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THE LINEAR MODEL FOR THE ROUTINE MAINTENANCE EVALUATION OF EARTHQUAKE RESCUE EQUIPMENTS

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ABSTRACT

The linear model for the routine maintenance evaluation of earthquake rescue equipments is presented. Based on the maintenance data of CISAR rescue equipments in the past five years, the routine maintenance costs is analyzed and the linear model is set up through divide the costs to four parts and their separate statistics. There are both simple linear model and weighted linear model and also the compare of deviation for the two models is there.

Keywords: linear model, routine maintenance costs, rescue equipments, deviation analysis.

INTRODUCTION

CISAR Team

China is one of the most-affected countries in the world by various natural disasters. Especially, the frequent earthquakes have caused massive human casualties and property losses, and brought immeasurable sufferings to the Chinese people. On April 27, 2001, China International Search and Rescue team (CISAR) was awarded the flag which marking the beginning of the building of the search and rescue forces in China.

Adopting an open and cooperative attitude, CISAR takes an active part in international efforts in the area of disaster-reduction cooperation within the framework of the United Nations, and has built up close partnership relations with UN-OCHA, and other international organizations around the world. Together with other family members of International Search and Rescue Advisory Group (INSARAG), CISAR has been devoted to the construction and improvement of an international cooperative disaster-reduction mechanism, especially in providing mutual collaboration with other countries in major natural disasters.

On November 14, 2009, CISAR has successfully passed the IEC（INSARAG External Classification）of heavy rescue teams, and be awarded the certificate by UN (INSARAG UN OCHA, 2008). CISAR was the 12th heavy rescue team in the world. On August 29, 2014, CISAR has successfully passed the IER（INSARAG External Re classification and kept to be heavy rescue team according to the INSARAG checklist (INSARAG UN OCHA, 2011).CISAR is engaged in its expansion now and will be increased to 480 members with new equipment by the end of 2010.

In the past five years, CISAR has participated in the following domestic and overseas missions as shown in Table-1. (CEA Office)

CISAR equipments

Since its foundation in 2001 to the expansion in 2010, CISAR has more than 6000 pieces of equipment and 20 search dogs which cost about 100 millions. The State Council allocated nearly 100 millions in 2010 to strengthen the equipment capacity in order to satisfy the need of more members of the CISAR. After the expanded equipments took their places after 2012,the amount of equipments for CISAR was more than 11 thousands.

Table-1. Missions the CISAR participated from the year 2010 to 2014.

Time	Type	Site
2010, Jan.13	Earthquake	Port-au-prince, Haiti.
2010, Apr.14	Earthquake	Yushu County, Qinghai Province, China.
2010, Aug.8	Mud avalanche	Zhouqu County, Gansu Province,China
2010, Aug.26	Flood	Karachi city, Sindh Province,Pakistan
2011, Feb.24	Earthquake	ChristChurch city, New Zealand
2011, Mar.11	Earthquake	Southnorth Sea,Japan
2013, Apr.20	Earthquake	Lushan County, Sichuan Province,China
2013, Jul.13	Mud avalanche	Dujiangyan City, Sichuan Province,China

Refer to the equipment management experience of external urban rescue teams and more then ten years' management practice of CISAR, there is earthquake standard for the classification for the equipments (Si *et al.* 2014).There are eight main classes and several sub classes under each main class as shown in Table-2.

RESCUE EQUIPMENTS MAINTENANCE

Parts and tasks of maintenance

The equipments maintenance here mainly refers to the six sub classes of rescue equipments which is dismantling equipments, shoring equipments, remove equipments, rope access, power and safety equipments. According to the different requirements, the maintenance costs could be divide to four parts which are two-stroke cycle maintenance cost, four-stroke cycle maintenance cost, repair cost, accessories cost.

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The routine maintenance cost is due to tasks conducted and quantities of rescue equipments. For the two-stroke cycle and four-stroke cycle parts, the tasks mainly include check of spark plug for the engine, changing machine oil and three filters such as machine oil, fuel oil and atmosphere. For the repair part, the task comprised not only the check and change of machine oil, hydraulic oil but also the clean of carburetor, the working pressure detection and whether there is any leakage which mainly for the hydraulic engines and tools. Besides, there will be some repair works for other equipments, etc. With the using, some accessories need to be purchased and stored up to guarantee the normal operation and sudden breakdown taking less affect.

Table 2. Classes for the CISAR equipments according to the standard.

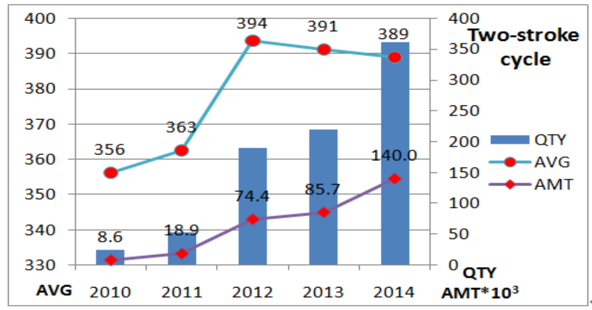
Main class	Sub classes
Detection	Gas Detection,Radioactive Detection,Leakage of electricity Detection
Search	Artificial Search,Instruments Search,Biology Search
Rescue	Dismantling Rescue,Shoring Rescue,Remove Rescue,Rope Access, Power Station,Safety Equipments
Medical	Medical treatment, Disinfect and epidemic prevention
Communi-cation	Site contact Communication, Telecommunication Communication
Technical	Construction evaluation,Technology and Information
Logistic	Official, Livelihood,Personnel,Repair
Vehicle	Equipment Vehicle,Support Vehicle

Data records of maintenance

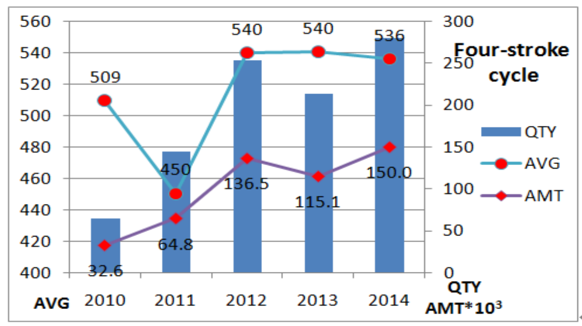
The CISAR equipment managers will schedule about eight times of routine maintenance every year and have kept the maintenance data of rescue equipments conformed to the four parts above since 2010 and arrange data to be constant records. There are several information of maintenance in the data such as the quantity of each part, the persons and content of maintenance, the time and site, and importantly the maintenance funds for each part.

The maintenance cost is significant for both the manager and the equipments because the manager can know the economical efficiency of the equipments to decide whether the continuative maintenance be scheduled or just abandon the use and give transposing according to the cost and the period of lifecycle which the equipment due to.

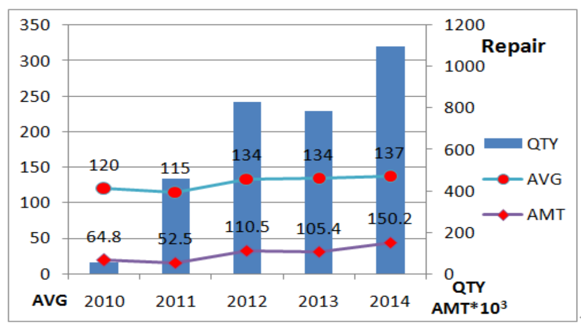
There are statistics of the quantity, the funds, the asset value of all the routine maintenance since 2010 and the data is divided as parts of two-stroke cycle, four-stroke cycle, repair, accessories to make analysis. Besides, the average (AVG) cost for each part in one year can be got by the way the funds amount (AMT) divided by the quantity (QTY). Figure-1 shows the statistics of AVG,AMT,QTY for the four parts during the past years.Figure-1(a) ,(b),(c),(d) severally shows the statistics for the maintenance of the two-stroke cycle, four-stroke cycle, repair and accessories.



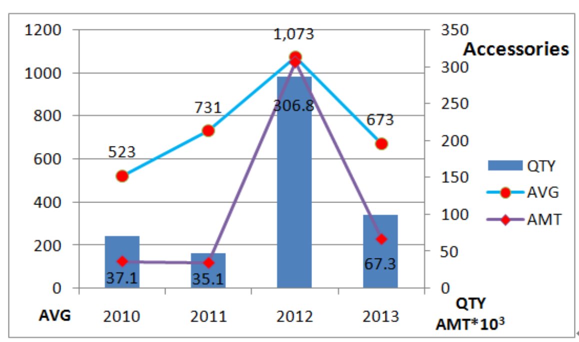
(a) Two-stroke cycle



(b)Four-stroke cycle



(c)Repair



(d) Accessories

Figure-1. The statistics of AVG,AMT, QTY for the four parts as two-stroke cycle, four-stroke cycle, repair and accessories from the year 2010 to 2014.

DATA ANALYSIS

Quantity of equipments

In Figure1,we can see the quantity for the four parts has big increase in 2012 compared with before because that the equipments purchased in the expansion of CISAR in 2010 have been configured to the rescue team and preserve at higher level in the next few years. There is also other influence factor that the equipments purchased since the foundation of CISAR are entering the period has more and more maintenance requirement to keep the using performance. So the quantity of equipments will be at high level in the next several years and make the maintenance costs also will be high.

Amount of funds

The amount of maintenance funds has similar trends with quantity which also has big increase in 2012. Obviously, the purchase of accessories will not happen every year but in some certain years due to the replace period and frequency of using, so there will be big rise and fall of amount in Figure1(d).In the evaluation and modeling for the routine maintenance costs, this should be give more attention to make the result be more factual .

Average of cost

Average is the result of amount of funds divided by quantity of equipments. In Figure-1(a),the average for two-stroke cycle equipments is at the same level with little reduction about 1 percent from 2012 to 2014 which indicate that though there is big increase for the quantity and amount, the average of cost has no addition but little abatement with managers' effort. The same result can be seen for four-stroke cycle equipments in Figure-1(b).

However, in Figure-1(c), there is converse trend for the repair part of rescue equipments and this is explicable and correct. First, after the equipment warranty, the repair work need to be scheduled ourselves instead of the franchiser and the amplification of repair funds is higher than the amplification of repair quantity, so the average will increase. Secondly, there are more repair work for the old rescue equipments with its more fault happened after years of using.

MODEL

Existed models

For the maintenance evaluation, there is economic model for the optimization of maintenance procedures in a production process with two types of maintenance: minimal maintenance (MM) and perfect preventive maintenance (PM)(S. Panagiotidou, G. Tagaras,2008) and effectiveness-based method(Hu *et al.* 2012).Based on the DS evidence theory, analytic hierarchy process and fuzzy comprehensive evaluation method, an integrated assessment model is proposed to make the scheduling plan of the large equipment maintenance project. (Wang Fangfang *et al.* 2012).

In order to improve MRO (Maintenance, Repair & Operations), the system approach, correlated goals, key performance indicators and life cycle cost of the equipment are used and become functional and business models. (A.V. Kizim, 2013). Based on the analysis of the MRO process of repair-service facility, a model using agent-based approach is built for increase of efficiency of use the available fund (V.V. Panteleev *et al.*2014).

Refer to the disaster and exercises, a mathematical model of the emergency equipment maintenance scheduling is presented to achieve a good balance between operational capability achieved by maintenance, cost-effectiveness, maintenance risks, and reserved maintenance capability for sustainable operations (Zheng *et al.* 2013).

Simple linear model

With the statistics we get the average cost (AVG) of every year for the four parts since 2010 to 2014 using following formula:

$$AVG = \frac{AMT}{QTY} \tag{1}$$

If there is further calculation for the average cost above, the result will be more general which can be regard as the base of evaluation of the maintenance for each part and the result can be calculated repeatedly with the future data to enhance the accuracy. The result AC_j is:

$$AC_j = \frac{\sum_{i=1}^{n} AVG_{ij}}{n} \tag{2}$$

i = the year which has the data from the year 2010 to 2014,and here i=1,2,3,4,5.
j = the four part of rescue equipments, and here j=1,2,3,4.
AVG_{ij} = the average cost for each part in every year from the year 2010 to 2014.
AC_j = the average cost for each part.

Calculate the AC_j using the known data of the past five years shown in Figure 1,there is AC ={378 515 128 750}and the number of set AC means the cost for the maintenance of four parts as two-stroke cycle equipments, four-stroke cycle equipments ,repair of equipments and accessories.

With the average cost for each part AC_j,if we assume the quantity of rescue equipments for each part is Q_j in one year,there is the evaluation total cost TC for the year:

$$TC = \sum_{j=1}^{4} AC_j Q_j = \sum_{j=1}^{4} \frac{\sum_{i=1}^{n} AVG_{ij}}{n} Q_j \tag{3}$$

Q_j = the assumed quantity for each part in the year want to evaluate the maintenance cost.
TC = the evaluation cost of the maintenance for the rescue equipments.

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With the result of AC calculated above, the total cost could be:

$$TC = 378Q_1 + 515Q_2 + 128Q_3 + 750Q_4 \quad (4)$$

Weighted linear model

The weighted factor of QTY is introduced to the simple linear model above and there is the weighted linear model. In order to cancel the undesirable influence of QTY, the parameter ω_{ij} is used to indicate the weight:

$$\omega_{ij} = \frac{QTY_{ij}}{\sum_{i=1}^{n} QTY_{ij}} \quad (5)$$

ω_{ij} = the weight factor of QTY.

With the effect of ω_{ij},the formula (2) above can be rewrite to be:

$$AC_j = \sum_{i=1}^{n} \omega_{ij} AVG_{ij} = \sum_{i=1}^{n} \frac{QTY_{ij}}{\sum_{i=1}^{n} QTY_{ij}} AVG_{ij} \quad (6)$$

Re-calculate the AC_j using the known data of the past five years shown in Figure1, there is new AC ={388 523 132 884} for the maintenance of four parts above.

With the new average cost for each part AC_j calculated by formula (6), there is the new evaluation total cost TC:

$$TC = \sum_{j=1}^{4} AC_j Q_j = \sum_{j=1}^{4} \sum_{i=1}^{n} \frac{QTY_{ij}}{\sum_{i=1}^{n} QTY_{ij}} Q_j \quad (7)$$

With the result of AC calculated above with formula (7), the evaluation of total cost TC could be:

$$TC = 388Q_1 + 523Q_2 + 132Q_3 + 884Q_4 \quad (8)$$

Deviation of models

In the simple linear model built above, there is no consideration about the proportion of quantity of every year to the sum of quantity of all years and caused deviations for the AMT recall each part and also there is deviations for the TCj. We calculate the recall TC_j through the set AC multiply by the QTY shown in Figure-1 which is:

$$\delta_{ij} = \frac{AC_j QTY_{ij}}{AMT_{ij}} \quad (9)$$

δ_{ij} = ratio of TC_j and AMT of each year, %

QTY_{ij} = QTY for each part from the year 2010 to 2014 shown in Figure-1

AMT_{ij} = AMT for each part from the year 2010 to 2014 shown in Figure-1.

With the formula (9), there are table 3 and 4 for the ratio δ_{ij} (%) using the separate AC_j calculated by formula (2) and formula (6) which belong to the simple linear model and the weighted linear model.

Table-3. The δ_{ij} (%) of SLM.

Part / Year	Two-stroke cycle	Four-stroke cycle	Repair	Accessories
2010	106.24	101.10	106.62	143.41
2011	104.41	114.39	111.35	102.55
2012	96.15	95.45	95.75	69.90
2013	96.77	95.34	95.40	111.50
2014	97.32	96.13	93.34	

Table-3 shows that there are differences between the calculated result of maintenance cost for each part of every year with the statistics of data shown in Figure1 ,especially big deviation exists for the accessories part compared with three parts since the purchase of accessories will not happen regularly but usually the time and quantity will be random with the using of rescue equipments.

Table-4. The δ_{ij} (%) of WLM.

Part / Year	Two-stroke cycle	Four-stroke cycle	Repair	Accessories
2010	108.90	102.68	110.03	169.02
2011	107.03	116.18	114.91	120.86
2012	98.56	96.94	98.81	82.38
2013	99.20	96.83	98.45	131.42
2014	99.76	97.63	96.32	

Compared the δ_{ij} in Table 3 and Table 4, there are character following:

In the year 2010 and 2011, the deviation is bigger in Table 4 than in Table 3 for the all four parts, but the difference between the two tables can be neglected.

Since the year 2012 to 2014, the result got with the weighted linear model for the all four parts is more approximate with the simple linear model except the accessories and there is also big deviation for the accessories part.

In order to make the result more approximate with the statistic maintenance data in Figure 1, we can use the AC_4 in formula (2) instead of the AC_4 in formula (7) for the accessories part because the four parts of the rescue equipments are independently with each other so the evaluation of the costs for each part is also independently. Then we can get the final evaluation formula for TC:

$$TC = 388Q_1 + 523Q_2 + 132Q_3 + 750Q_4 \quad (10)$$

Using the formulas (4),(8),(10),there are three results for that total cost evaluation TC, the comparison could be done with the statistic maintenance data in Figure-1 in order to see the approximation of the three formulas using :

$$\eta_i = \frac{TC_i}{\sum_{j=1}^{4} AMT_{ij}} - 1 \quad (11)$$

i = the year which has the data from the year 2010 to 2014, and here i=1,2,3,4,5.
j = the four part of rescue equipments, and here j=1,2,3,4.
TC_i = the three results calculated with the formulas (4),(8),(10) in the year 2010 to 2014.

The result of η_i is shown in table 5 and the result of formula (10) is the most suitable with the comprehensive comparison of the last three years since the closer the more close to the actual status.

Table-5. The result of η_i (%).

Formula / Year	(4)	(8)	(10)
2010	20.58	32.93	21.71
2011	9.93	15.74	11.99
2012	-16.9	-9.65	15.75
2013	-1.4	4.06	0.47
2014	-4.44	-2.14	-2.14

CONCLUSIONS

Based on the statistics of data for the routine maintenance of CISAR rescue equipments, there are analysis for the QTY, AMT and AVG in order to build linear models to evaluate the routine maintenance cost future. Two linear models are presented here which is separately the simple linear model and the weighted linear model and through the comparison between the original AMT and the calculated TC_j, there are both deviation in the two models and each model is separately suitable for the evaluation of different parts of rescue equipments. So the composite using of the two models is better than individual one.

Though here are two linear models for the evaluation, improvements also can be realized considering the economic factors such as CPI (Consumer Price Index) and PLC (Produce Life Cycle).The CPI will cause all the economic cost increase not only for the maintenance of earthquake rescue equipments but also every aspects during people's life and the equipments at the last period of its PLC will have more requirements than the ones at the beginning of the PLC. How to add the influence of other factors should be taken seriously.

Here the evaluation of routine maintenance is discussed, but there are also maintenance tasks caused by uncertain earthquakes and exercises. As example, there were four rescue missions in the year 2010 but we have the least numbers of QTY and AMT for the four parts than other years since the statistics are only for the routine maintenance and don't involve the missions and exercises. We prefer to use the probability theory or the Markov chain technology to build the model for the uncertain part such as rescue mission and exercises. The sum of the routine maintenance and the uncertain part could be better model and evaluation of the maintenance cost would be more realistic and useful.

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