitoring technologies, there have been developed all kinds of condition monitoring systems and inspection systems in many domestic refining and chemical enterprises. "Real-time monitoring, diagnosis and analysis system" is used in centrifugal compressors and reciprocating compressors, "spot inspection and management system" is applied in industrial pumps, and "corrosion thickness measurement system" is utilized in pipelines or pressure vessels. Through data acquisition, signal processing and alarm management module, all of those systems can provide various analytical interfaces consisting of charts and reports for the practitioners who are in charge of equipment monitoring. Besides, these systems can provide both online and offline data characterizing the running status of equipments for diagnostic analysis layer, risk analysis layer and transaction management layer in the upper level [4-5].

The establishment of Dynamic Data Platform of the Running Status will successfully change the current situation that condition monitoring system, inspection system, fault diagnosis system and RCM system are isolated from one another, which have caused difficulty in access to dynamic data. By adopting the cross-database access mode, data models which comprise the data acquired from spot inspection, online monitoring and manufacturing process can be erected, and therefore an open data interface can be provided for analytical software and management software in the upper layer. In addition, the scalability of access to chemical instrument data, electrical equipment data, and corrosion thickness measurement data are also considered.

3.2 Intelligent Maintenance Analysis and Decision System

As is known to all, rotary and static equipments are the two major types that are concerned in safety risk management in process industry, and various safety risk management methodologies have been proposed for them respectively. Intelligent Maintenance Analysis and Decision System in this chapter offers to resolve the problem on how to work out inspection plans and maintenance measures more scientifically through "expert system of analysis and diagnosis", "maintenance, inspection and management system for electromechanical equipments" and "safety inspection and management system for pipeline accessories in special equipments".

3.2.1 DRCM

As to the drawing up of maintenance plans for rotary equipments, one of the currently widely-used theories around the world is RCM, a universal systematic engineering method for ascertaining proactive maintenance requirements and optimizing maintenance measures for equipments. RCM is deemed as an effective tool for the management to achieve high level of maintenance, which includes determining key equipments and working out maintenance strategies on the basis of reliability-centered data analysis. Meanwhile, it can perform classification of maintenance tasks so that it is a favorable technology to formulate predictive maintenance tasks for equipments [6-7]. RCM introduces Pareto Principal in Management Principle into the management of equipments, and according to Pareto Principal, high-risk equipments that should be attached more importance to account for about 10% to 20% of the total. As a result, RCM can help to concentrate the limited maintenance resource more wisely, thus ensuring the fulfilling of the full potential of the equipments and making the process of maintenance more efficient and standardized. Faults in factories often result from insufficient maintenance or inability to predict faults when equipments are under operation, while effective predictive maintenance can help enterprises realize more than 80% proactive maintenance and less than 20% planed maintenance [8].

Traditional RCM mainly takes account of the probability and aftermath of the fault, and it may be conducted once every 2 or 3 years. However, during these periods some factors for analysis may have already been changed so that RCM may be inaccurate and blunt. To avoid this, we must grasp equipment condition and its changing trend through condition monitoring and fault diagnosis, so that we can integrate condition-based monitoring (CBM) with traditional RCM, which forms DRCM. RCM tool have been merged with CMMS (Computerized Maintenance Management System), and its latest developing trend is integrating asset management and maintenance system due to support from condition maintenance system and online monitoring system [9-13]. The MSI acquires various parameters that can indicate the running status of the equipment through all kinds of condition monitoring and inspection systems, and it analyzes fault patterns and their causes via RCM system, fault diagnosis system and decision-making system. As a result, the transition from raw data to overall capability evaluation of the equipment can be realized. When incipient fault symptoms or faults actually emerge, they can be spotted in time, recognized accurately or even predicted in advance, and the characteristics, causes, and places where they happened can be pinpointed precisely. Meanwhile, maintenance suggestion reports will be generated and submitted to the planning department, maintenance feedbacks will be acquired to form all-life-cycle management of the faults, and maintenance records will be stored for further RCM analysis.

As equipment fault diagnosis engineering develops in recent years, diagnosis theories are also improving all the time. Previously they mainly aimed at making partial diagnosis on damaged parts by obtaining fault symptoms. Nowadays, they are committed to making systematic diagnosis by investigating interactions among different systems, inputs, outputs and operation environments. Radical-treatment maintenance (RM) is a new maintenance method proposed on the basis of new diagnosis theories of equipment fault diagnosis engineering, and its core ideology is to find out or predict the source of fault through systematic diagnosis, and then take timely measures to eliminate such source or eradicate the condition that engenders it. Fundamental reasons of faults arise from many aspects such as human factor, hardware factor, software factor and operational factor. By adopting radical-treatment technology, the fundamental reason of the fault must be found out and prevented from happening again. By combining RCM, CBM and RM altogether, MSI can ascertain the fault (including its pattern, phenomenon and probability), the cause and the aftermath, which better directs the drawing up of maintenance plans.

Illustration of Intelligent Maintenance Analysis and Decision System is shown in Fig.3.

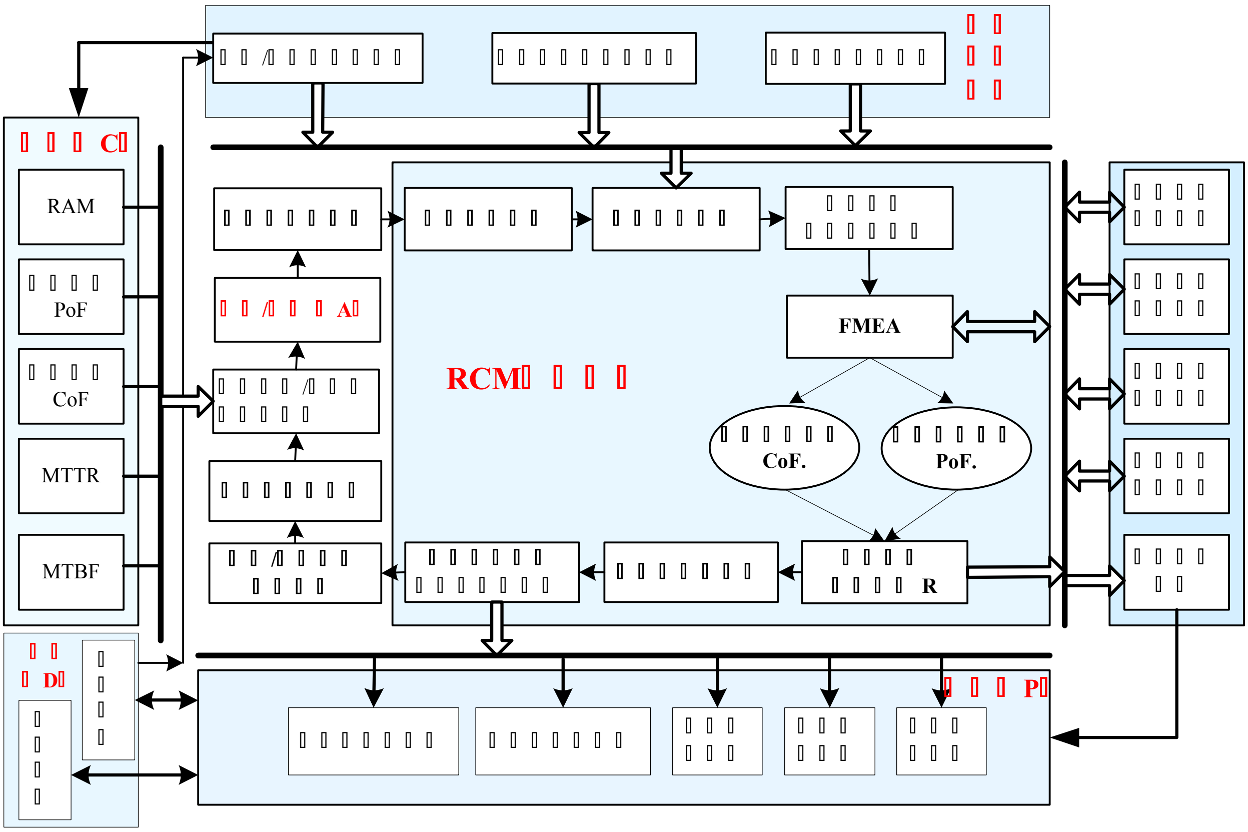

Fig.3 Intelligent Maintenance Analysis and Decision System

(1) Archive management module

The content of this module is the input of Intelligent Maintenance Analysis and Decision System. This module is the most essential part of enterprise equipment management, which checks and maintains history database, resource database, reliable standard database that are needed by RCM evaluation and analysis.

(2) RCM evaluation module

In this module, the management can conduct FMEA analysis according to factory regulations, risk rules, risk matrix criteria and fault probability analysis, and amend risk distribution based on the FMEA results. In respect to the high risk fault, Radical-treatment analysis is proposed in order to find out the fundamental reason and make finalize elimination measures and optimized inspection tasks.

(3) Plan module

This module contains predictive and preventive maintenance tasks, which are the output of Intelligent Maintenance Analysis and Decision System. Also, there are plans to reduce risks, promote reliability, availability and safety of equipments, which is the starting point for RCM evaluation.

(4) Do module

It carries out equipments operation management and fault management, which are used for checking and maintaining and optimizing RCM tasks. Operational data, fault data and maintenance data are stored in archive management module, which serve as history data.

(5) Check module

KPI index is the key by which evaluation, inspection and maintenance is performed. It quantified operational efficiency of equipments through RAM, PoF (probability of fault), CoF (consequence of fault), MTBF (mean time between failures), MTTR (mean time to repair) and so on. The analysis results are stored in the history database.

(6) Adjusting module

The management adjusts factory regulations and goals by evaluating the effectiveness of the tasks. Reliability-centered maintenance strategies complete the spiral ascending of equipment risk management by PCDA loops, as shown in Fig.4.

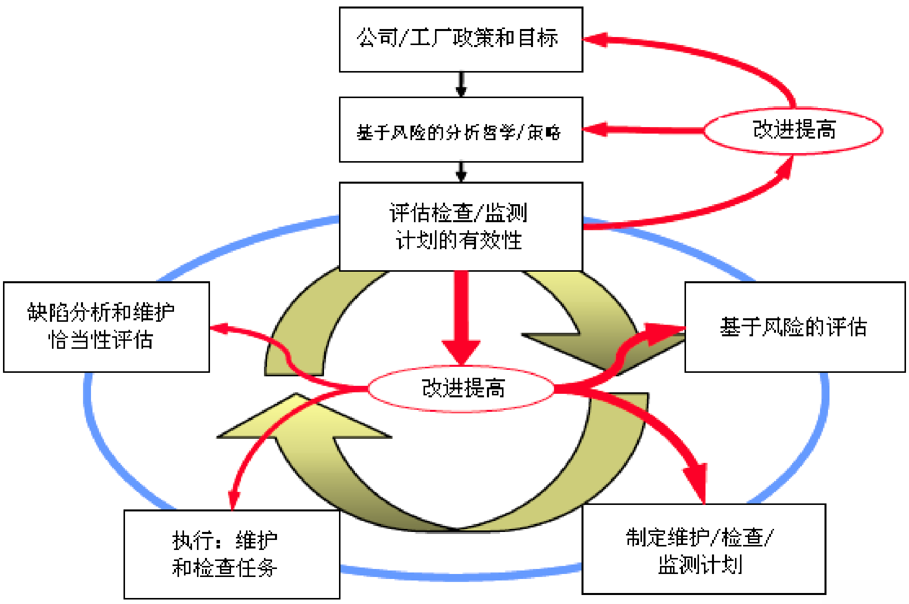

Fig.4 Ascending Process of Intelligent Maintenance Analysis and Decision System

3.2.2 DRBI

As for the formulation of inspection plans of static equipments or pipelines, DRBI is created in MSI. Generally speaking, RBI can optimize and manage the inspection programs based on risk rating and it can reduce risk at current inspection level. Furthermore, according to different risk grades of the equipments, RBI will offer a specific inspection program in terms of economy, health, safety and environment. Under the acceptable risk level, RBI could spot equipments that do not need inspection or risk reduction, making inspection and management more efficient and centralized. In most cases, apart from reducing risk, RBI program could analyze the probability and aftermath of potential risk in the system, pinpoint vulnerable links, thus enhancing cost-effectiveness. However, tradition RBI does not consider the changing trend of various equipment operational parameters as time goes by. In this paper, the concept "dynamic" is introduced, with all kinds of monitoring systems and inspection systems attached to MSI. Corrosion database is established to monitor and predict the changing trend of equipment operational parameters, and condition-based inspection (CBI) is combined with time-based inspection (TBI) so that DRBI is formulated and previous inspection plans can be optimized, as shown in Fig.5.

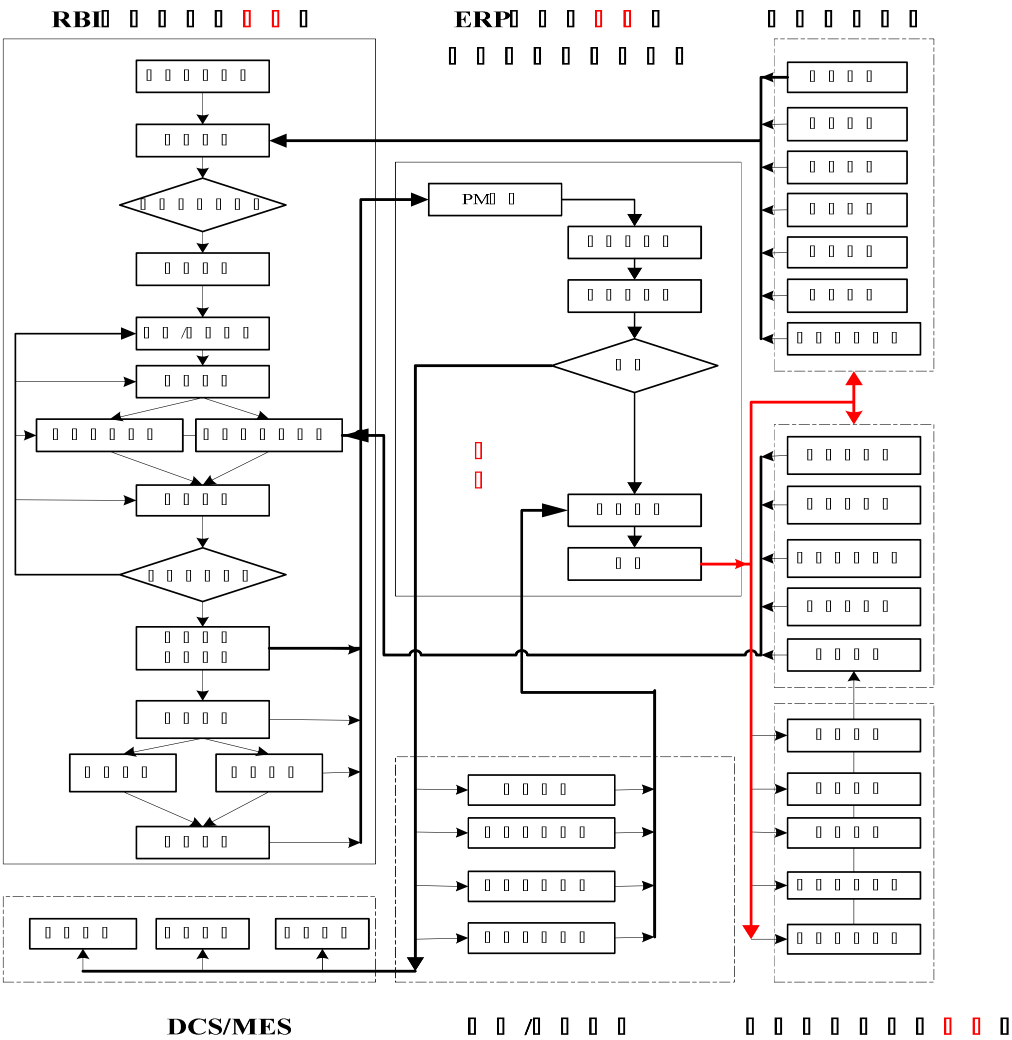

Fig.5 Dynamic RBI Technical Framework

3.3 Dynamic Safety Evaluation and Supervision System

Safety depends on both risk and the ability to reduce it. In view of this, two kinds of safety index are proposed. One is Disaster Prevention Index (DPI) that is set up according to probability of the risk, which covers areas of equipment operation, management and control, and the other is Disaster Reduction Index (DRI) that is established according to risk grades, which covers all links in enterprise emergency rescue system.

DPI mainly refers to the following aspects:

(1) Equipments operations: overload production status; running duration;

(2) Rotary equipments: numbers and ratio of the online-monitored equipments; application rate and intact rate of equipments in use; inspection status;

(3) Pressure equipments: corrosion status of equipments; numbers of overpressure vessels; numbers of overload equipments; application rate and verification rate of pressure relievers;

(4) Instruments: numbers of safety interlock; intact rate and application rate;

(5) Electrical equipments: application rate of “grounding for lightening”; insulation protection; anti-explosion apparatus;

(6) Environment: alarm for combustible gas; alarm for dust concentration;

(7) Practitioners: professional level, experience and training status;

DRI mainly refers to all links in enterprise emergency rescue system, such as emergent isolation, emergent pressure relieving, spray system, fire fighting apparatus, anti-explosion capability, explosion suppression capability, labor security, medical capability and so on.

Dynamic Safety Evaluation and Supervision System can be erected based on both DPI and DRI, based on which enterprises could set up a reasonable examination mechanism to check their own safety risk index, spot vulnerable links in time, take maintenance measures purposefully to promote the overall safety level.

4 Establishment of System Integration Model Based on SOA

4.1 Service-Oriented Architecture

Service-Oriented Architecture (SOA) is the software system architecture which combines individual entity that complete specific task altogether, so that the demand for business integration can be met. In a SOA-based system, all functions of application programs are accomplished by combining loose-coupled components (services) which have unified interface. These interfaces are defined in a neutral way and are independent of any hardware platform, operation system or programming language, which makes services of each system able to interact in a generic way. In all, the appearance of SOA has brought about huge impact on software architecture designing in the enterprise level [14-15].

4.2 SOA-based Data Model and Enterprise Service Bus Model

Amid the process of informatization in refining and chemical enterprises, there are increasing demands for data exchanges and system integrations among data acquisition layer (which contains all kinds of inspection systems and monitoring systems), safety risk analysis layer (which contains DRCM, DRBI, and KPI) and assets management layer (which contains EAM and ERP). In view of this, MSI sets up Data Service Layer and Service Bus Layer by making full use of the enterprise's current investment on its IT infrastructure and the loose-coupling characteristics of SOA, just as Fig.6 shows:

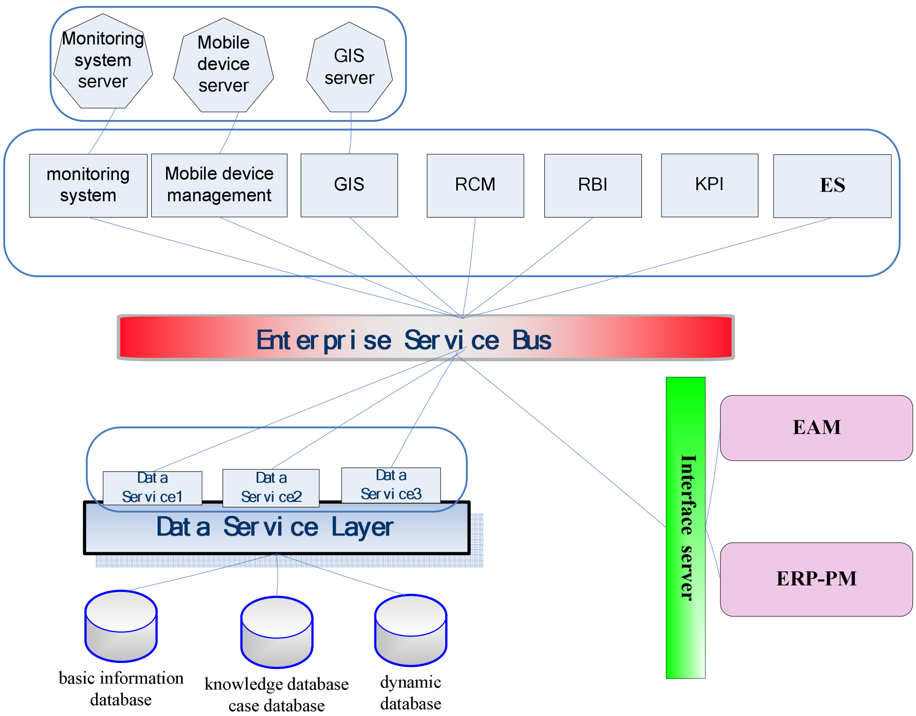

Fig.6 System Integration Model Based on SOA

4.2.1 Data Service Layer

Generally, application systems in upper layers will access business data objects, which are defined by data model and stored in standardized database. In MSI, the data required by varieties of analysis systems and management systems in upper layers are stored in basic database, knowledge base, case base and dynamic database. Data Service Layer firstly sets up physical data model on the basis of the standardized database, and then conducts logical data standardization based on this model, which creates the logical data model defined according to certain business rule. As a result, standard calling methods to access the data model can be provided for upper layer's analysis systems and management systems. Meanwhile, unified control over data access, caching and safety could also be provided in Data Service Layer according to specific needs.

4.2.2 Service Bus Layer

Integrating all kinds of heterogeneous business systems, business service layer can realize systematic functions in the form of shared services and assembles related reusable services according to business requirements. Meanwhile, service management, data transformation, service router, service combination and service registration are all provided in business service layer. Particularly, "service" represents reusable application modules, and it is not only Web Service, but also application resource that can be available by any open method, including such techniques as Tuxedo, CORBA, EJB, HTTP, Message Mechanism, Adapter and DCOM. Whether adopting application systems developed by Java, C and C++ or heterogeneous systems realized by CORBA, Web Service and Message Mechanism, "service" can serve as reusable business assets. In the meantime, safety supervision and controlling of services are realized through service configuration and management in Service Bus Layer.

5 An Engineering Application Case

To validate the functions of MSI proposed in this paper, an engineering application case is shown in the following.

Firstly, a unified visualized interface for spot inspection of pumps and online monitoring of key equipments is developed by GIS, through which the running status and alarm status of equipments are easy to identify, as shown in Fig.7 and Fig.8.

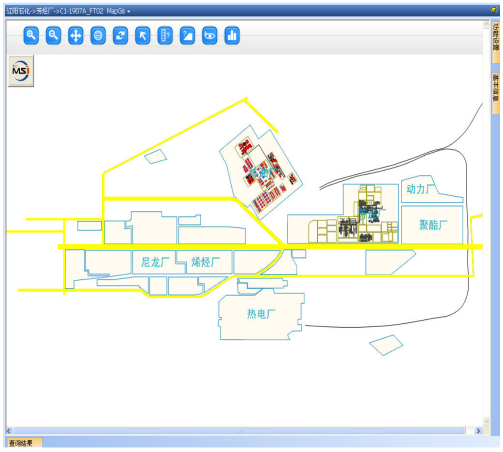

Fig.7 General View of Visualized Interface for spot inspection of pumps and online monitoring a)

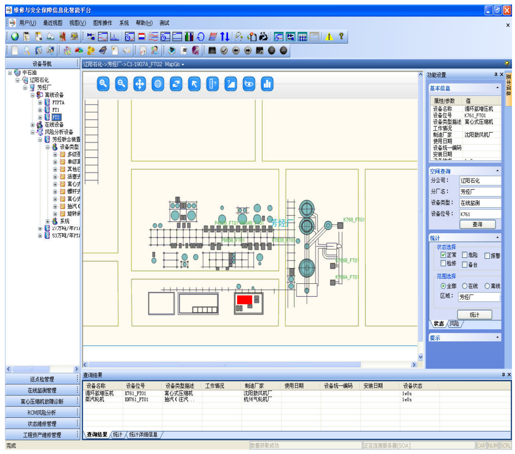

Fig.8 General View of Visualized Interface for spot inspection of pumps and online monitoring b)

Secondly, upgrade the previous distant network of monitoring and diagnosis by SOA, and input the numbers of key equipments, spot inspection date of pumps, online monitoring data of key equipments and MES/DCS production process data (for the purpose of diagnosis) into the dynamic database, As a result, distant inquiry of equipments status can be accomplished, as shown in Fig.9.

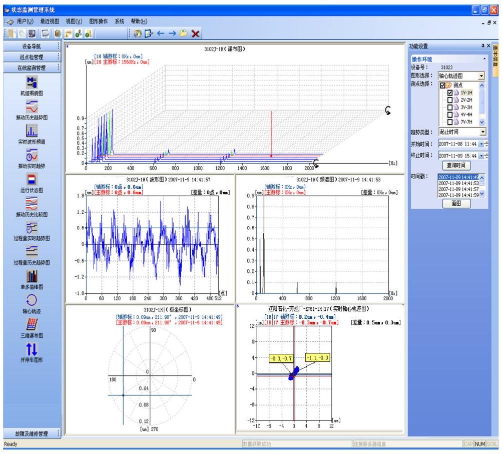

Fig.9 Visualized Interface of Distant Inquiry of Equipments Status

Thirdly, safety risk analysis is conducted on the basis of systems functions and their fault patterns, and proactive maintenance measures towards specific faults are finalized, which can direct the decision-making, monitoring and inspection plans, as shown in Fig.10.

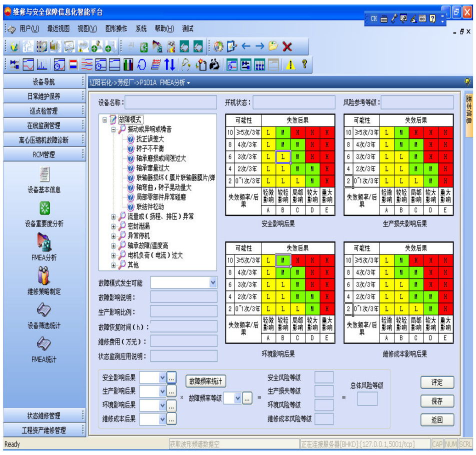

Fig.10 Visualized Interface of Risk Analysis

Finally, standardized interfaces are provided for EAM and ERP through unified data platform, and decision-making basis are provided for process management, as shown in Fig.11 and Fig.12.

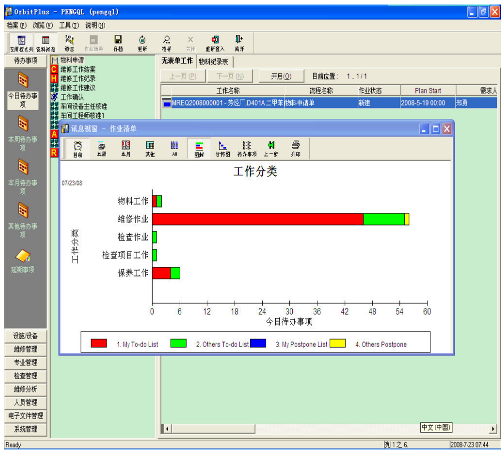

Fig.11. Process Management of the Inspection and Maintenance Plan a)

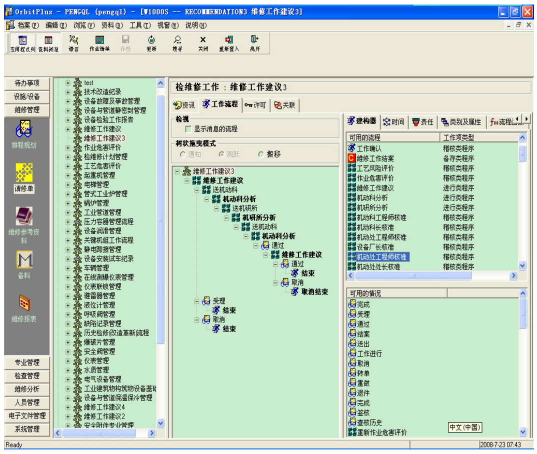

Fig.12. Process Management of the Inspection and Maintenance Plan b)

6 Conclusions

Informatization construction of safety risk management in large-scale refining and chemical enterprise is an effective approach to guarantee the stable operation, improve the cost-effectiveness, and extend the life-span of the equipments. In view of this, the MSI developed in this paper combines various advanced management concepts with current equipment management mode on the basis of systematic diagnosis theories and SOA. It has been put into widely application in Petrol China, which, has brought about considerable benefits. In future, MSI is scheduled to be popularized in more enterprises.

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References:

[1] Gao Jinji, Thought of Future Equipment Engineering, Engineering Sciences, December 2003.

[2] Gao Jinji, Equipment Diagnosis Engineering and Surface Engineering, Engineering Sciences, Issue 2, 2001.

[3] Gao Jinji, Implementation and Monitoring Network and Fault Diagnosis Expert System for the Group of Pumps, Engineering Sciences, September, 2001.

[4] Mari Cruz Garcia, SIMAP: Intelligent System for Predictive Maintenance Application to the health condition monitoring of a wind turbine gearbox, Computers in Industry, Volume 57, Issue 6, August 2006, Pages 552-568.

[5] Jay Lee, Intelligent prognostics tools and e-maintenance, Computers in Industry, Volume 57, Issue 6, August 2006, Pages 476-489.

[6] Hossan A. Gabbar, Hiroyuki Yamashita, Kazuhiko Suzuki. Computer-aided RCM-based plant maintenance management system. Robotics and computer integrated manufacturing, 2003, 19:449-458.

[7] Hall R. Optimizing preventive maintenance using RCM. Maintenance 1992;7(4).

[8] M.C.Eti, S.O.T.Ogaji, S.D. Probert. Integrating reliability, availability, maintainability and supportability with risk analysis for improved operation of the Afam thermal power-station. Applied Energy, 2007, 84:202-221.

[9] Hounsell D. Tomorrow's CMMS. Plant Maintenance Resource Center, USA: Trade Press Publishing Corporation; 1996.

[10] RELEX, Computerized maintenance management systems; RCM tools, RELEX Software.

[11] Parida S, Koto NR, Prasad MM. Development and implementation of reliability centered maintenance using vibration analysis: experiences at Rourkela steel plant 15th WCNDT, Rome: 2000.

[12] Deshpande VS, Modak JP. Application of RCM to a medium scale industry. Reliability Engineering and System Safety 2002; 77(1):31-43.

[13] McCall J. Maintenance policies for stochastically failing equipment: a survey. Mgmt Sci 1964; 11(5).

[14] Zhang Haichuan. SOA-based Equipment Ensuring Field Information System Integration Research, Microcomputer Information, Volume 6-3, Issue 22, 2006.

[15] Davis. The Definitive Guide to SOA - BEA AquaLogic Bus, Publishing House of Electronics Industry, January 2008.