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The Research and Development of Safety Assessment Software System for Portal Cranes

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Abstract: The safety assessment index system is formulated for portal cranes according to the operation features of this type of crane. The comprehensive assessment matrix and subsequent assessment results are finalized for all levels of index according to the variable weight analytic hierarchy process (AHP). The safety assessment software system is developed for portal cranes on the basis of above outcomes. Relying on C# programming language, the software has enabled the functions of data acquisition and result processing. In addition, it shows a remarkable utility value of the safety assessment of portal cranes and is capable of the safety assessment for the portal cranes in service.

1. Introduction

With the steady growth of import and export trade in recent years, the cargo transportation tends to be more and more giant, specialized and standardized, which promotes the fast development of large-scale docks. As a result, these docks witness an increasing number of port cranes. Portal cranes have been widely applied to docks and stacking yards. They have a huge body and a complex structure but can be used in the open air for heavy-duty operations[1]. With the increasing service life, portal cranes suffer structural deterioration, which lead to fatigue cracking, rust corrosion, deformation, abrasion and other defects. These defects pose a potential threat to the work safety of every port[2]. About 30% of the accidents at a dock are caused by design, installation, application, maintenance and human factors of portal cranes. In this view, the severity of work safety is quite remarkable[3, 4]. Therefore, safety assessment is of great necessity during the operation of this type of equipment. Paying more attention to work safety will easily cause economic loss, while the continued service of equipment beyond its lifecycle by intuitive feeling at cost reduction may cause a catastrophic accident.

At present, relevant enterprises, including inspection institutions, mainly verify the conformity of safety status of all risk indexes involved in regular inspections, and seldom analyze the risk sources, failure consequences and potential risks in a systematic way. Moreover, they are lack of comprehensive judgment on the overall safety of portal cranes[4-7]. These enterprises are urgently required to perform a scientific safety assessment to all portal cranes in service, minimize production costs by ensuring the work safety and work out targeted, scientific, reasonable equipment maintenance management regulations. The safety assessment for portal cranes focuses on the safety of equipment and personnel. Based on the principle and methodology of safety system engineering, it identifies and analyzes all hazard sources of equipment operation. However, it is a highly specialized process and traditional safety management approaches are defective in terms of efficiency ratio and flexibility. A growing demand for substituting the traditional approaches with the software featuring high efficiency and excellent operability emerges[8, 9]. To meet such a growing demand, the paper has discussed the research and development (R&D) and application of safety assessment software for portal cranes, thus ultimately makes the portal crane management more scientific and effective.

2. Principle of the safety assessment for portal cranes

2.1 AHP of weights

In this process, a complex problem can be expressed into a sequential hierarchical chart and specific calculations are implemented to achieve an effective assessment on the relative importance of various factors that affect the core problems of the whole process, thus working out the assessment value of these problems. It is mainly characterized by quantifying the empirical judgment on decision makers and modeling the decision-making process according to the laws of thought and psychology. In face of complex target factor structures and lack of necessary data, it can be applied more conveniently, thus facilitating scientific management and ensuring a broader application[10].

The AHP-based basic safety assessment method for portal cranes enables to identify the hazard sources and the logical arrangement of these hazard sources. This method better adapts to the characteristics that the logical relation of subordination among different mechanisms, structures and other components of a portal crane are clear and can be easily judged but massive statistical data are absent. This method can effectively eliminate a plurality of risk factors that produce notably varied impacts on a whole crane. Therefore, the application of AHP helps create an appropriate risk assessment model for portal cranes. While using this model, anyone should take into account the weakness that the top-level factors are not so sensitive to the changes of basic factors caused by the excessive number of basic factors.

2.2 Formulation of the assessment index system

According to the basic structure and operation features of portal crane, its safety performance can be divided into four levels[10]. Figure 1 shows the safety assessment structures diagram of portal crane:

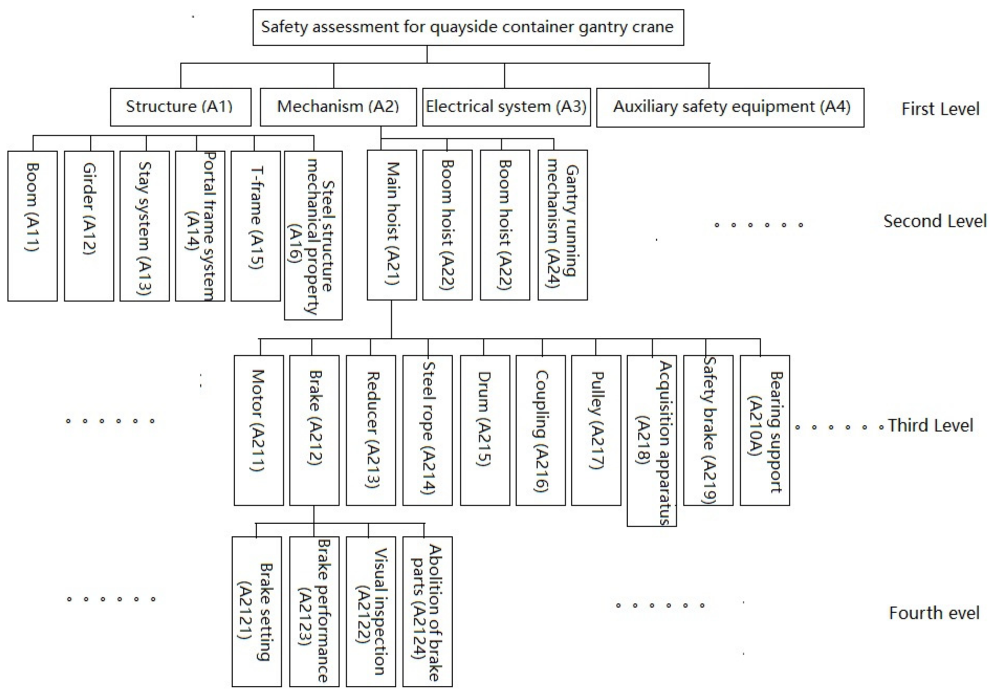

Figure 1 Structure of Safety Assessment forPortal Cranes

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2.3 Determination of assessment index weights

A comparison matrix is established to obtain the maximum eigenvector. After the safety assessment structure model is established, the degree of influence brought by each assessment index on the related assessment indexes of the previous level can be obtained by solving the maximum eigenvector of comparison matrix among the assessment indexes. Relevant professionals can refer to the 1-9 quantitative scales in Table 1 for each value of the comparison matrix, thus expressing the relative importance of safety assessment indexes for portal cranes.

Table 1 Value and Definition of 1-9 Quantitative Scales

Scale	Definition
1	Two factors are equally important after comparison
3	The former factor is more important after the comparison between two factors
5	The former factor is obviously important after the comparison between two factors
7	The former factor is remarkably important after the comparison between two factors
9	The former factor is extremely important after the comparison between two factors
2，4，6，8	The intermediate value in the above comparisons

2.4 Comparison matrix consistency verification

AHP suggests that the consistency of comparison matrix is accepted when the consistency ratio (CR) of each comparison matrix is lower than 0.10. Where, the equation of the maximum characteristic root λ_{max} is obtained as Formula (1):

$$\lambda\max = \sum_{1}^{n} \frac{(A\omega)i}{n\omega i} (i = 1,2 \ldots n) \tag{1}$$

The consistency index (CI) of comparison index is shown in Formula (2):

$$CI = \frac{\lambda\max - n}{n-1} \tag{2}$$

The average random index (RI) of comparison index can be found from RI Order List.

The random consistency ratio (CR) of comparison index is shown in Formula (3):

$$CR = \frac{CI}{RI} \tag{3}$$

2.5 Safety performance assessment value D

After the equipment to be assessed is checked, the inspectors score the assessment indexes according to the result of inspection and normalize the score of each index to obtain the real-time status score corresponding to each assessment index. Then the safety performance assessment value D of the equipment can be calculated according to Formula (4). The real-time safety and risk status of the equipment can be effectively assessed according to the value D.

$$D = \sum_{1}^{n} \omega i * Ii (i = 1,2 \ldots n, 0 \le D \le 1) \tag{4}$$

The value D can be divided into different ranges according to the characteristics of portal crane. The corresponding safety status and necessary measures are listed in Table 2:

Table 2 Different Assessment Value Ranges and Necessary Measures[10]

Range of value D	Safety status	Necessary measure
D >0.8	Level 1	The equipment risk is negligible
0.6≤ D <0.8	Level 2	The equipment is in good condition but should be actively monitored
0.4≤ D <0.6	Level 3	The equipment can work normally but it needs to repair the equipment or replace corresponding parts to ensure the operation safety
0.2≤ D <0.4	Level 4	Stop the equipment for overhaul and start it upon conformity through self-inspection
D <0.2	Level 5	Stop the equipment for overhaul or scrap it

2.6 Determination of the penalty function

The risk assessment model based on AHP for portal cranes is a tree structure. The general target Z, which is less sensitive to the change of assessment index, is defined as the assessment index at the lowest level. According to the level definitions, all the assessment indexes at the four level and the assessment indexes that cannot be further broken down at the third level serve as all the assessment indexes at the lowest level. The penalty criteria can be determined for the risk assessment index system of portal cranes by organizing related experts on a discussion and study. Variable weights are the assessment index at the lowest level. When any index at the lowest level is not acceptable (by getting zero), the penalty function will adjust the weighted value of this index according to the penalty criteria, thus produces a greater impact on the general target Z.

Because there are many indexes that affect the safety risk assessment of portal crane, it is difficult to compile a formula type penalty function. Therefore, the penalty function is compiled in the form of point function to essentially give weight penalty values item by item. The weight penalty value shown by the penalty function is used to start the assessment index penalty function when the corresponding assessment index fails the inspection. When nonconformity occurs during the inspection, the penalty weight will change into the weight of original layer × the corresponding penalty value, and the weight of the related assessment index of the same layer will be recalculated and distributed according to the residual weight. If the sum of penalty weights of several assessment indexes exceeds 1 due to the start of penalty function, the higher-level index directly subordinates to the index will be judged as unqualified.

In weight progressive penalty, the weight penalty value corresponding to some assessment indexes is the identifier of the higher-level indexes that these indexes are subordinate to. According to the penalty rule, the penalty function will be started when the actual measurement of these indexes fails to meet specific criteria. Then the weight of these indexes will be progressive to the weight value corresponding to the penalty identifier. If the original weight of a certain index is $U1\times U11\times U111 = 0.39\times 043\times 0.29 = 0.049$, the penalty function will be started when the actual measurement of this index fails to meet specific criteria. Then the weight will become the weight value 0.39 corresponding to the identifier. The penalty function is used to change the weight value when the actual measurement fails to meet specific criteria, which strengthens the impact of important assessment indexes on the general target Z. According to the repeated discussions by related experts, 197 indexes are finalized as the risk assessment indexes of portal crane, 44 penalty functions are determined, and corresponding rules are formulated, all of which lay a foundation for the further development of the safety assessment software for portal cranes.

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3. Design and development of the safety assessment software

3.1 Software design

According to the above principles, the software consists of two main modules: data acquisition and result processing. Input the index data collected in the field into the software, and then get the assessment results of the indexes at all levels and the whole crane according to the variable weight AHP embedded in the background. The programming language used in this system is C#, which is a secure, stable, simple and elegant object-oriented programming language derived from C and C++. It inherits the powerful functions of C and C++ and removes some of complex features. It combines the simple visual operation of VB with the high operation efficiency of C++, thus serving as the preferred language for .NET development. See Figure 2 for the software architecture.

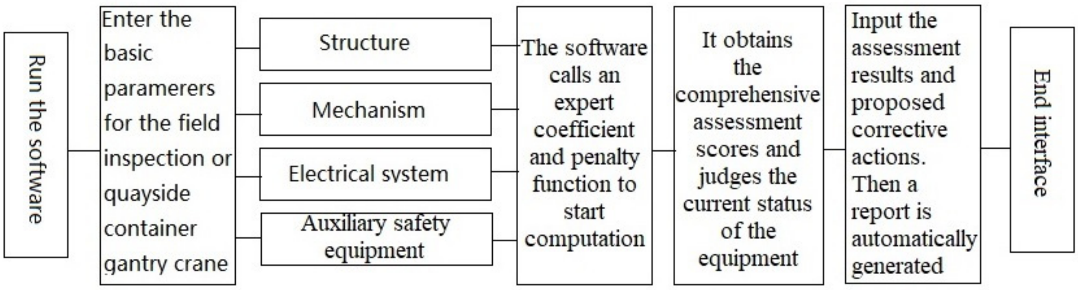

Figure 2 Software Architecture

3.2 Operation cases

In order to verify the universality and reliability of the software, a portal crane with a rated lifting capacity of 30t, a lifting speed of 50/120(m/min), a lifting height of 30m, a working level of A8 and a service life of 15 years is taken as the assessment object.

The operating process of the safety assessment software is shown in Figure 3. Run the software to log in the system, create an assessment project, input the basic information on portal crane and the results of field inspection into the software after confirmation, determine the risks of portal cranes based on the assessment, and propose corresponding corrective actions. After confirmation, generate an assessment report and print it. The software also has the feature that the assessment weight indexes can be modified by setting different authorities, thus providing more custom options on the safety management of enterprise equipment. Relevant enterprises can determine the corresponding index coefficients based on different management requirements.

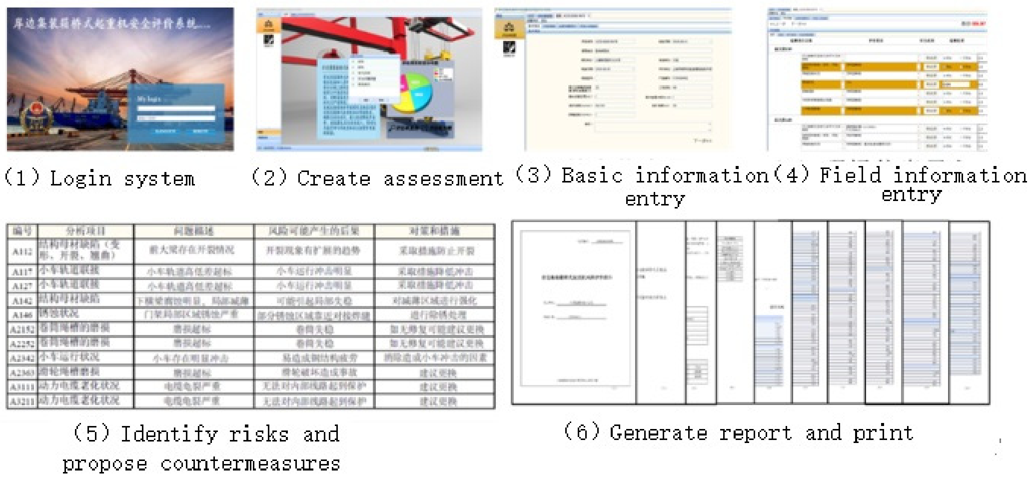

Figure 3 Software Assessment Process

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4. Conclusion

The software is developed by C# programming language, which realizes the information management of safety assessment for portal cranes. The software is capable of not only assessing a whole portal crane but also helping relevant enterprises to implement scientific management and meet the needs of different users. With the development and application of the software, the threshold of portal crane safety risk assessment is will be lowered. Relevant operators can operate the software only after taking simple training. By inputting field inspection information, the risk status of portal crane can be efficiently obtained, thus greatly reducing the accident risk and promoting the science and information level of safety management.

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