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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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Discussion on Problem-Based Engineering Management System

Abstract The paper puts forward the idea of problem-based engineering management, expounds its connotation and guiding ideology and moreover, substantially demonstrates its practical significance in the engineering management system for the maintenance of Chinese military aircraft engines.

Keywords: problem, engineering management, system

1 Foreword

Engineering has enhanced the human world. Throughout the history of civilization, no activities but engineering ones have had a large impact on the survival and development of mankind in many different areas. The process of understanding and changing the world is the process of discovering and solving problems (Liu, 2014, May 19), which makes engineering the principal activity fulfill this objective. Therefore, to identify and solve problems is always the lifeblood of engineering since the beginning of time. In this sense, engineering objectives are all set to correctly recognize and effectively tackle problems. All engineering objects are of real or practical problems that are likely to occur in compliance with physical laws. Engineering management is involved in the planning, organizing, managing, coordinating and controlling of the various engineering activities (Xiang, 2013a). Nowadays, reform is forced/ brought about by problems. Engineering managers around the world are pondering how to correctly recognize and effectively solve the problems they are confronted with. In 2010, UNESCO published the world's first summary report on engineering – *Engineering: Issues, Challenges and Opportunities for Development.* The report defines engineering as exercising "critical roles … in addressing the large-scale pressing challenges facing out societies worldwide" (UNESCO, WEFO, CAETS, & FIDIC, 2010). Moreover, the Aalborg Center for Problem-Based Learning in Engineering Science and Sustainability under the Auspices of UNESCO has created the Problem/Engineering-Based Learning (PBL) (Khairiyah et al., 2013). The paper has planned to create a Problem-Based Engineering System (PBEMS) to implement Problem-based Engineering Management (PBEM) based on the study on the PBL pattern and the long-term practice in the maintenance field of military aircraft engines. The system has been successfully applied and proved effective in the maintenance of military aircraft engines.

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2 PBEMS connotation and guiding ideology

2.1 Connotation

PBEM is a variety of management activities conducted for a particular project. It is based on the exploration, analysis, and determination of the critical problems in engineering, aims at systematically solving the problems, and takes all employees, complete processes and total factors as a way and approach to focus on and settle problems. The overall design of PBEMS adopts engineering philosophy as its theoretical foundation and combines it with the general theories and methodologies of systematology, engineering science, management science and economics. The system is designated to discover important problems in engineering based on problem exploration, analysis and determination, formulate corresponding solutions and evaluation standards and carry out relevant management activities to effectively solve relevant problems item by item and to exert its integrated role, eventually realizing the engineering objective.

2.2 Guiding ideology

To adapt to the Chinese national condition, PBEM should be designed to solve the problems in engineering results and processes in reality and at present while preventing potential and new problems and fulfill the engineering objective while satisfying the constraint conditions such as project investments, resources and environment. To this end, the following guiding ideology should be upheld (He, Wang, & Wang, 2013):

2.2.1 Stick to problem-oriented engineering philosophy

PBEM should put problems first. More specifically, take the exploration, analysis and determination of problems as the origin and foundation of engineering management; regard problem settlement as the target and find ways and means to solve these problems. When necessary, invent or present a new way and approach, or more generally, meet changes with changes not with reliability stated in the method-oriented philosophy, for the project is likely to end in failure if the problems can not be fully solved with the existing methods.

2.2.2 Always follow the engineering system thinking method of combining specialization with systematic management and the engineering integration method of thinking of objective stimulus and system linkage

PBEM should regard the entire project as a system. Analyze the system to determine the problem sub-items that need be solved and take the settling of problem sub-items as a subsystem. Observe and study each subsystem's functions in the system and the correlation of two subsystems with the method of decomposition and coordination (Wang, 1998). Solve the problems in each subsystem respectively and then optimize and integrate the subsystems based on the overall objective of the system. Therefore, to ensure the pertinence and effectiveness of the problems solution, the subsystems need be determined according to different specialties. To guarantee the optimal efficiency of the overall system, all subsystems need be systematically managed. Through the combination of specialization management and systematic management, problem sub-items are effectively solved, factors are optimized, and subsystems are mutually adjusted under the stimulus of engineering objectives to form a balanced and orderly system linkage structure, eventually optimizing the overall objective.

2.2.3 Adhere to the engineering control idea of system optimum, locality suboptimum, resource conservation, environmental friendliness, and sustainable development (Xiang, 2013b)

Economic globalization, while creating huge material wealth, has also brought substantially serious resource and environmental-related problems and has affected sustainable development. Thus, PBEM must stick to the principles of resource conservation and environmental friendliness, settle the problems with a minimum amount of resources and cost to the environment and fulfill sustainable development. At the same time, PBEM must carry out the idea of system optimum and locality suboptimum, pursue the optimal overall effect in problem settlement (instead of the best effect in solving individual problem sub-items), so as to better satisfy the constraint conditions of resources and the environment.

2.2.4 Abide by the problem-led and innovation-driven engineering contingency theory

The problems faced by PBEM are complicated and dynamic. They should be examined from the view of change and tackled with the methods of innovation. In other words, flexibly use appropriate methods and approaches, along with the innovation of technology and organizational and commercial modes, to settle different problems and those at different stages and states of the development and change.

3 PBEMS practices – PBEMS for the maintenance of Chinese military aircraft engines

3.1 Problems posed

Aircraft engines are great examples of engineering excellence. They are designed, manufactured and repaired at places hailed as the most advanced in the aviation industry. China is still relatively backward in this field because of its short industrialization history, poor background and weak economic foundation. The autonomous research and development capacity in aircraft engine design and manufacturing is not strong, and complete machines have been chiefly imported and imitations have been made to meet the demand for a long time (Liu & Chen, 2010). Aircraft engines had to be completely disassembled for maintenance when used after a period of time, and more than two thirds of their total life is filled largely by repair and to extend its life. The traditional maintenance method is to replace the defective components with new ones, purchase the spare parts from the manufacturers, and consign the repair of each control system (such as fuel oil systems, lubrication systems, electronic systems) to corresponding specialized manufacturers that often need dozens of supporting manufacturers. The above method is characterized by low efficiency and technical content, high costs, long periods, enormous waste, simple and extensive management and requires perfect matching and cooperation services. The recently introduced new-type military aircraft engines are complicated with highly technical content and multiple parts and ancillaries that involve many countries, areas, and factories and no supporting manufacturers/institutes are established in China. Furthermore, the country of origin always imposes a tight blockage on essential maintenance technology and management system and transfers are not allowed. Hence, if the method-oriented philosophy, namely the traditional maintenance pattern is applied, the purchase price of spare parts is much higher and the buyer will be restrained by the international political impact and the foreign parties to autonomously overhaul and guarantee their equipment. If the problem-oriented concept is to be employed, autonomous and efficient integration must be achieved so we can maintain several hundreds of annually-imported aircraft engines that are each made up of tens of thousands of parts and numerous cross-generation models produced with multi-national technological systems. To get rid of the constraint and make the independent maintenance support capability of aircraft engines with Chinese characteristics equal with China's great power status and goals, the system namely PBEMS described above has been established by adhering to the problem-oriented concept, focusing on management, and through independent innovation, an aircraft engine maintenance support base of One Platform and Three Multiple Integrations (troubleshooting the aircraft engines of cross-country technology systems, numerous models and generations, multi-purpose on an overhaul platform) has been constructed. The autonomous right of maintenance and guarantees has been firmly held and the power of discourse and influence in this domain has been greatly promoted.

3.2 System connotation and framework

PBEMS for the maintenance of Chinese military aircraft engines (*Figure 1*) refers to the systematic arrangement of a series of engineering management activities conducted for solving the independent maintenance support problems of Chinese military aircraft engines. The system is aimed at forming the maintenance support capability of One Platform and Three Multiple Integrations in accordance with the PBEM guiding ideology, the AO2PM3 maturity model on construction engineering management of Chinese military aircraft engine maintenance lines, and the ways and means that set up an enterprise standard system of integrative management and differential maintenance, a

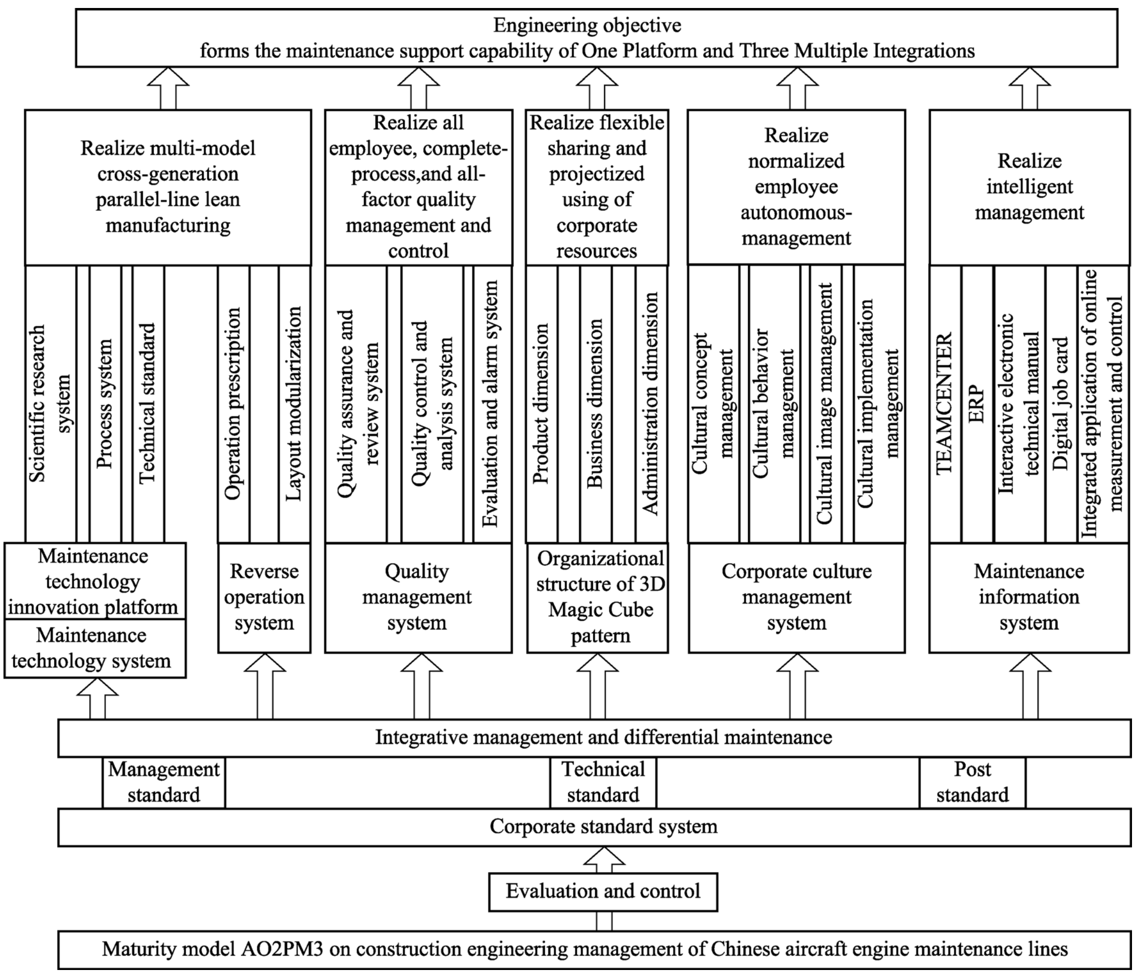

Figure 1. PBEMS for the maintenance of Chinese military aircraft engines.

specialization-based maintenance technology system, a reverse operation system of systematic management, a reliability-focused quality management system, a flexible and efficient organizational structure of 3D Magic Cube pattern, a corporate culture management system focusing on problems and encouraging innovation, and an intelligent maintenance information system.

3.3 System foundation and evaluation standard–maturity model AO2PM3 on construction engineering management of Chinese military aircraft engine maintenance lines (Xiang, Zhong, & Tang, 2013)

In 2004 on the basis of studying and analyzing maintenance patterns, national conditions, and military situations of Europe, U.S.A., and Russia, a project management maturity model for aircraft engine overhaul organizations, namely the maturity model AO2PM3 of construction engineering management of Chinese military aircraft engine maintenance line (as shown in *Figure 2*) was presented by using the concept and method of the Organizational Project Management Maturity Model (OPM3) issued in December 2003 by the American Project Management Institute (PMI). OPM3 is a method through which the evaluating organization manages individual project and project portfolios can realize strategic target capability (Wu, Xi, & Xiao, 2009). If every problem sub-item of some project is managed as a project, the OPM3 concept and method will highly agree with the idea of problem-based engineering management. The maturity model AO2PM3 embraces such modules as project capability (that is platform building, incorporating organizational structure, process approach, resource supply, and corporate culture), line construction processes (also called functional formation, comprising infrastructure, equipment and tooling, process and technology, quality assurance, complete machine test and repair, fitting test and repair, outlay management, and spare parts supportability), and line construction achievements (namely maintainability). Each module is a problem sub-item and subsystem of the whole project and regarded as a soft system. More specifically, linearly program subsystems (Wang, 1998)

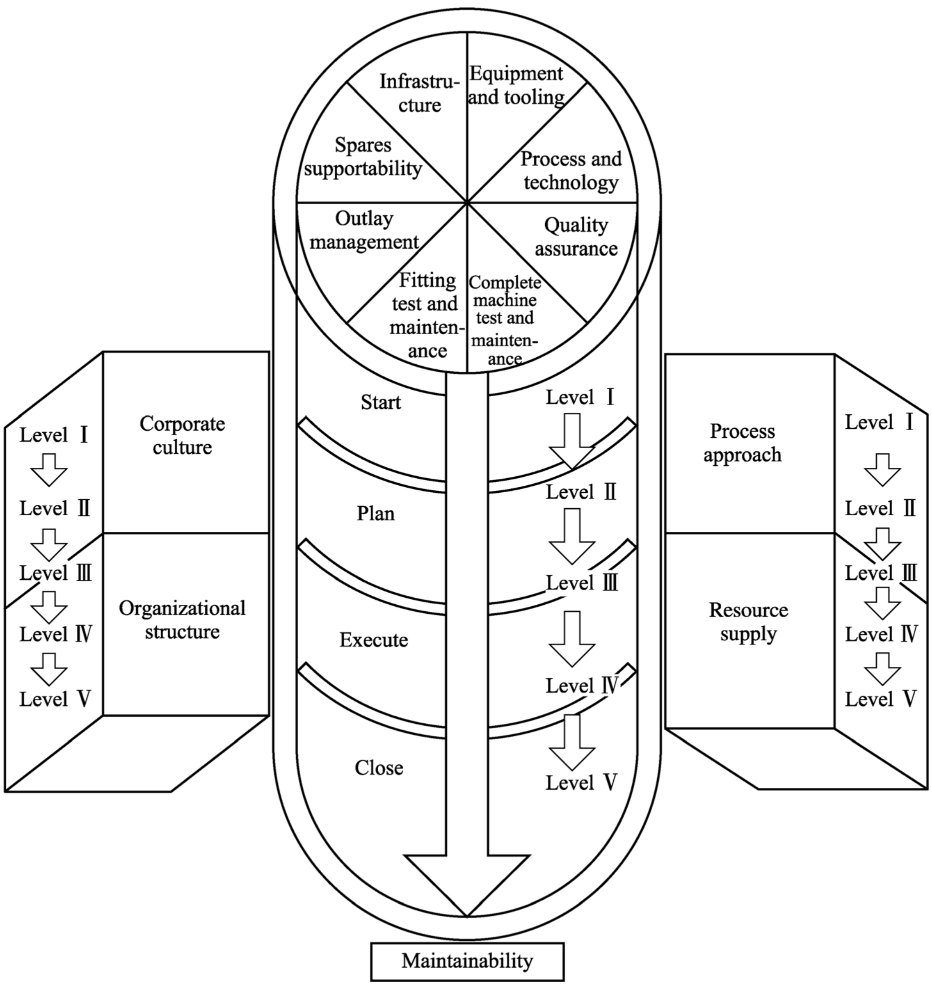

Figure 2. Maturity model AO2PM3.

in combination with the study of the Wuli, Shili, and Renli (WSR) method; set the objective functions respectively under corresponding constraint conditions with the quantitative and qualitative methods and the equation given below:

$$\mathrm{MaxZ} = \sum_{j-1}^{n} c_j x_j \sum_{j-1}^{n} a_{ij} x_j \leqslant (=, \geqslant) b_i, i = 1,2,\ldots,m,$$

wherein different constraint conditions of each subsystem represent different settlement degrees of problem sub-items, the objective functions for the linear programming of each subsystem constitute the variables (constraint conditions) for the linear programming of the large system. The objective functions obtained indicate the maintainability degrees and also the line construction achievements, namely the settlement of problem sub-items and the engineering objectives fulfilled after each subsystem is coordinately operated, optimized, and integrated. The total score is 1,000, and the first degree is 200 points. Hence, the maintenance line maturity can be computed by importing the designed or measured value. The greater the degree is (from I to V), the more mature the maintenance line becomes, the more effectively the problem is solved, and the higher the maintenance levels and capabilities. The model was used to assess the domestic aircraft engine maintenance line built at the early stages by an aircraft engine maintenance company. The maturity was only at level II. Later, on this basis, the project of One Platform and Three Multiple Integrations was constructed under the guidance of the level-V maturity model AO2PM3.

3.4 System formation

3.4.1 Enterprise standard system with integrative management and differential maintenance (Xiang, 2013c)

As the aircraft engines of different types differ greatly in structure, performance, materials and technology; and additionally, the maintenance requirements may vary between countries, manufacturers, products and users, the One Platform and Three Multiple Integrations requires an enterprise standard system that can realize the integrative management of all products and allow differential maintenance for different products. Therefore, different relevant requirements shall be integrated to establish three enterprise standard systems in management, techniques and jobs. Integration of the management standard supports the One Platform management structure, and the customer-made lean-orientation technical standard allows the Three Multiple Integrations differential maintenance for different products so as to ensure acceptable performance and reliable quality. Vertical and fexible job standards make personnel at all levels and of all types satisfy the requirements of diversification and flexibility of the One Platform and Three Multiple Integrations.

3.4.2 Maintenance technique system of specialization

For key technique problems to be solved by forming independent maintenance capabilities, the maintenance technique systems covering scientific research, technology, processes and standards should be developed and constructed, including substitution by material localization, key component remanufacturing, easy-wear and changeable parts self-making and self-repairing, complete machine joint debugging and testing, failure mechanism research and prevention. Multiple specialized repair modules are established based on these systems and each module is a subsystem for solving problems. For example, by developing maintenance technology for key parts and components through independent innovation, the remanufacturing technique system for key parts and components of military aircraft engine will be established that covers different failure modes, types, structures and materials. As a result, the independent repair problems of key components like vanes have been solved, difficulties in purchasing spare parts have been effectively relieved, and maintenance costs has been largely reduced with more efficiency, a shorter cycle and less waste and environmental pollution (Huang & Li, 2012).

3.4.3 Reverse operational system of systematic management (Xiang, 2007)

Through the succesive implementation of three-times BRP (Business Process Reengineering), the reverse operational system was established to focus on troubleshooting, follow the provided “prescription” and according to the work schedule, where product mainstream pulls specialized repair modules. Just like a doctor prescribing medication for patients based on their circumstances, each component of a disassembled engine will be checked for failure and a “prescription” will be provided and followed for further checks, repairs or remanufacturing of different specialized repair modules. As well, the system integration, evaluation and verification will be performed. Integrating the maintenance technique system with reverse operational system, i.e., the combination of specialized and systematic management, has solved the lean production problems of doubling maintenance of multi-type cross-generation aircraft engines.

3.4.4 Quality management system focusing on reliability

The four main requirements for aircraft engines raised by US military standards are performance, applicability, reliability and maintenance (Chen, 2014). As for maintenance requirements, they mainly concern reliability. From the angle of quality management, reliability refers to the ability of a product to perform the required functions within the time limit and under certain circumstances (Qin, 2008). Compared with other indicators of engineering quality, reliability fully gives a view of systematic, timely and conditional restrictions on engineering. The key of maintenance engineering for military aircraft engine is to ensure the reliable operation after maintenance. Since problem-based maintenance engineering management of Chinese military aircraft engines has to go through a very complicated and dynamic process, to effectively solve every problem and realize the engineering objectives of solving problems in a systematic way, it is required that reliability should be controlled throughout the engineering process by all personnel and for all elements so as to guarantee engineering quality. We have established a problem-based quality management system involving quality assurance and auditing, quality control and analysis, reliability assessment and warning (as shown in *Figure 3*) which are used to perform process control of subdivided work and unique digital identification management for quality maintenance of military aircraft engines. This forms a quality management network of all extents and scopes, and realizes the transformation of quality control from post-inspection to comprehensive identification, evaluation, early warning and treatment of specific risks during maintenance, in support of quality management with system guarantees, process controls and risk precautions for quality controls of all elements by every person throughout the process.

3.4.5 Flexible and efficient organizational structure of 3D Magic Cube pattern.

The organizational structure of traditional maintenance is in the form of linear functions or matrices. Its main problems are that resources are dispersed to the functional departments where, due to the segmentation of functional management (business), cannot be effectively put into the product realization process (Child, 2009) for prompt responses to requirements of the One Platform and Three Multiple Integrations in a rapid and effective allocation of resources, especially human resources. Therefore, the unique organizational structure of the 3D Magic Cube pattern in products (as shown in *Figures 4–7*), businesses and functions has been established. Meanwhile, the job relation diagram has been drawn for all personnel from the manufactured, commercial and functional aspects so that they can have a clear understanding of their positions and relationships on these three dimensions (as shown in *Figure 8*). The occupational abilities and post requirements of personnel at all levels and of all types have been explicitly stipulated in vertical and flexible job standards and order-oriented and improvement training. Therefore, the resource utilization mechanism is formed with a product-led, business support and functional guarantee which helps to break down the functional barriers and rapidly integrate resources to establish project teams according to the demand for products or the business, realizing the flexible sharing and engineering-oriented utilization of enterprise resources and providing organizational guarantees for problem-led and innovation-driven engineering.

3.4.6 Corporate culture management mechanism focusing on problems and encouraging innovation (Xiang, 2010)

PBEM is a soft system, mainly depending on the judgment and intuition of people, in which the human factor plays a

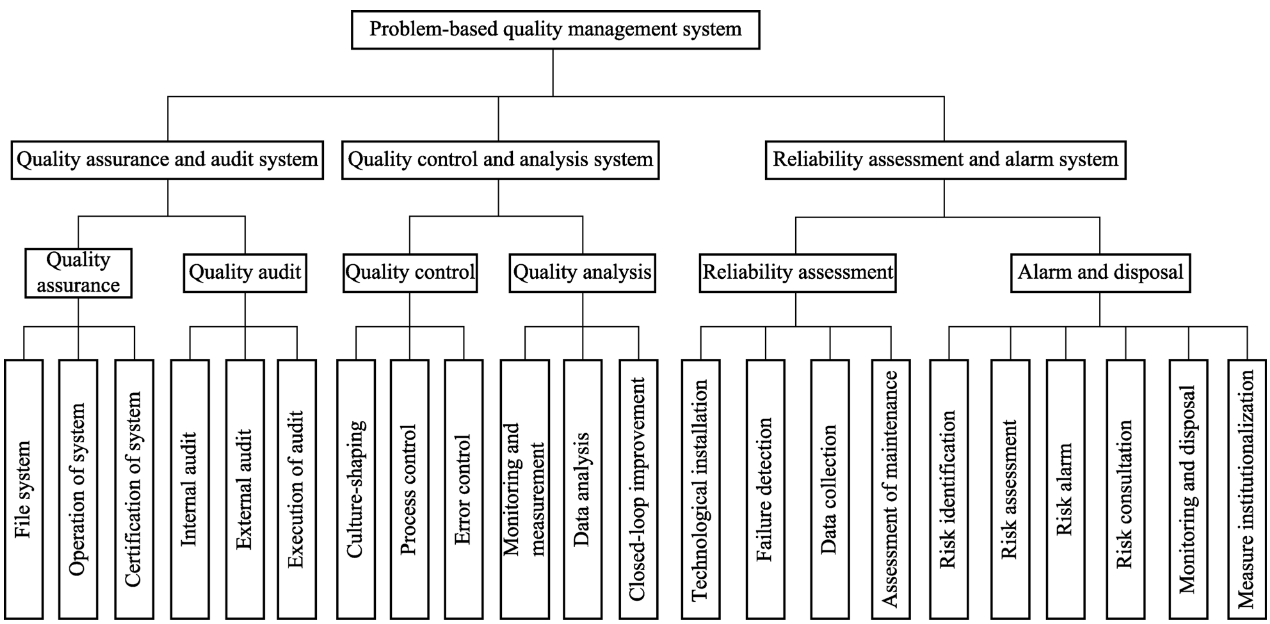

Figure 3. Problem-based quality management system.

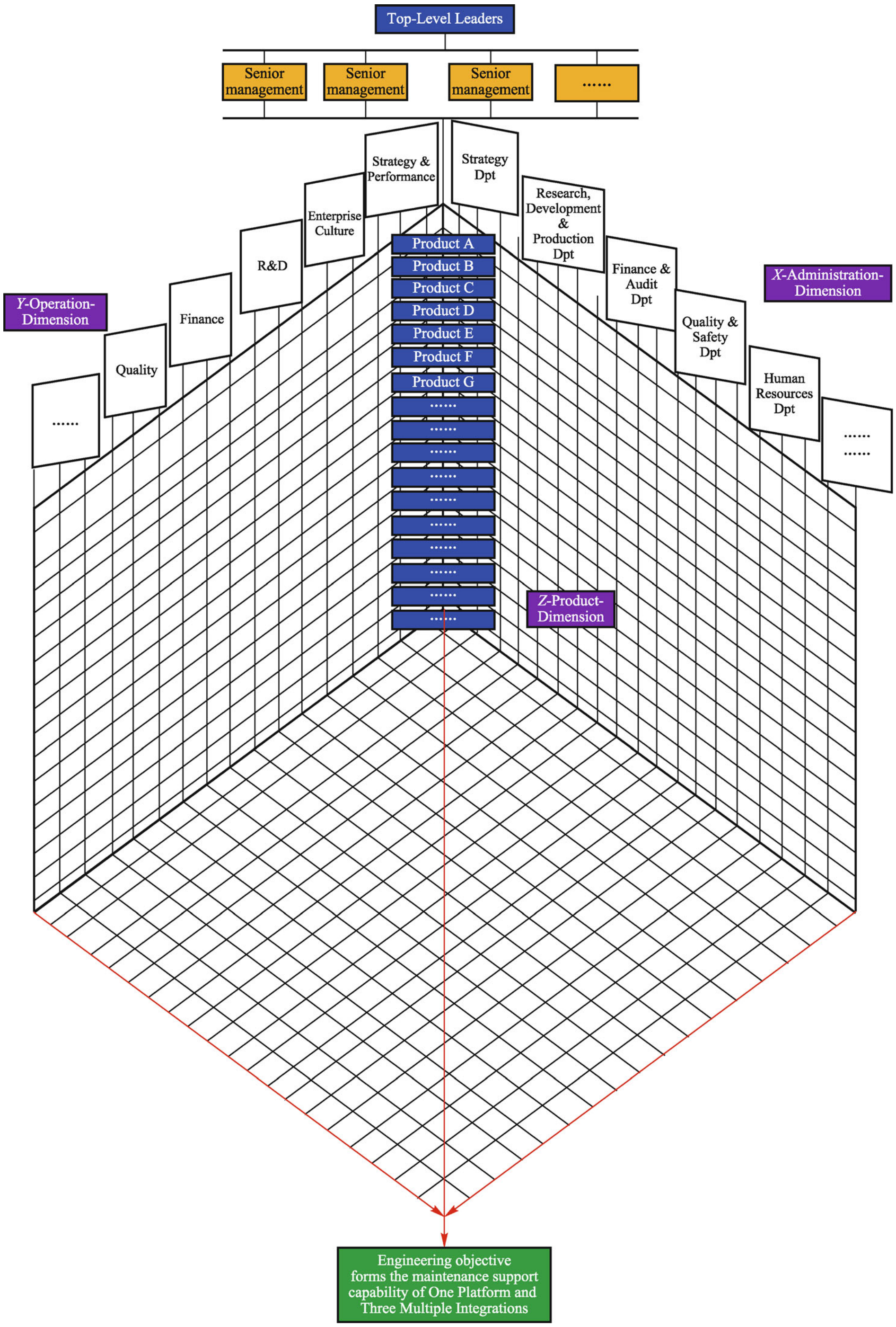

Figure 4. 3D Magic Cube pattern.

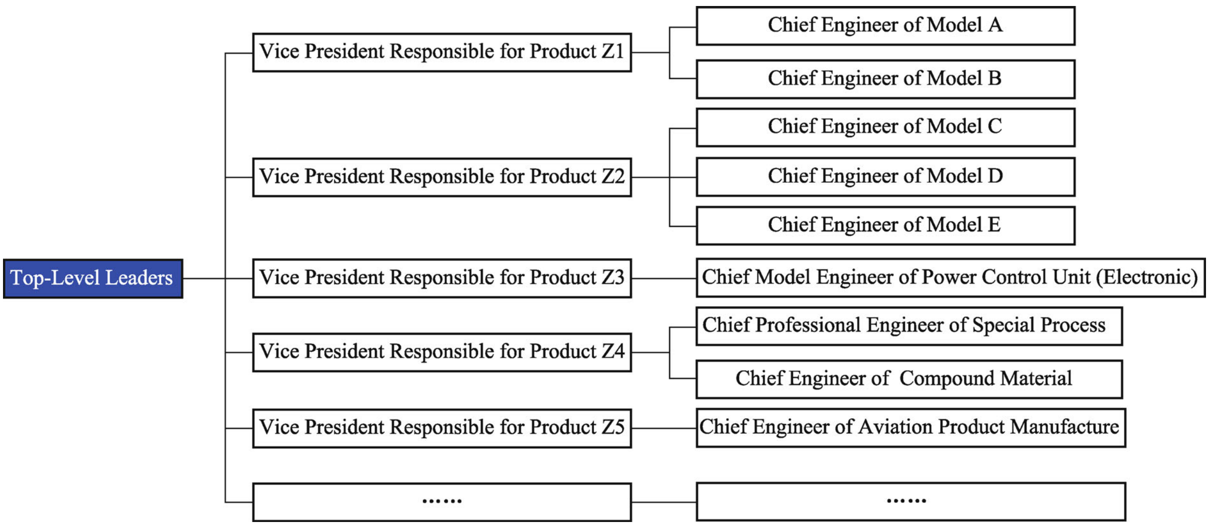

Figure 5. Product-dimension organization structure.

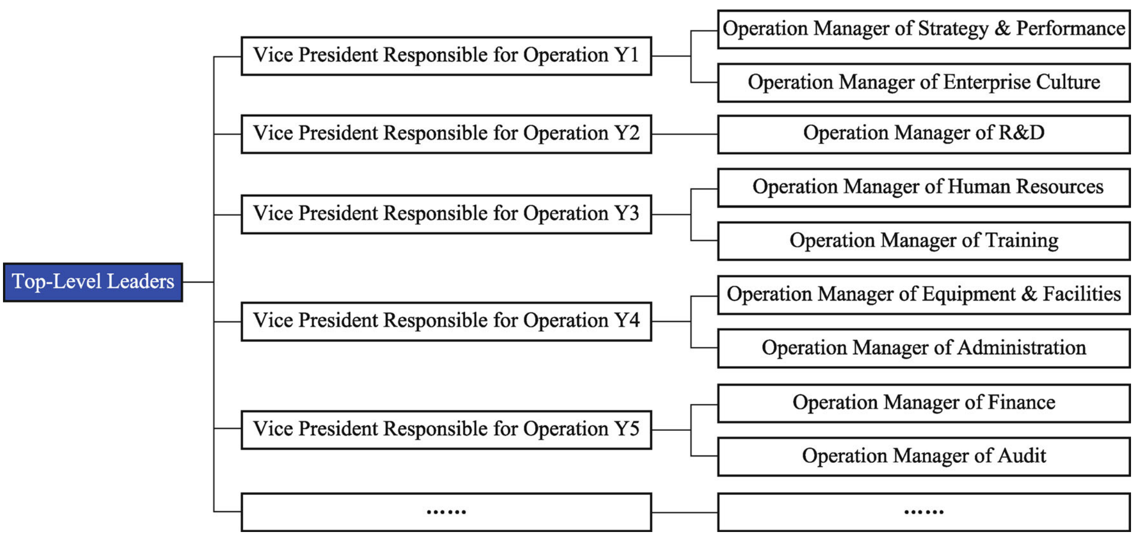

Figure 6. Operation-dimension organization structure.

key role (Wang, 1998). In order to effectively motivate the energetic and innovative spirits of all personnel, prompt all personnel to consciously pay attention to problems and be dedicated to solving those problems, an enterprise culture management system was established, taking sincerity, creativity, rapidity, effectiveness and harmony as its core values. By comparing the different parts of the aircraft to the enterprise's cultural ideas, it is easy for personnel to remember due to the vivid description and has a strong incentive function (as shown in *Figure 9*). For example, aircraft engine parts symbolize the spirit and tenet of enterprises to provide impetus for development, the pulpit cabin part symbolizes core values and innovative spirit of the enterprise. Meanwhile, a problem-based personnel self-management system has been established. At the beginning of each year, the personnel will address problems they want to solve, and the enterprise will organize relevant personnel to review the problems. After approval, all personnel can assemble project teams at their leisure to bid for problems that need to be solved. Enterprises will provide funding and support for teams which win the bids. When the problems have been solved, relevant personnel will evaluate the results and award team members in accordance with their achievements. The award is part of an annual performance bonus for personnel. The more problems the personnel solve, the higher the bonus they will receive. In this way, the problem-based normalization of personnel self-management can be achieved.

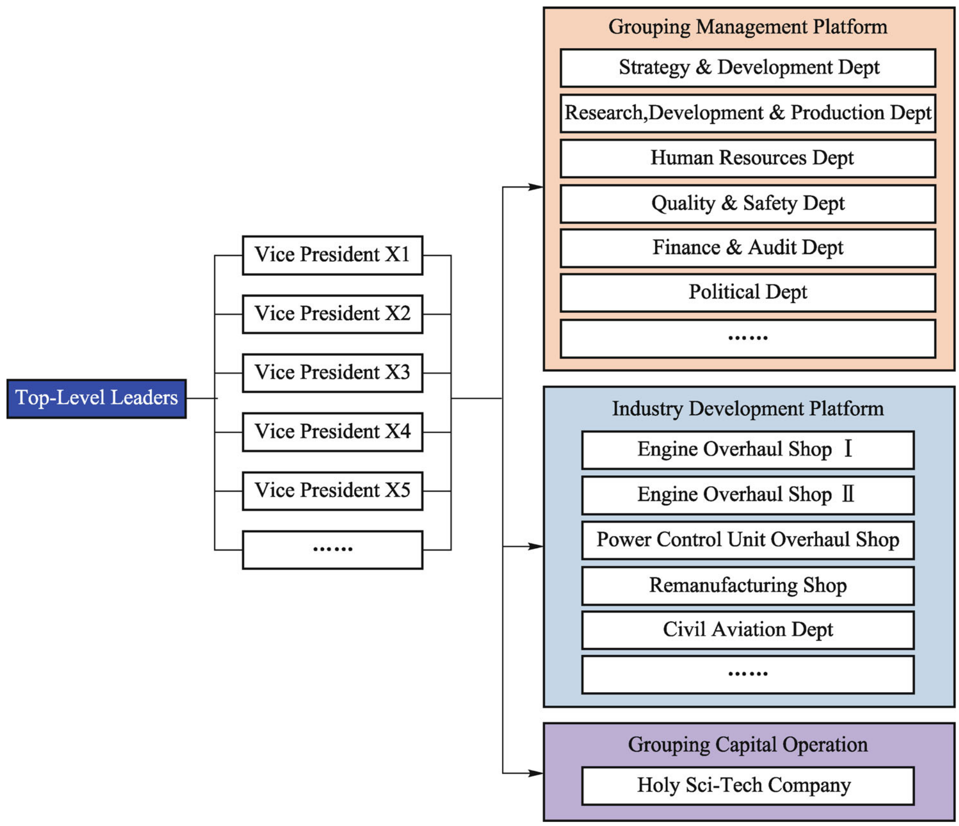

Figure 7. Administration-dimension organization structure.

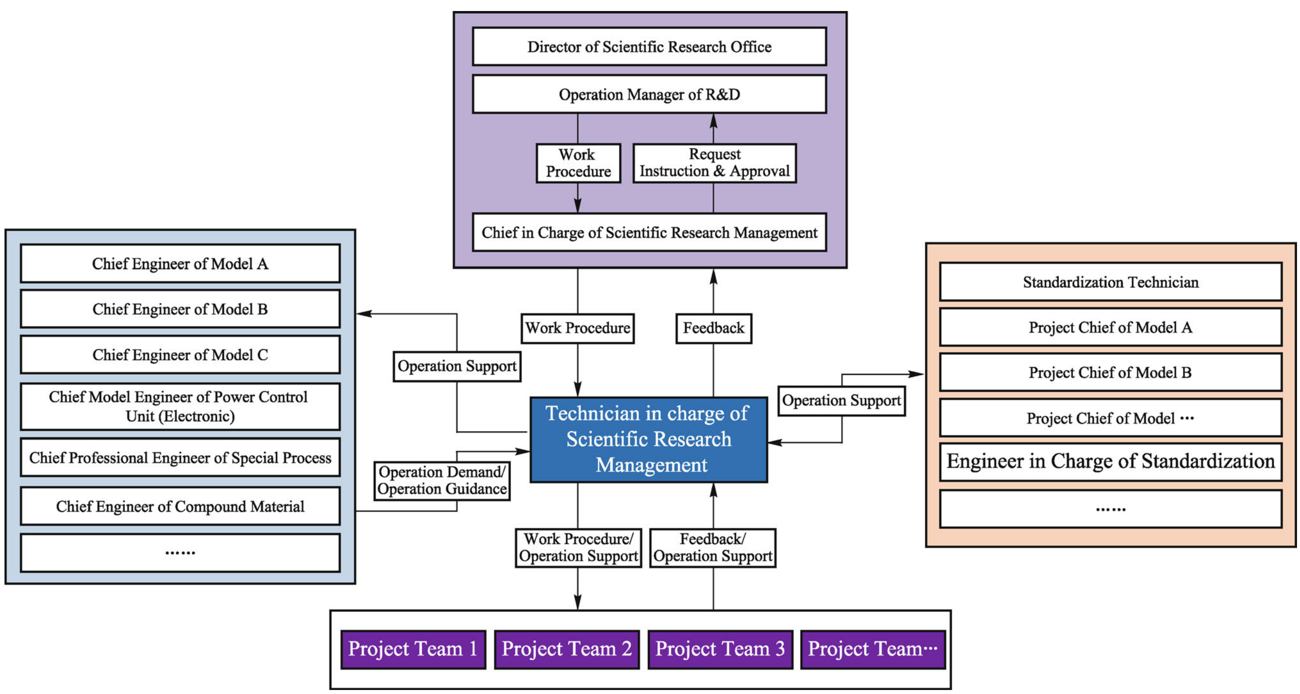

Figure 8. Post relations for R & D management technician.

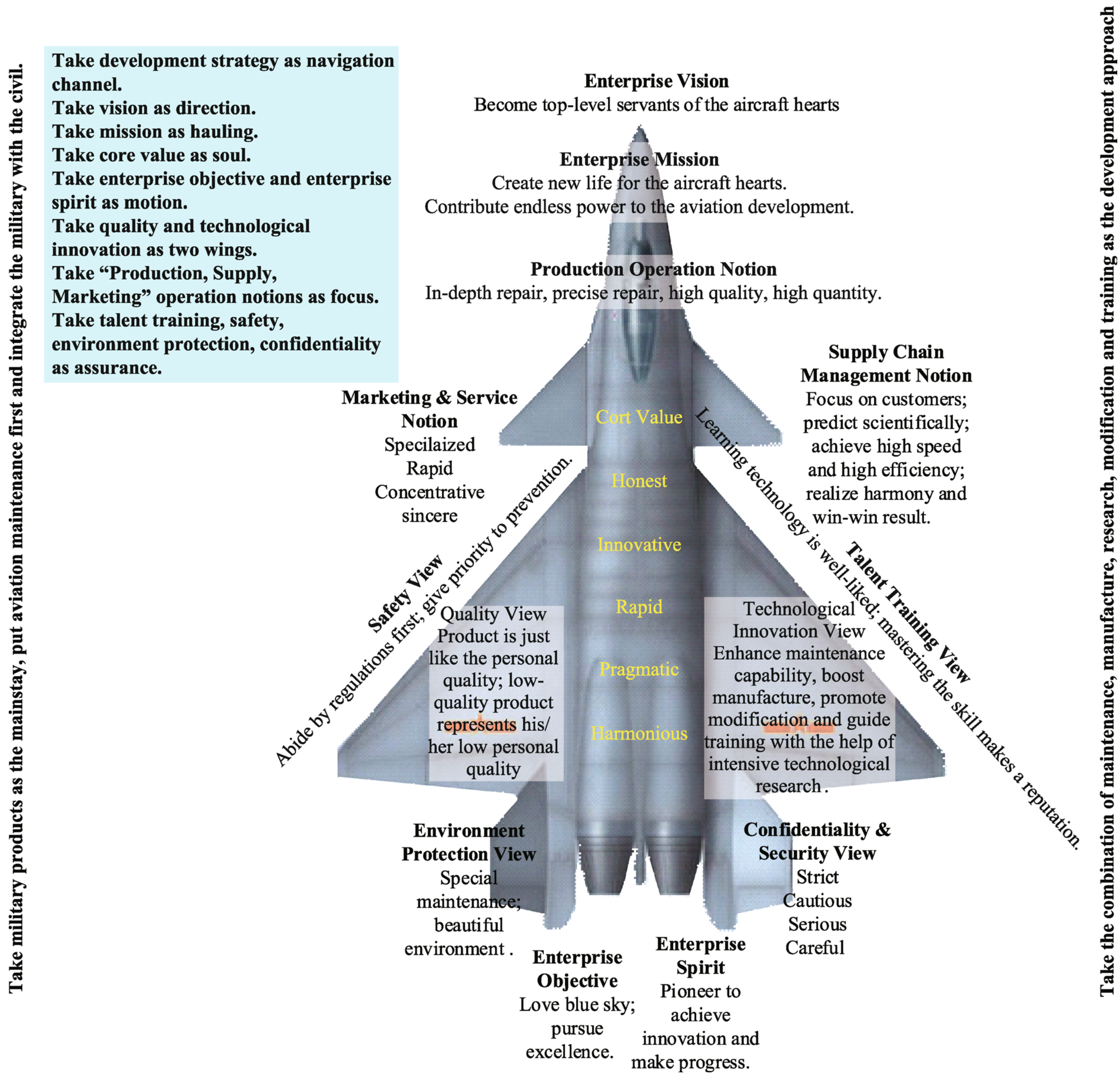

Figure 9. Enterprise culture notion system.

3.4.7 Intelligent maintenance information systems

The unique maintenance operation information system for aircraft engines has been established. This system is composed of ERP, Teamcenter, Interactive Electronic Technical Manual, Digital Work Card, On-line Measurement and Control Integrated Application and other subsystems which provide complementary functions, unified data and an integrated workplace to realize intelligent management and provide support for the highly efficient running of the three-dimensional cube-type organizational structure.

4 Effect of the maintenance engineering management system of Chinese military aircraft engines based on problems

4.1 The maintenance base for military aircraft engines with the largest international concentration ratio, of most types and functions has been established and has proceeded to the top in the ability and level of maintenance and guarantee

Advanced independent overhaul lines for military aircraft engines have been introduced with a construction time and cost reduction of a third, doubling independent maintenance lines for home-made, and multiple-type cross-generational military aircraft engines have been established in the same maintenance base with its grade of maturity improving from Level II to Level V, and maintenance capabilities have exceeded the designed objective over 2.4 times the maximum. The first aircraft engine remanufacturing technology application research and development center has been built in China, becoming the first organization at home that has implemented aircraft engine blade 3D printing and remanufacturing technology, repaired over 40,000 key components of advanced military aircraft engines that are irreparable in their countries of origin, installed key components on over one thousand sets of engines and have flown safely for over 330,000 hours. In recent years, the enterprise has obtained dozens of national-level, provincial-level and ministerial-level awards for scientific and technological progress and management innovation.

4.2 The maintenance quality, cycle and cost have ranked among the top internationally, generating remarkable economic, military and social benefits

A repaired aircraft engine has an apparently lower failure rate than a new engine, which can fly a cumulative 2 million hours during a service life of 20 years without any responsible maintenance accidents. However, an American F-16 fighter is involved in 1.77 A level accidents caused by engines every 100,000 flight hours, and this figure once reached 1.88 (Chen, 2014). The maintenance cycle is on average 2/3 shorter than that required by users, and the maintenance price is 1/4 that of a new product on average. Service lives of poly-type military aircrafts engine are prolonged. The sales revenue, the total pre-tax profits and employees' incomes have separately increased 6 to 7 times under the conditions that the total amount of staff has only increased by 10% and the maintenance prices remain unchanged. This engine has played an important role in several major military and non-military actions, such as joint military exercises, earthquake relief work. It also saves energy and material and reduces emissions obviously. The material applied in maintenance, power consumption, water consumption and CO_2 emissions are only 12%, 31%, 40%, and 11% of the new product respectively.

4.3 Guiding industry development and boosting the overall progress of the high powered equipment industry in China

The AO2PM3 model and problem-based Chinese military aircraft engine maintenance engineering management system can facilitate the transformation of generational modes of fighting capacity and support capacity (Xiang, 2012) which have been popularized and applied to several aeronautical maintenance companies and equipment support companies. They have been teaching cases of senior commanders at the National University of Defense Technology, and relevant works have been used as teaching materials in relevant companies, universities and armies. Solving maintenance problems can accelerate development of new models (Chen, 2014). The development department has adopted suggestions for improvement of tens of imported aircraft engines and three generations of domestic ones proposed by a company that was the first one in China to participate in design of six performances (i.e., reliability, maintainability, indemnificatory, testability, safety, and environmental adaptability) of new type aircraft engines as a maintenance company.

5 Conclusions

It is indicated by practice of our military's characteristic aircraft engine maintenance engineering management that constructing a problem-based engineering management system is one way conforming to the national conditions to solve development problems of current economic society, which will make greater contributions to the development and progress of China's engineering management theories and practice as well as the transformation and upgrading of China's economic society if it is further improved to perfect its system structure and theoretical foundation.

References

Chen, G. (2014). *Structural Design Analysis of Aircraft Engines*. Beijing: Beihang University Press, 563–641

Child, J. (2009). *Organization: Contemporary Principles and Practice (2nd ed)*. Chichester, West Sussex: John Wiley and Sons Ltd., 1–26

He, J., Wang, M., & Wang, Q. (2013). *Status and Development of Chinese Engineering Management*. Beijing: Higher Education Press, 159–163

Huang, W., & Li, Z. (2012). *Foreign Aircraft Engine Concise Handbook*. Xi'an: Northwestern Polytechnical University Press Co., Ltd.

Khairiyah, M., Mahyuddin, A., Mohamad, T.B., Graaff, E., Kolmos, A., & Phang, F.A. (2013). *Proceedings PBL across Cultures*. Aalborg, Denmark: Aalborg University Press

Liu, D., & Chen, G. (2010). *Aircraft Engine-the Heart of the Aircraft*. Beijing: Aviation Industry Press

Liu, Y. (2014, May 19). Strengthen Problem Awareness, Adhere to Problem Orientation. *Study Times, p.1*

Qin, X. (2008). *Quality Management (2nd ed.)*. Beijing: Science Press

UNESCO, WFEO (World Federation of Engineering Organizations), CAETS (International Council of Academies of Engineering and Technological Sciences), & FIDIC (International Federation of Consulting Engineers). (2010). *Engineering: Issues, Challenges and Opportunities for Development*. Paris: UNESCO, 5

Wang, Y. (1998). *Theory, Methodology, and Application of Systems Engineering– Theory, Methodology & Application*. Beijing: Higher Education Press, 1–14

Wu, Z., Xi, X., & Xiao, W. (2009). *Organizational Project Management Maturity Model (OPM3)* (*2nd ed*). Beijing: Publishing House of Electronics Industry, 563–641

Xiang, Q. (2007). Construction of a flexible guarantee mode for base-level maintenance of military aviation equipment. *Aeronautic Journal*, 7(2011), 50–71

Xiang, Q. (2010). Use theories to arm, culture to navigate, and innovation to lead the scientific development of corporations. *War Industry Culture*, 9, 34–41

Xiang, Q. (2012). Innovation impetus. *China Air Force*, 10, 60–62

Xiang, Q. (2013a). *Aircraft Engine Maintenance Engineering Management*. Beijing: China Machine Press, 3

Xiang, Q. (2013b). Recognition and practice on remanufacturing engineering management of military aircraft engines. *Engineering and Science*, 15, 67–72

Xiang, Q. (2013c). Build a maintenance engineering management system for new aircraft engines. *China Aviation News*. Retrieved from http://www.cannews.com.cn/2013/1017/53451.shtml

Xiang, Q., Zhong, J., & Tang, M. (2013). Study on the project management maturity model of aircraft engine maintenance capability construction of a certain-type aircraft engine. *Project Management Technology*, 11, 102–107