Cost-benefit analysis on remote maintenance for industrial robot

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Abstract—Abstract: The maintenance of industrial robots can be divided into two types: on-site maintenance and remote maintenance, each of which has its advantages and disadvantages. Firstly, the two types of maintenance modes, cost and benefit are analyzed and compared. While cost of on-site maintenance mainly includes downtime loss, maintenance cost and expert cost, downtime loss includes production loss and manpower waste, maintenance cost includes testing cost and material cost, and expert cost includes travel expense and labor cost. Cost of remote maintenance also includes downtime loss and maintenance cost, but does not include expert cost. Downtime loss and maintenance cost of remote maintenance is same as that of on-site maintenance, but the value is different. Then, cost-benefit method is used to analyze and establish cost-benefit model of two maintenance modes. Finally, an automobile manufacturing enterprise is taken as an example, and the cost and benefit of on-site maintenance and remote maintenance is analyzed and calculated to apply and verify the proposed method. The method proposed in this paper can provide help for the maintenance mode selection of industrial robots.

1. INTRODUCTION
The number of industrial robots increases rapidly year by year, and the on-site maintenance work increases day by day, which will have three effects: First, with the rapid increase of business trips and on-site maintenance work, manufacturer and application enterprises are not able to cope with the maintenance requests all over the country, so the application enterprises often complain about the slow maintenance response [1]. Second, as a high-tech intelligent equipment, industrial robot is used in large scale in recent years, and it is integrated with multi-disciplinary technologies. Because of lack professional maintenance personnel, enterprises need technical guidance from manufacturer of industrial robot. Third, as key equipment of enterprises, industrial robots are often used in key processes of production lines because of their high price. Generally, industrial robot has no backup equipment, and if there is a fault that it cannot be repaired in time, the enterprise will suffer a huge loss of production halt [2]. Therefore, it is necessary to solve the contradiction of heavy task, high technical requirements and large downtime loss in maintenance process. Remote maintenance is the feasible method to solve this problem.

Internet is used to monitor and diagnose fault of industrial robots remotely, which can improve the response speed and predict ability of maintenance, and reduce the failure rate, it is very important to efficient operation of industrial robots. In industry, ABB (Asea Brown Boveri) has developed a "remote
service” platform, which can realize remote real-time monitoring, data analysis and processing, fault prediction and other functions. FANUC has also put forward its own remote monitoring service scheme, which supports remote monitoring and diagnosis, and it can timely inform on-site operators and service engineers for fault maintenance [3-4].

On-site maintenance and remote maintenance of industrial robots are quite different in terms of personnel, equipment, environment, etc., and the costs and benefits are also different. Enterprises always hope to choose the most appropriate maintenance mode, shorten the maintenance time and reduce the maintenance cost [5]. Therefore, this paper analyses and compares the cost-benefit of the two maintenance modes, provides help for the correct decision-making of enterprises.

2. COST BENEFIT ANALYSIS

2.1. Cost analysis

The equipment maintenance cost mainly includes downtime loss and maintenance cost. The maintenance cost includes inspection cost, spare parts cost, labour cost, material cost, safety cost and other costs. The maintenance cost can be divided into two parts: first, the cost of manpower, tools and materials in the maintenance process, accounting for about 35% of the maintenance cost [6]. The other part is the purchase, transportation, inventory and installation cost of spare parts, which is called spare parts cost, accounting for about 65% of the maintenance cost. The meaning of each cost is as follows:

1) Loss of downtime ($dC$). When the robot breaks down, it needs to detect, repair or replace the broken parts. In the maintenance stage of industrial robot, the downtime will cause reduction of production, and the downtime loss accounts for a large proportion in the maintenance cost. The downtime loss can be reduced by shortening the maintenance time.

2) Labor cost ($lC$). Labor cost is mainly the training cost of the maintenance personnel, so that they can carry out daily inspection and maintenance of industrial robots. In addition, when the fault is more complex, the manufacturer needs to assign experts to carry out maintenance, which will need expert costs, including subsidies and travel expenses.

3) Spare parts cost ($sC$). The cost of spare parts accounts for a large proportion in the maintenance cost, which is mainly used to replace the damage parts in the fault position [7]. The cost of spare parts includes purchase cost, transportation cost, storage cost, etc. Enterprises can classify and manage spare parts according to their value and frequency, so as to reduce the cost of spare parts.

4) Material cost ($mC$). In addition to spare parts, the maintenance process of industrial robots also needs to consume a certain amount of auxiliary materials, such as lubricating oil, cleaning supplies, maintenance tools, etc.

5) Security costs ($sAC$). There are hidden dangers in the use and maintenance of industrial robots, which easily lead to accidents. Enterprises need to provide necessary insurance costs for employees and repairers.

6) Other cost ($oC$). Other cost account for a relatively low proportion of the maintenance cost, mainly refer to unplanned cost, such as the workers’ wages during the downtime, the compensation for delay in delivery, etc.

The composition of site maintenance cost ($osC$) is shown in Figure I:
There are many similarities in cost composition between remote maintenance and on-site maintenance, as well as some different costs, such as equipment cost of remote maintenance ($C_{mr}$), it concludes purchase cost, maintenance cost and installation cost. Network security cost ($C_{ns}$) is unique to remote maintenance. The composition of remote maintenance cost ($C_r$) is shown in Figure II:

2.2. Benefit analysis
The purpose of remote maintenance is same as that of on-site maintenance, which is to change the industrial robot from failure to normal state. So the benefits of these two maintenance modes have the same composition [8]. The difference is that the remote maintenance technology can monitor the working state of industrial robots in real time, predict the faults of industrial robots, and increase the cost-benefit.

The maintenance benefits of industrial robots are divided into economic benefits, social benefits and environmental benefits. Economic benefits refer to the social labor savings achieved through the exchange of goods and labor. In this paper, it mainly refers to the benefits such as loss reduction and order increase brought by maintenance activities. Social benefit originally refers to the role of implementation projects in ensuring social stability, promoting social development and improving people's welfare. Environmental benefits mainly refer to the maintenance activities of industrial robots.
can extend equipment life, increase the operation time, and reduce the negative impact of product scrap on the environment.

3. **COST BENEFIT CALCULATION**

The cost-benefit method is used to analyze benefit of unit cost, and to evaluate the feasibility of each maintenance mode for industrial robot. The main analysis steps are as follows:

\[ C_{o} = C_{d} + C_{l} + C_{m} + C_{s} + C_{r} + C_{o} \]  

(1)

As mentioned above, the benefits of industrial robot maintenance are mainly economic benefits. The social and environmental benefits account for a small proportion; they will not be discussed and analyzed in this paper. Therefore, in this paper, the field maintenance benefit is approximately equal to the economic benefit.

2) According to fig1 and fig2, the cost and benefit of remote maintenance can be calculated according to formula (2):

\[ C_{r} = C_{d} + C_{l} + C_{m} + C_{s} + C_{o} + C_{r} + C_{s} \]  

(2)

The benefit composition of remote maintenance is similar to that of on-site maintenance. The benefit of remote maintenance is approximately equal to the economic benefit.

3) The cost-effectiveness of industrial robot maintenance is the ratio of benefit and cost. The cost-effectiveness of on-site maintenance and remote maintenance can be calculated according to formula (3) and formula (4).

\[ V_{o} = \frac{E_{o}}{C_{o}} \]  

(3)

\[ V_{r} = \frac{E_{r}}{C_{r}} \]  

(4)

Cost-effectiveness of the two maintenance modes was compared to help enterprises choose suitable maintenance mode for industrial robot. The more cost-effectiveness of maintenance can bring more economic benefits.

4. **CASE STUDY**

An industrial robot of an automobile manufacturing enterprise has broken down and stopped for maintenance. The maintenance cost is shown in Table 1:

| Cost content                  | value |
|-------------------------------|-------|
| Downtime cost                 | 15    |
| Spare parts cost              | 3     |
| Labour cost                   | 0.03  |
| Material cost                 | 0.4   |
| Safety cost                   | 0.8   |
| Other expenses                | 0.25  |
| Remote maintenance equipment cost | 20     |
| Network protection fee        | 6     |

In general, the time required for on-site maintenance is 2 times of that for remote maintenance, and even 3 times of that for complex cases. According to statistics, the average time of remote maintenance is 1 hour, and the average time of on-site maintenance is 3 hours, as shown in Table 2:

| Benefit category          | On-site maintenance | Remote maintenance |
|---------------------------|---------------------|---------------------|
| Direct economic benefit   | 30                  | 50                  |
| Indirect economic benefit | 10                  | 13                  |
Firstly, the cost of on-site maintenance is analyzed:

\[ C_{os} = (15 + 0.03) \times 3 + 0.4 + 0.8 + 0.25 = 46.54 \]  

The benefit of on-site maintenance can be obtained by data given earlier:

\[ E_{os} = 30 + 10 = 40 \]  

The cost-effectiveness of on-site maintenance can be obtained:

\[ V_{os} = \frac{40}{46.54} = 0.086 \]  

The cost of remote maintenance can be obtained by substituting data:

\[ C_r = 15 + 0.03 + 3 + 0.4 + 0.8 + 0.25 + 20 + 6 = 45.48 \]  

The benefit of remote maintenance can be obtained by substituting data:

\[ E_r = 50 + 13 = 63 \]  

Therefore, the cost-effectiveness of remote maintenance can be obtained:

\[ V_r = \frac{63}{45.48} = 1.385 \]  

Therefore, \( V_r = 1.385 > V_{os} = 0.086 \), the cost-effectiveness of remote maintenance is better than that of on-site maintenance.

5. CONCLUSION

The cost and benefit of on-site maintenance and remote maintenance for industrial robot are compared and analyzed. At present, while the maintenance of industrial robots still mainly depends on on-site maintenance, remote maintenance accounts for a small proportion. However, remote maintenance has the advantages of fast response, small downtime loss and so on. At present, more and more attention has been paid to remote maintenance, and it will get more rapid development and more applications in the future. Now, there are few cases of remote maintenance, so the cost and benefit are analyzed and calculated roughly in this paper. With the development of remote maintenance in the future, we will also conduct a more detailed analysis.

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REFERENCES

[1] Paul J. K., Marike K., et al. (2017)A skill-based robot co-worker for industrial maintenance tasks. Procedia Manufacturing, 11:83-90.
[2] Riccardo P., Tania C.( 2019)Robot fault detection and remaining life estimation for predictive maintenance. Procedia Computer Science, 151:709-716.
[3] Panerati, J., Minelli, M.,et al. (2019)Robust connectivity maintenance for fallible robots. Auton Robot, 43:769-787.
[4] Kathryn M., Nazmul S.,et al.CExperience Based Generation of Maintenance and Achievement Goals on a Mobile Robot. Paladyn, J. Behav. Robot,7:67-84.
[5] Christer S., Per N., Aditya P.(2016) Preventive and corrective maintenance-cost comparison and cost-benefit analysis, Structure and Infrastructure Engineering, 12: 603-617.
[6] Bramde J. (2016)Reducing costs by clustering maintenance activities for multiple critical units. Reliability Engineering & System Safety,145:93-103.
[7] KangKyu L., Seungwoo H., Jun-H.O. (2019)Development of a Lightweight and High-efficiency Compact Cycloidal Reducer for Legged Robots. International Journal of Precision Engineering and Manufacturing,11:1-11.
[8] Su H.N., Jiheum P., et al. (2017) A comparison between reduced-port robotic surgery and multiport robot-assisted laparoscopy for myomectomy. European Journal of Obstetrics & Gynecology and Reproductive Biology, 213:53-57.