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PROBE ON NETWORK-BASED COLLABORATIVE MAINTENANCE MODE FOR AFTER-SALES EQUIPMENT

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Abstract: As the structure and technologies of modern equipment become more and more complicated and it is hard to improve equipment's after-sales maintenance service under traditional mode, in this text, network-based collaborative maintenance mode for after-sales equipment was proposed. Specifically, under the leading of equipment manufacturer under guaranty or equipment user outside guaranty, manufacturer, user, designers, maintainers, spare parts suppliers and maintenance experts were integrated to establish dynamic alliance to carry out maintenance operations together based on network. In addition, the business process of network-based collaborative maintenance was analyzed and an information economics model of network-based collaborative maintenance was established to demonstrate the effectiveness of this maintenance mode.

Keywords: Network-based collaborative maintenance mode; after-sales equipment; dynamic maintenance alliance; maintenance project; business process; information economics model.

1. INTRODUCTION

With the integration of global economy and the development of transnational corporation, the market competition among enterprises is becoming more intense. In order to have more market share, recently, enterprises have adopted some new maintenance modes, methods and technologies to improve their after-sales service[1]. As to equipment manufacturer, after-sales service is to provide transportation, installment,

debugging and continuous maintenance service for the product of equipment, and its core is maintenance service. Therefore, the key to improve after-sales service for manufacturer is to improve maintenance service.

In order to improve after-sales maintenance service, there are four jobs needed to be done well: real-time acquisition of equipment's signal, accurate diagnosis of potential fault, scientific decision for equipment maintenance and pressing implementation of equipment maintenance plan. At present, as equipment develops into large, high-speed, mechatronics and structure-complicated which are traded in global dimension, equipment's after-sales maintenance service exhibits several characteristics as follows:

(1)The division and cooperation of maintenance works become increasingly complex

Because the structure and technologies of modern equipments are becoming complicated, it's difficult for any manufacturer to possess all the resources and technologies of equipment production, so do all the resources and technologies for equipment's after-sales maintenance service; on the other hand, it's costly for any manufacturer to establish specialized team for equipment's after-sales maintenance service which will distribute manufacturers' resources and debase manufacturers' market competitiveness. Therefore, the social and professional division of after-sales maintenance service has become a development trend.

(2) Multi-partners' participation in after-sales maintenance service is a new characteristic

Due to the decentralization of resources, the information and technologies of equipment maintenance, for example, suppliers have the spare parts for maintenance, equipment user (equipment manufacturer's customer) has the information of equipment's use and fault, designers and maintenance experts have the technologies for equipment failure diagnosis and maintenance, and maintainers have special maintenance team and tools. Therefore, It usually happened to have the problem of lacking maintenance information for any enterprise or organization to carry out maintenance service individually, and then equipment's after-sales maintenance service needs all of them to cooperate.

(3) Network-based collaboration in maintenance works becomes an inevitable trend

Transnational production and global trade make manufacturers more geographically dispersed relative to their customers, and then the geographical distance between equipment user and manufacturer, designers, maintainers, spare part suppliers, maintenance experts may becomes more distant, traditional maintenance mode of manufacturer or its maintenance agents' maintenance service on call can not meet with the maintenance requirements of agility, high-quality and low-cost. With the development of the technologies of computer, network communications and remote signal detection, it is an inevitable trend that maintenance participants monitor and test equipments, make group decision and carry out collaborative maintenance remotely through network. Hence, in order to improve equipment's after-sales maintenance service and make user's equipments run safely, economically and everlastingly, it's necessary to study collaborative maintenance service mode.

In the past, business community adopted a number of new modes in after-sales maintenance service, such as professional maintenance mode in ordnance equipment

industry, chain operation mode and 4S mode which integrates sale, spare parts, service and survey in auto industry, and regional agents mode and the third-party maintenance mode for household appliances; a lot of improved maintenance modes were also proposed in academic circles, such as tele-maintenance mode[2-5], integrated maintenance model[6,7], e-maintenance mode[8,9] and the third-party maintenance mode[10,11]. These practices and researches have solved the problem of long-distance between the manufacturer and its customers and maintenance technologies dispersion to a certain extent. However, because manufacturer and its customers don't possess all the maintenance technologies, it's not enough to integrate their technologies to carry out maintenance service, and it is necessary to integrate the resources of equipment user, manufacturer, designers, maintainers, spare part suppliers, maintenance experts, such as information, technologies, spare parts and human; besides, there is no research on the mode of collaborative maintenance service carried out by dynamic alliance (we call it dynamic maintenance alliance in the following text).

Therefore, in this text, a network-based collaborative maintenance service mode was proposed for after-sales equipment. Concretely, equipment designers, maintainers, spare parts suppliers and maintenance experts were integrated to establish dynamic alliance by the leader of manufacturer under guaranty or equipment user outside guaranty, and the process of maintenance service was divided into three stages that were fault diagnosis, maintenance decision and maintenance implementation, and sub-alliance was established to carry out maintenance work in each stage. Finally, an information economics model of this network-based collaborative maintenance mode was established to demonstrate the effectiveness of this maintenance mode.

2. NETWORK-BASED COLLABORATIVE MAINTEN -ANCE SERVICE MODE FOR AFTER-SALES EQUIPMENT

2.1. Business process analysis of collaborative maintenance service mode

There are usually three methods for equipment maintenance: breakdown maintenance (BM), preventive maintenance (PM) and Condition Based Maintenance (CBM). BM is a kind of maintenance method based on a failure shutdown, and its basic idea is not to repair until breakdown; PM is a proactive maintenance method including equivalent period PM and variable period PM; CBM is an effective PM which carries out equipment maintenance work based on the real-time status of and use plan of the equipment.

Network-based collaborative maintenance mode is a CBM mode, and its foundation is to set up a monitoring system to monitor equipment's real-time status so as to acquire equipment's signal. The signal is a reflection of the performance status, and can predict the current status and its future development through signal analysis. Under network-based collaborative maintenance mode, equipment user identifies the failure initially through monitoring equipment and preliminary analysis of the signal collected according to equipment's abnormal status. If equipment user can maintain its equipments on its own, he can make a maintenance plan according to equipment use plan; if equipment user can not maintain its equipments or can not diagnose equipment's failure accurately, he can refer himself to its equipments' manufacturer to provide after -sales

maintenance service such as technical guidance or maintenance implementation. Manufacturer, according to its maintenance ability, can cooperate with equipment user to diagnose equipment's fault according to equipment's status signal and judge whether it is necessary or not for other enterprises or organizations to join in the maintenance service operation.

If equipment failure can be processed only by manufacturer and user, traditional maintenance mode will be ok; if not, integrating manufacturer, user, designers, maintainers, spare parts suppliers and maintenance experts to establish dynamic alliance to carry out maintenance service together will be a better solution. Usually, dynamic maintenance alliance can be established by the manufacturer as the leader under guaranty or the user as the leader outside guaranty. The business process of dynamic maintenance alliance under collaborative maintenance mode is shown in Figure 1.

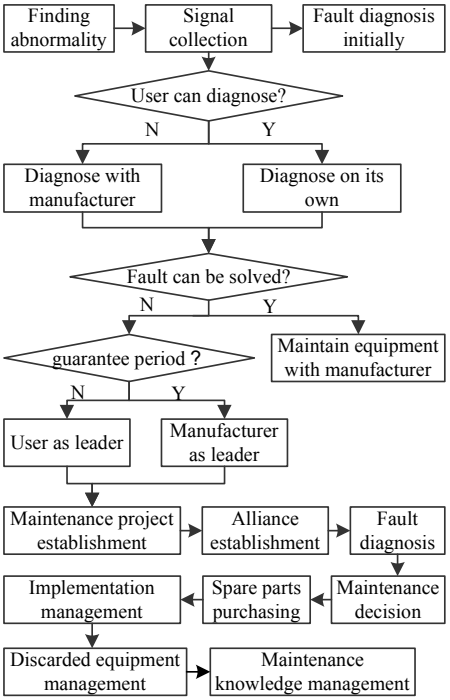

Figure 1: The business process of dynamic maintenance alliance under collaborative maintenance mode

(1) Maintenance project establishment

Maintenance project establishment is the initial work of maintenance service, and the investor of the maintenance project (manufacturer under guaranty and user outside guaranty) determines the preliminary scheme through the project assessment, such as project scale analysis, investment analysis, implementation plan analysis, feasibility analysis, infeasibility analysis and risk analysis.

(2) Alliance establishment

After the establishment of the maintenance project, the investor determinates a corresponding project team based on the preliminary scheme of the project, that is, temporary dynamic maintenance alliance. As described above, maintenance project can be divided into three stages including fault diagnosis, maintenance decision and maintenance implementation under collaborative maintenance mode, each stage has different principal and participants for different working contents and technical requirements. The principal in each stage can be elected through consultation among the members of dynamic maintenance alliance, and the participants in each stage can be selected from the members of dynamic maintenance alliance in view of the technical requirements and the members' ability, and the principal and participants in each stage constitute the sub-alliance for stage maintenance operation, including fault-diagnosis sub-alliance, maintenance-decision sub-alliance and maintenance -implementation sub-alliance. The establishment process of sub-alliance in each stage is shown in Figure 2.

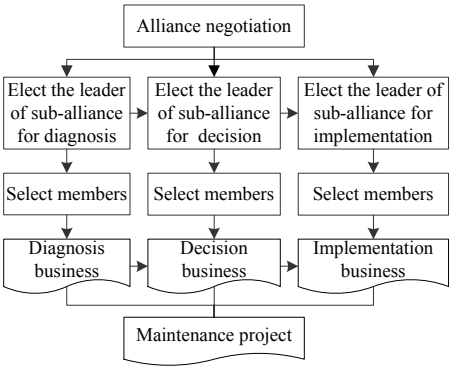

Figure 2：The processes of sub-alliance establishment

(3) Fault diagnosis

According to the previous signals and initial diagnosis result, the fault-diagnosis sub-alliance queries the similar fault diagnosing cases to the current case through matching them. If there is a similar case, the fault-diagnosis sub-alliance extracts it and analyzes the difference between them to deduce the diagnosis result, otherwise, the fault-diagnosis sub-alliance analyzes the signal and the initial diagnosis result, re-diagnoses the failure and even collects equipment's signal again if necessary.

(4) Maintenance decision

Maintenance decision usually comprises five kinds of decision, including the decision of maintenance type, maintenance method, maintenance period of periodic

maintenance, spare parts supplier selection and maintenance implementation plan, which is to answer these questions: what's the scale and scope of maintenance; what maintenance method (BM, PM or CBM) should be adopted; how much is the period of periodic maintenance; which supplier should be selected and what's the maintenance plan. Based on the diagnosis result, the maintenance-decision sub-alliance retrieves the similar decision cases to the current case through matching them. If there is a similar one, the maintenance-decision sub-alliance extracts it and analyzes the difference between it and the current case to deduce the decision result, otherwise, the leader of maintenance-decision sub-alliance notifies the members to take part in group decision and evaluate all possible schemes of each decision problem to obtain the nearly same decision results according to equipment using status, maintenance technologies, the status of spare parts inventory, suppliers' quotation for spare parts, and spare parts supplying situation. The process of group decision based on network is shown in Fig.3.

(5) Spare parts purchasing

According to the decision results and the maintenance implementation plan, the investor of maintenance project (the leader of dynamic maintenance alliance) and the selected spare parts suppliers (the manufacturer can also be spare parts supplier) make a purchasing plan of spare parts and track the usage and replenishment of spare parts.

(6) Maintenance implementation management

The leader and the members of maintenance -implementation sub-alliance control the schedule of maintenance project implementation with Gantt chart and operation Kanban; at the same time, the leader establishes the members' archives which consist of members' maintenance skills, role in the sub-alliance, working progress, performance in each stage and other contributions, and monitors members' identity strictly to prevent business from subcontract.

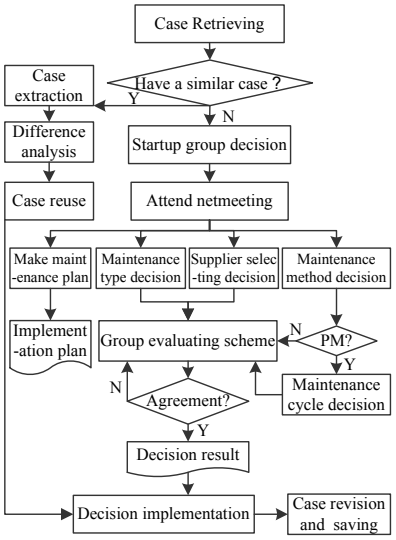

Figure 3：The process of network-based group decision

(7) Discarded equipments management

Usually, because of the integrated technologies of dynamic maintenance alliance, discarded equipments can be repaired to a certain extent and reused in a certain environment or reused by some other enterprises; in addition, the members of dynamic maintenance alliance may also participate in other maintenance projects and maintenance alliances, and have the advantage of knowing equipment market demand, which increases the circulation of discarded equipments. For example, because manufacturer knows the market demand of the equipment, discarded but repaired equipments can be sold to customers who need the secondhand equipments.

(8) Maintenance knowledge management

Dynamic maintenance alliance and sub -alliances collect, store and share the cases of fault diagnosis, maintenance decision and maintenance implementation as well as members' technologies, experience and knowledge.

2.2. Network-based collaborative maintenance mode

Network-based collaborative maintenance mode is a new group collaboration mode in maintenance service which integrates the resources of all participants and carries out maintenance operation through a collaborative business system for equipment's after-sales collaborative maintenance service. This system can use ASP (Application Service Provider) mode, that is to say, application service provider sells or lends system software to manufacturer, and is responsible for developing, maintaining and upgrading the system and its background support library. Manufacturer buys or hires the systems software, and stores information, data and knowledge about maintenance into the background support library of the system.

Therefore, according to the mode and the business process of equipment's after-sales collaborative maintenance service, we analyzed the functional requirement of collaborative business system for equipment's after-sales collaborative maintenance service and designed its frame structure, which consists of three-layers structure, including user interface, network communication layer and business collaboration layer as shown in Figure 4.

Equipment user, manufacturer, designers, maintainers, spare parts suppliers and maintenance experts visit the system through its URL and can register to be corresponding system users, such as system user of equipment user, system user of manufacturer, etc. The system user of manufacturer should pay the ASP a certain rental to gain access to the system, and then have right to give the system login account to its customers (equipment users) in selling equipment. If one equipment user has an equipment to be maintained, it can inform the equipment manufacturer of maintenance demand through information bulletin board. The manufacturer judges whether it is necessary to establish dynamic maintenance alliance or not according to the fault information of the equipment. If necessary, dynamic maintenance alliance can be established by the leader of manufacturer under guaranty or the equipment user outside guaranty. The leader issues the requirement information about maintenance project cooperation through the information bulletin board after establishing the maintenance project, such as copartners' information, technologies and spare parts supplying information, and authorizes the system users of designer, maintainer, spare parts supplier and maintenance expert who apply for participation in maintenance service, as shown in Figure 5.

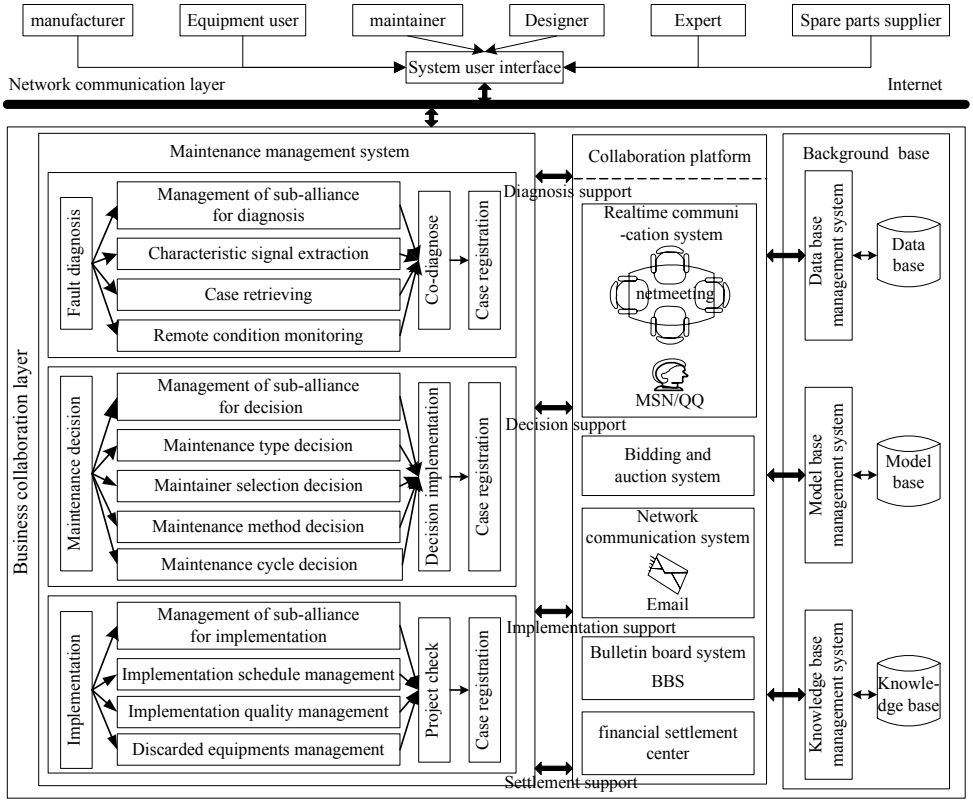

Figure 4：Collaborative business system for equipment's after-sales collaborative maintenance service

System users who have become the members of dynamic maintenance alliance login into business collaboration layer after authorizing, and then with the support of the background database, model base and knowledge base and through the collaboration platform of the system, they can carry out maintenance businesses such as fault diagnosis, maintenance decision, maintenance implementation, maintenance knowledge management, discarded equipments disposal and financial settlement.

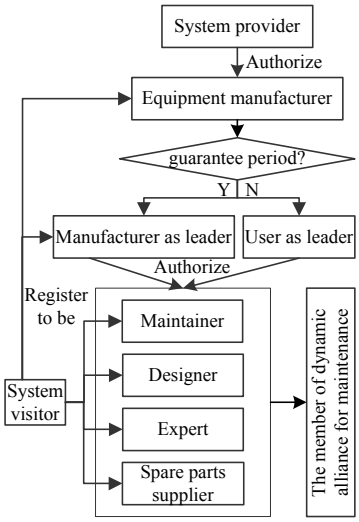

Figure 5：The role change of the members of dynamic alliance in collaborative business system

3. INFORMATION ECONOMICS MODEL OF NETWORK-BASED COLLABORATIVE MAINTENANCE MODE

Information, which is expressed in language, words, numbers, symbols, images, sound, scenes and expressions, exists in the process of human interaction with the outside world. Under the network-based collaborative maintenance mode, information (knowledge and technologies are considered to be a kind of information) interaction among the members of dynamic maintenance alliance is the key to succeed in collaborative maintenance. Therefore, the efficiency of information exchange among members reflects the level of collaborative maintenance. In the following text, an information economics model of dynamic maintenance alliance was established to prove the efficiency of collaborative maintenance mode.

3.1. The information acquisition efficiency of dynamic maintenance alliance

Information can be transmitted within enterprise or among enterprises, which could be called information-sharing and information exchange respectively. Equipment maintenance operation requires information about equipment's technologies, structure, status and suppliers of spare parts, which is scattered in a number of enterprises or organizations. Therefore, if an enterprise wants to carry out maintenance operation individually, he must acquire the information he lacks.

Under traditional maintenance service mode (individual enterprise maintenance mode), maintenance work is done by single maintenance enterprise like manufacturer,

equipment user or maintenance contractor. In this way, the maintenance enterprise needs to find the owners of maintenance information it lacks in the beginning (the owner of information is called information trade object in the following text), and exchanges information with these information trade objects later. Under collaborative maintenance mode, the leader of dynamic maintenance alliance searches maintenance cooperators (information trade objects) and establishes dynamic maintenance alliance to carry out collaborative maintenance operation. In this way, the members of the dynamic maintenance alliance transmit information between each other through network-based interactive information exchange platform (collaborative business platform). Therefore, the information exchange mode is different under the two maintenance modes, as shown in Figure 6 and 7.

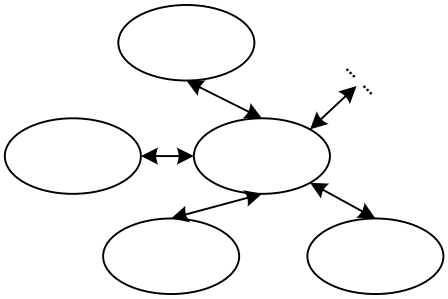

Figure 6：Information exchange mode under individual enterprise maintenance mode

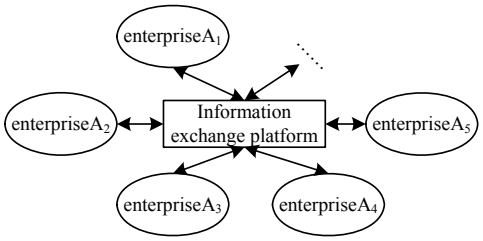

Figure 7：Information exchange mode under network -based collaborative maintenance mode

We assume that information exchange between two information trade objects is composed of four processes: information transmission, absorption, feedback transmission and absorption, as shown in Figure 8.

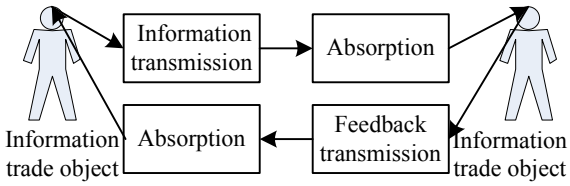

Figure 8：Four processes of information exchange

Therefore the duration of an information exchange is the sum of the time of four processes, and the time of an information acquisition is the sum of the time searching information trade objects and the time of information exchange. In the following discussion, we will establish four kinds of models of information acquisition time, which are the time model of a maintenance enterprise acquiring all the maintenance information under individual enterprise maintenance mode, the time model of a maintenance enterprise (the leader of dynamic maintenance alliance) acquiring all the maintenance information under collaborative maintenance mode, the time model of all the information trade objects (including maintenance enterprise) acquiring all the maintenance information under individual enterprise maintenance mode and the time model of all the information trade objects (including maintenance enterprise) acquiring all the maintenance information under collaborative maintenance mode.

1. The time models of a maintenance enterprise acquiring all the maintenance information

We assume that a maintenance project needs n types of information whose information quantities are I_1, I_2,…and I_n and owned by enterprise A_1,…and A_n respectively, and we also assume that the time for one enterprise to search another enterprise is T_1 and the time of transmission, digestion, feedback and absorption are t_1, t_2, $t_1$and t_2 (in fact, they are proportional to information quantity).

1) Under individual enterprise（suppose it is A_1）maintenance mode

Enterprise A_1 searches enterprise A_2…A_n who have the information enterprise A_1 needs and exchanges information with them. A_1 should spend the time $(n-1)(T_1+2(t_1+t_2))$ acquiring the needed information.

2) Under collaborative maintenance mode

Based on information exchange platform, the members of dynamic maintenance alliance exchange information with each other simultaneously. The time for the leader or any member to acquire all the maintenance information is $t_1+(n-1)(t_2+T_1)$.

Hence, it could be concluded that, the information acquisition time of a maintenance enterprise under collaborative maintenance mode is $(2n-3)t_1+(n-1)t_2$, $(n\geq 2)$ less than that of individual enterprise maintenance mode, and the value of $(2n-3)t_1+(n-1)t_2$ is approximately proportional to the number of the members. It indicates that the more the members of the dynamic maintenance alliance are, the higher the information acquisition efficiency is, that is, when $n\geq 2$, equipment's after-sales maintenance service should adopt collaborative maintenance mode.

2. The time models of all the information trade objects (including maintenance enterprise) acquiring all the maintenance information

If each enterprise carries out maintenance project individually, the time for all enterprises to acquire all the maintenance information under individual enterprise maintenance mode and collaborative maintenance mode will be different.

1) Under individual enterprise maintenance mode

We assume that one enterprise doesn't share the information about information trade objects it found with other enterprises, for example, A_1 has found enterprise A_2,…and A_n, but it won't tell A_2 the information about enterprise A_3,…and A_n, this makes A_2 should spend extra time searching A_3,…and A_n. In this case, the total time for n enterprises to acquire all the maintenance information is equal to the sum of the time for each enterprise to acquire all the maintenance, that is $\frac{1}{2}n(n-1)(T_1+2(t_1+t_2))$, $(n \geq 2)$.

2) Under collaborative maintenance mode

Because the members of dynamic maintenance alliance could acquire information simultaneously through information exchange platform, in this case, the total time for them to acquire all the maintenance information is $n[t_1+(n-1)t_2]+(n-1)T_1$, which is composed of the time $(n-1)T_1$ for the leader to search the members, the information transmission time nt_1 for the members to transmit their own information to the information exchange platform and the information absorption time $n(n-1)\ t_2$ for the members to absorb the others' information form the information exchange platform.

So it could be concluded that, the information acquisition time of all the information trade objects (including maintenance enterprise) under collaborative maintenance mode is $n(n-2)t_1+\frac{1}{2}(n-1)(n-2)T_1$ less than that under individual enterprise maintenance mode, and the value of $n(n-2)t_1+\frac{1}{2}(n-1)(n-2)T_1$ is approximately proportional to second power of the number of the members(when n is large). It proves that collaborative maintenance mode is the best one to transfer maintenance information among enterprises.

3.2 Scale economic benefit of collaborative maintenance mode

Trade cost is the expenditure spent on information search, contract negotiation and trade implementation which make up of a trade [12]. Hence we divide the cost of information trade(information trade cost for short in the following text) between enterprises into the cost of searching for information trade objects(information search cost for short in the following text) and information exchange cost (include information cost and the expenditure on contract negotiation) .

Information search cost refers to the expenditure to find trade object. We assume that there is no information trade object who knows any of the other ones, and then any trade object have to spend some resources such as human, material resources and financial resources in searching other information trade objects.

Information exchange cost is the cost of information exchange among information trade objects. Because any trade object only owns some of the whole maintenance information and there is no intersection of the information of any two information trade objects, if information object only wants to carry out equipments maintenance operation on its own, it should acquire information it lacks and pay some money. The information trade cost under collaborative maintenance mode is different from that under individual enterprise maintenance mode. The problem was narrated with a maintenance case as below.

On the assumption that the market exists N (N is a constant) same maintenance projects, each maintenance project needs n type of information that their quantities are I_1、I_2、…、I_n and owned by information trade object A_1,…,A_n respectively. At the same time, on the assumption that the cost of searching for any one of information trade object A_1…A_n is C_1, information exchange cost is C_2, the cost of alliance establishment is C_3, and in addition to information trade cost, the other costs about maintenance under individual enterprise maintenance mode and alliance collaborative maintenance mode are the constants of $C_0^{'}$ and $C_0^{''}$ respectively.

1) Under individual enterprise maintenance mode

If any one of information trade object A_1,…, A_n carries out maintenance operation on its own, and A_1,…, A_n carry out $N_1, N_2, \cdots, N_n$ maintenance businesses respectively. Any one of A_1,…,A_n search the others in market, the total information search cost of N maintenance projects is $\frac{1}{2}n(n-1)C_1$, the total information exchange cost of N maintenance business is $\frac{1}{2}n(n-1)C_2$, so the total cost of N maintenance business can be expressed as $C' = \frac{1}{2}n(n-1)(C_1 + C_2) + NC_0^{'}$, and the average cost per project is $\frac{1}{2N}n(n-1)(C_1 + C_2) + C_0^{'}$.

2) Under alliance collaborative maintenance mode

If one of A_1…A_n as the leader, establishes a dynamic maintenance alliances to carry out equipments maintenance operation together. In order to find other N-1 cooperators, The leader searches the other information trade objects in market, and its information search cost (is also alliance's information search cost) is $(n-1)C_1$, and its information exchange cost is $(n-1)C_2$, so the total cost of N maintenance project can be expressed as $C'' = (n-1)(C_1 + C_2) + NC_0^{''}$, and the average cost per project is $\frac{1}{N}(n-1)(C_1 + C_2) + C_0^{''}$.

The cost difference of average cost per project between individual enterprise maintenance mode and collaborative maintenance mode is $\frac{1}{2N}(n-1)(n-2)(C_1 + C_2) + (C_0^{'} - C_0^{''})$, which shows that the more decentralized is the maintenance information, the worse is the economy of individual enterprise maintenance

mode. The average cost per project $\frac{1}{N}(n-1)(C_1+C_2)+C_0^{''}$ under collaborative maintenance mode is less than the average cost per project $\frac{1}{2N}n(n-1)(C_1+C_2)+C_0^{'}$, which shows the former has bigger scale economic benefit.

4. CONCLUSION

Based on current development of the technologies of equipment maintenance, computer, network communications and remote signal collection and detection, we proposed a network -based collaborative maintenance mode. It is a maintenance mode that the investor of the maintenance project establishes a dynamic maintenance alliance and three sub-alliances, and the members of sub-alliances co-detect signals, co-diagnose fault, co-make maintenance decisions and co-maintain equipments. Subsequently, we established the information exchange efficiency and benefit models of the maintenance mode to demonstrate the effectiveness and economy of it.

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