A correlative model between maintainability and structure design

Chunhui Guo[1]* , Chuan Lyu[1] , Jin Yan[1],Ranran Wang[1] and Yu Xiao[1]

[1]*School of Reliability and Systems Engineering, Beihang University, State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, Science and Technology on Reliability and Environmental Engineering Laboratory, Beihang University, No.37 Xueyuan Road Haidian District,Beijing, China + guochunhui@buaa.edu.cn, lc@buaa.edu,cn, prejyan@buaa.edu.cn, wrrbuaa@163.com, halomoon@me.com*

* *Corresponding author*

Abstract. As an important quality characteristic, maintainability is the ability of a product to be repaired efficiently and economically. As the structure design largely determines the level of product maintainability, so maintainability factors should be put more consideration in the structure design. The traditional structure design put less attention on maintainability design, resulting in higher product maintenance cost. In order to enhance the relationship degree between maintainability design and structure design to achieve integrated design, this paper presents a correlative model of maintainability and structure design. First, maintainability factors and structure design factors are classified and compared. Second, according to graph theory, the correlative model is established in the form of graph and formula. Finally a case of the lubrication system is used to verify the scientific of this model.

Keywords—correlative, maintainability, structure, graph

1. Introduction

As the level of product design continues to increase, it becomes more and more important to improve user satisfaction with the product. As a design characteristic, maintainability represents that the product can be economically and efficiently repaired and decides mostly whether the product is welcomed by the user . Therefore, maintainability design occupies an increasingly important position in product design.

Most of the current maintenance design stay in product design inspection and verification[1, 2], which can only simply Improve maintainability. According to the maintenance process and experience, it is easy to find that maintainability is closely related to product structure design. In order to fundamentally improve the maintainability of products, it must pay close attention to the maintainability design in structure design. Therefore, how to combined structure design and maintainability design becomes an important issue.

At present there are some related research in this field, Concurrent engineering emphasizing on maintainability design and structure design in parallel is proposed and developed in [3].D Zhou et al have proposed the use of digital prototyping and virtual environment to achieve parallel engineering[4]. H Zhou et al put forward the view that the maintainability model is integrated into the design process [5]. Concurrent engineering emphasizes that the two design patterns parallel and most of the virtual reality technology requires a virtual prototype, little useful for the early structural design.

In order to achieve the combination of structural design and maintenance design, this paper proposes a correlative model between maintainability and structure design. Through the method of this article, maintainability design can be well introduced into the structure design and the problem of disconnection between structure design and maintainability design is fundamentally solved, which lays a good foundation for the improvement of product maintainability.

The model is expressed in two forms of graph and formula, which realizes the combination of number and shape, which is convenient for both theoretical research and application.

The paper is subdivided into 4 sections. The next one gives model construction. First, maintainability factors and structure design factors are classified and compared. Second, according to graph theory, the correlative model is established in the form of graph and formula. Finally a case of the lubrication system is used to verify the scientific of this model.

2. Model construction

The model construction process is divided into three steps, respectively model factors definition, model graphical expression and model formula expression, just as Figure 1 shows

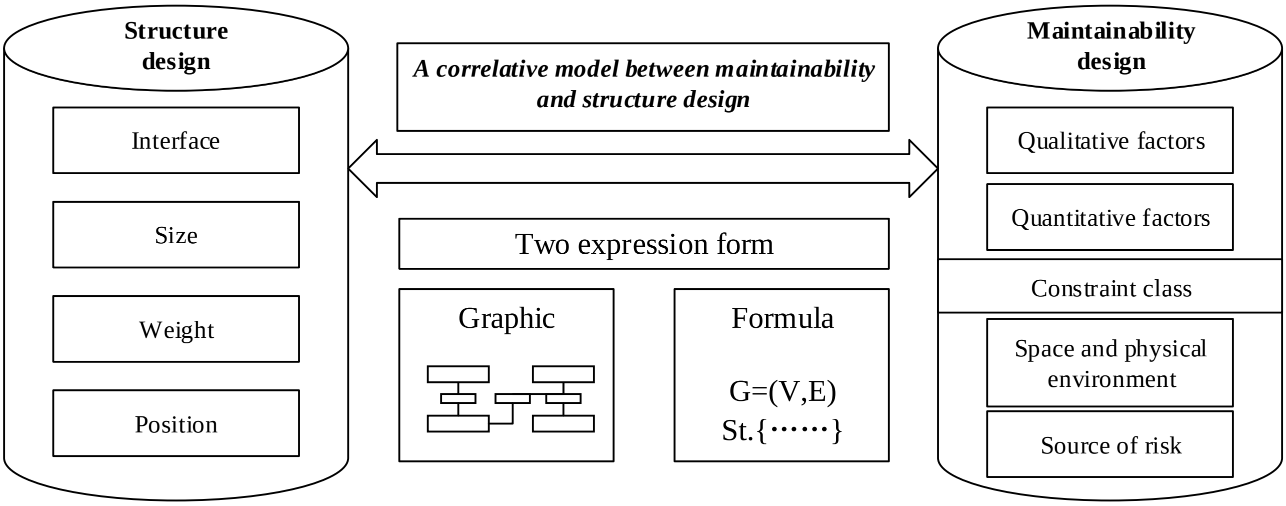

Figure 1. The structure of model construction

2.1 *Model factors definition*

First of all, the model factors need to be defined. In order to achieve the integrated combination of maintainability design and structure design, we have respectively extracted maintainability design factors and structure design factors.

According to the maintenance process and experience, the maintainability factors will be divided into qualitative and quantitative as shown in Figure 2. The qualitative factors are obtained from [6] and the quantitative factors are obtained by classifying the maintenance time.

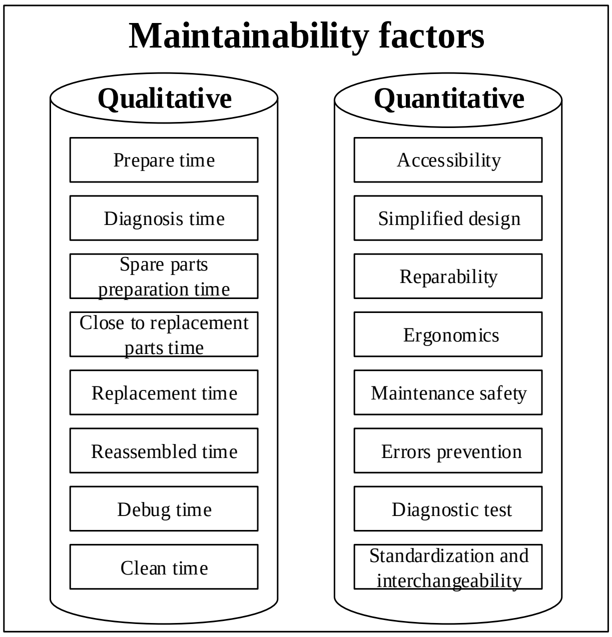

Figure 2. Maintainability factors definition

According to the structure design process, the structure design factors are divided into the following four kinds: interface, size, weight and position.

Due to the constraints in maintainability design and to make the model more realistic, source of risk and space and physical environment are set as model constraints. Source of risk means features of potential harm to personnel and equipment in the unit. Space and physical environment means physical or non-entity environment of the facilities.

2.2 *Model graphical expression*

According to graph theory and model factors, we decided to graphically represent the model. Just as Figure 3. Solid line rectangle represents units. Solid line triangle represents constraint class. Solid line hexagon represents maintainability factors. Solid line circle attached to a rectangle represents structure design factors. Solid line represents influence level. Solid line represents influence level.

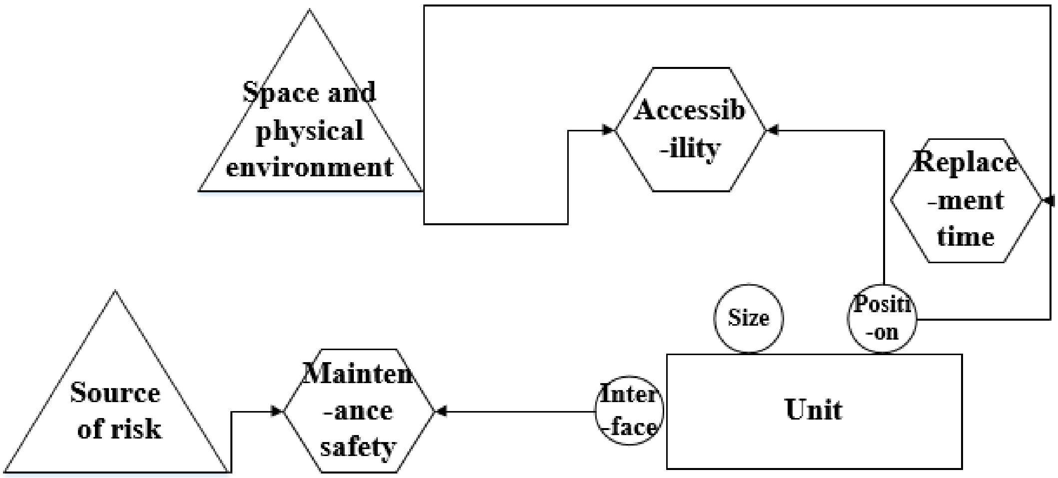

Figure 3. Model graphical expression

2.3 *Model graphical expression*

In order to make the model scientific and standardized, refer to the theory of graph method, the graphic model is transformed into a formula expression.

$$G = (V, v, E, s, W, w) \qquad (1)$$

V : Unit.

v : Structure design factors.

E : Maintainability factors.

s : Constraint class.

W : Influence level between structure design factors and maintainability factors.

$$W = \left\{ \begin{matrix} a_{11} & \mathrm{L} & \mathrm{L} & a_{1n} \\ \mathrm{M} & \mathrm{O} & \mathrm{L} & \mathrm{M} \\ \mathrm{M} & \mathrm{L} & \mathrm{O} & \mathrm{M} \\ a_{n1} & \mathrm{L} & \mathrm{L} & a_{nn} \end{matrix} \right\} 1 \le i, j \le n$$

Where $a_{ij} = \begin{cases} 0 \text{ if there is no relationship} \\ 1 \text{ if there is a relationship} \end{cases}$

w : Influence level between constraint class and maintainability factors.

$$w = \left\{ \begin{matrix} b_{11} & \mathrm{L} & \mathrm{L} & b_{1n} \\ \mathrm{M} & \mathrm{O} & \mathrm{L} & \mathrm{M} \\ \mathrm{M} & \mathrm{L} & \mathrm{O} & \mathrm{M} \\ b_{n1} & \mathrm{L} & \mathrm{L} & b_{nn} \end{matrix} \right\} 1 \le i, j \le n$$

Where $b_{ij} = \begin{cases} 0 \text{ if there is no relationship} \\ 1 \text{ if there is a relationship} \end{cases}$

For presentation of W and w, the matrix form is adopted, just as Table I and Table II show

3. Case study

Figure 4. Oil pump

In order to verify the scientific and accuracy of the model, the case study is carried out based on the partial data of the vehicle lubrication system.

3.1 *Lubrication system description*

The function of the lubrication system is to continuously deliver sufficient amount of clean, moderate temperature oil to all the transmission parts while the engine is working, forming an oil film between them. Its basic components include oil pan, oil pump, oil filter, oil filter, main oil channel, pressure limiting valve, suction pipe and so on. This article focuses on the correlative model construction of oil pump as shown in Figure 4.

- The role of the oil pump: a certain amount of oil from the sump out is sent to the surface of the parts to maintain lubrication in the lubrication system cycle.
- Oil pump installation location: most of the oil pumps are installed in the crankcase, and some diesel engine oil pumps are installed in the crankcase outside.
- Oil pump drive mode: gear drive mode.
- Main maintenance problem: Oil spill, blocked.

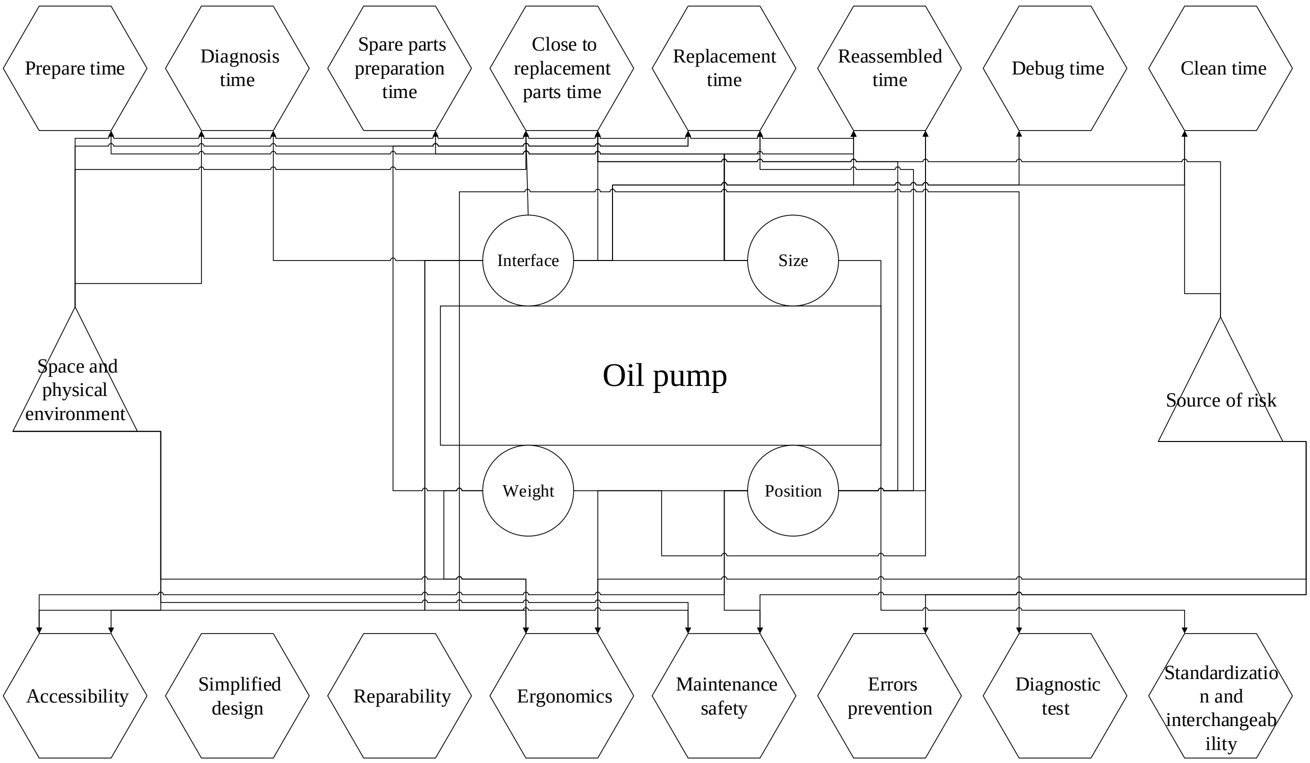

Figure 5. Graphic model express of oil pump

3.2 *Graphic expression of oil pump*

According to the previous section of the analysis of the oil pump, combined with the oil pump maintenance steps and structure design, we can get the model shown in Figure 5.

3.3 *Formula expression of oil pump*

According to the graphical model, the construction formula is as follows

$G = (V, v, E, s, W, w)$

V ={oil pump}

v ={interface,size,weight,position}

E ={maintainability factors}

s = {space and physical environment, source of risk}

W =influence level between structure design factors and maintainability factors, as Table 1 shows.

w =influence level between constraint class and maintainability factors, as Table 2 shows.

Table 1. Influence level between structure design factors and maintainability factors

Influence level	**Interface**	**Size**	**Weight**	**Position**
Prepare time	0	1	0	0
Diagnosis time	1	0	0	0
Spare parts preparation time	0	1	0	0
Close to replacement parts time	1	1	0	0
Replacement time	0	0	1	0
Reassembled time	0	1	1	1
Debug time	1	0	0	0
Clean time	1	0	0	0
Accessibility	0	0	0	1
Simplified design	0	0	0	0
Reparability	0	0	0	0
Ergonomics	1	0	1	1
Maintenance safety	1	0	0	0
Errors prevention	0	0	0	0
Diagnostic test	1	0	0	0
Standardization and interchangeability	0	1	0	0

Table 2. Influence level between constraint class and maintainability factors

Influence level	**Space and physical environment**	**Source of risk**
Prepare time	0	0
Diagnosis time	1	0
Spare parts preparation time	0	0
Close to replacement parts time	0	1
Replacement time	0	0
Reassembled time	1	0
Debug time	0	0
Clean time	0	1

Influence level	Space and physical environment	Source of risk
Accessibility	0	0
Simplified design	0	0
Reparability	0	0
Ergonomics	0	1
Maintenance safety	1	1
Errors prevention	0	0
Diagnostic test	0	0
Standardization and interchangeability	0	0

4. Result and discussion

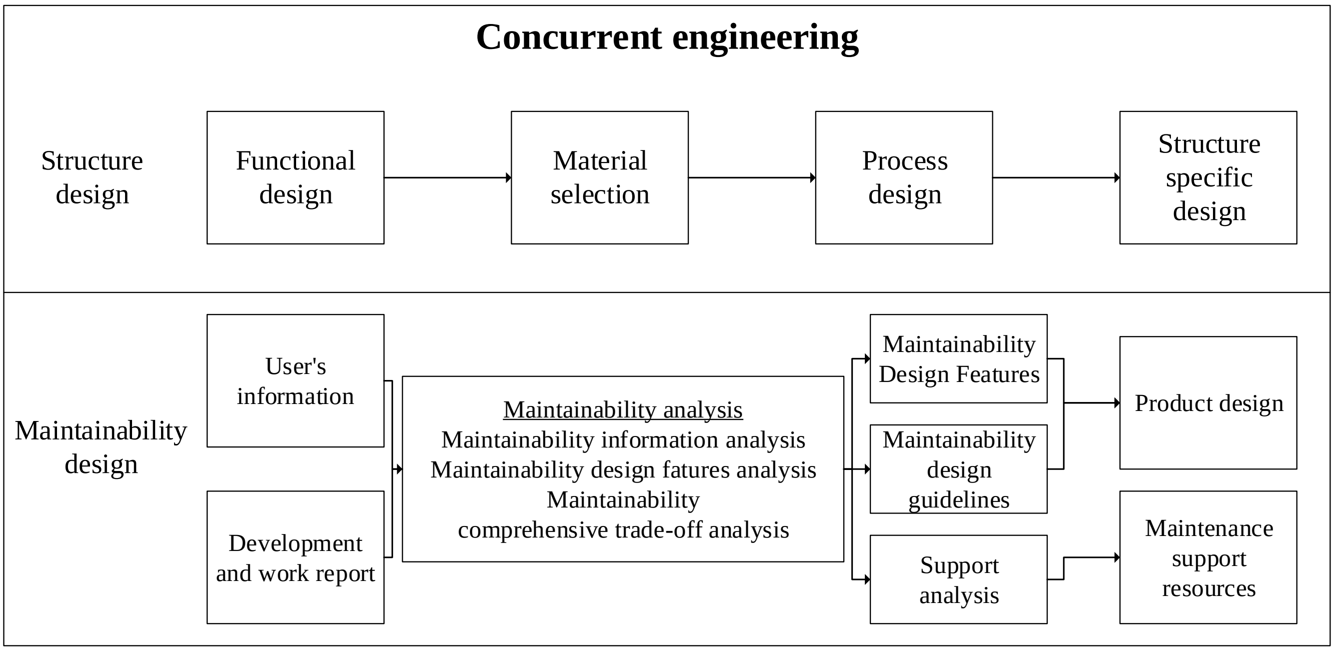

Figure 6. Concurrent engineering

Through the construction of the correlative model between maintainability design and structure design, the integration of the two is achieved.

We can see from the figure and formula model that the structure of oil pump has a big relationship with maintainability factors. Similarly, maintainability factors are subject to environmental constraints.

The model shows that the interface of oil pump have a big relationship with diagnosis time, close to replacement parts time, debug time, clean time, ergonomics and maintenance safety, diagnostic test. The size of oil pump have a big relationship with prepare time, spare parts preparation time, close to replacement parts time, reassembled time and standardization and interchangeability. The weight of oil pump has a big relationship with replacement time, reassembled time and ergonomics. The positon of oil pump have a big relationship with reassembled time, accessibility and ergonomics. Space and physical environment and source of risk have different constraints on maintainability factors. These results can remind designers in the process of structure design to focus on maintainability factors related to structure design factors.

Concurrent engineering can achieve the parallel development of both structure and maintainability design, just as Figure 6. Maintainability and structure design parallel development do play a role in improving work efficiency, but pure parallel do not achieve the integration design. In comparison, the correlative model achieves the integration of the two design pattern, which is more in line with the design of modern products specification. Through the construction of this correlative model, designers can be provided with ideas and methods of integrated design early in the design process.

The model is expressed in two forms of graph and formula, which realizes the combination of number and shape, which is convenient for both theoretical research and application. In particular, the expression of the formula can make the model more concise and easier to construct, which is very important for the future theoretical research.

5. Conclusion

Aiming at the problem that the structure design and maintainability design in product design are not closely related, a correlative model between maintainability and structure design is constructed in this paper. Through the combination of maintainability design and structure design factors, the integrated design is realized, which provides designers with the design method in the early design process, laying the foundation for the improvement of product maintainability design level.

The innovation of this paper has the following two points: (1) Put forward a correlative model between maintainability and structure design to achieve the goal of integrated design. (2) Express the model in two forms: graph and formula.

There could be many extensions to be made to the basic model developed in this paper. For example, model factors can be expanded in more detail. The application of the model still needs further study.

References

[1] A. Coulibaly, R. Houssin, and B. Mutel, "Maintainability and safety indicators at design stage for mechanical products," *Computers in Industry*, vol. 59, pp. 438-449, 2008.

[2] Z. Tjiparuro and G. Thompson, "Review of maintainability design principles and their application to conceptual design," *ARCHIVE Proceedings of the Institution of Mechanical Engineers Part E Journal of Process Mechanical Engineering* 1989-1996 (vols, vol. 218, pp. 103-113, 2004.

[3] J. Stjepandić, N. Wognum, and W. J. C. Verhagen, *Concurrent Engineering in the 21st Century: Springer International Publishing*, 2015.

[4] D. Zhou, M. H. Wang, Z. Q. Guo, and C. Lv, "Maintenance Simulation and Maintainability Design Based on Virtual Reality," *Key Engineering Materials*, vol. 467-469, pp. 457-461, 2011.

[5] H. Zhou, M. Z. Gan, A. Q. Liu, and J. M. Liu, "Maintainability design of product based on concurrent engineering," *Journal of Machine Design*, 2003.

[6] Q. Li, D. Huang, F. Wang, Y. Zheng, J. Li, and D. Yan, "Analysis of the equipment maintainability qualitative evaluation index based on interpretive structure modeling," in International Conference on Fuzzy Systems and Knowledge Discovery, 2016, pp. 649-653.