Analysis of Man-machine-environment System in Industrial Design and Comprehensive Evaluation of Products

Man-machine Relationship

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Abstract: The study of safety, reliability and amenity in industrial design is to analyze the factors in the "man-machine-environment" system by means of ergonomics so as to provide reliable design parameters and test data for product design. According to ergonomics, how about the design of product man-machine relationship? Does safety, reliability and suitability meet the design requirements? This requires a more objective and fair evaluation standard. The evaluation of product man-machine system is not only the judgment of the value of the product designed, but also the judgment of the product design results. Based on the analysis of various factors in the "man-machine-environment" system, this paper presents a comprehensive evaluation method of man-machine relationship of products by using fuzzy theory.

1. Introduction
Industrial design is center on a man design, all services are for people, the core of which is product design. In addition to according the aesthetic principles of product design, but also attaches great importance to the use of products safety, reliability and pleasant, to improve the working environment of users; And ergonomics is a design object based on man in the "man-machine-environment" system, based on the physiological and psychological characteristics of human beings and the aim of improving the quality of human work.

This paper mainly studies the relationship between man and machine, man and environment, machine and environment, and takes human factor as an important condition and principle of system design. It provides a theoretical basis and method for making product design into a "man-machine-environment" system which is easy to operate, labor-saving, safe, reliable, efficient and comfortable.

2. Analysis of Man-machine-environment System
The "man-machine-environment" system is referred to as man-machine system. Man, machine and environment, which constitute the "three factors" of man-machine system, can be regarded as three relatively independent subsystems of man-machine system. Although each of them has its own factor attributes, as a systematic research, it does not mean the sum of the factors attributes of each subsystem, but depends on the organizational structure of the system and the degree of synergy within the system. Therefore, to study the factors in the "man-machine-environment" system, we should not only study the factors in each subsystem of man, machine and environment, but also study the overall structure and attributes of the system in order to make the best use of man, machine and environment so as to make the whole system safe, efficient and comfortable to people and life support function, the ultimate goal is to make the system comprehensive use efficiency highest.

From this we can see that in man-machine system, besides man, machine and environment factors,
there are also comprehensive factors formed from this, that is, the factors in man-machine-environment are composed of man, machine, environment and comprehensive factors.

2.1. Man’s Factors
1) The parameters of human body size mainly include the working posture and the space range of human activities under static and dynamic conditions.
2) Man's mechanical parameters mainly include maneuvering force, speed and frequency, accuracy and endurance limit.
3) The ability of man’s information transmission mainly includes the ability of information acceptance, storage, memory, transmission and output, and the physiological limit ability of various sensory channels.
4) Human reliability and adaptability to work mainly include the ability of psychological adjustment in the process of labor, the mechanism of psychological reflex, and the possibility and cause of human error under normal conditions.

2.2. Machine Factor
1) Information display mainly refers to all kinds of display devices that give feedback information to people after the "machine" receives instructions from people. Such as a variety of displays (screen display, analog display, digital display, etc.), instrument display, sensory information devices (audio information transmission, tactile information transmission, olfactory information transmission, etc.).
2) Operational control mainly refers to the various devices that the "machine" recipient sends out instructions, such as buttons, knobs, handles, control rods, hand wheels, rockers, steering wheels, keyboards, etc.
3) Safety protection mainly refers to the safety protection facilities and devices when the "machine" has errors or human errors, such as overload protection (external force overload protection and electrical overload protection), rescue and escape devices.

2.3. Environmental Factors
Environmental factors include a wide range of contents, whether outdoors or indoors, people are faced with different environmental conditions, they directly or indirectly affect people's work, system operation, and even affect the safety of human life. Generally speaking, the environmental factors that affect people are:
1) The physical environment includes temperature, humidity, lighting, noise, vibration, radiation, air pressure, gravity, magnetic field, etc.
2) The chemical environment mainly refers to toxic gases and vapors, industrial dust and smoke, and water pollution.
3) The psychological environment mainly refers to the aesthetic factors (shape, color, texture, decoration and functional music, etc.) of the machine being used, and the working space (size, height of workshop, layout of the machine, road traffic, etc.).
4) The social environment mainly refers to social status (political, economic), employment status, interpersonal relationship and so on.

2.4. The Comprehensive Factors
The comprehensive factors can’t be simply understood as the sum of man, machine and environment factors, but the comprehensive use efficiency formed by them after the integration of man-machine system, that is, rational division and cooperation of man-machine, man-machine information transmission and exchange. Man and the machine between the continuous transmission and exchange of information, constantly changing the state, constantly realizing people's wishes, so that the system keeps coordinating work.

2.4.1. Rational division and coordination of man and machine
The rational division and cooperation of man and machine should comprehensively consider the characteristics and functions of man and machine, so as to make them develop their advantages and
avoid their disadvantages, and give full play to the comprehensive utilization efficiency of man-machine system.

For a rough comparison of man and machine in nine aspects, such as creativity, information processing, reliability, control ability, work efficiency, sense ability, learning ability, induction, durability, you can refer to literature [2]. All the heavy, fast, fine, regular, monotonous, high-speed operation, complex operation of the work, are suitable for the "machine" to undertake; all the "machine" system design, maintenance, monitoring, fault handling, as well as procedures and instructions for the arrangement, are suitable for people to undertake.

2.4.2. Man-machine information transfer and exchange
Man-machine information transmission and exchange refers to the person issue instructions to "machine" through the executive organs (hands, feet, mouth, body, etc.), and to accept the "machine" feedback information through the sensory organs (eyes, ears, nose, tongue, body, etc.). The intermediary area of man-machine information transfer and exchange is called "man-machine interface" [3]. It includes the man-machine interface of operation control system, information display system and the environment.

In the modern production process, the original data of the production equipment is input into the "machine" as information, which is reflected by the display device on the "machine" and constitutes the man-machine interface of the information display system. The display device feeds back to the human auditory or visual organs through visual or auditory signals and transmits them to the human brain. After analysis and judgment, the human brain makes a decision, to add a control device to the "machine" by his hands or feet and to give the operation action, to form the human-machine interface of the operation control system. Due to operation action, the control signal generated by the control device is then transmitted to the "machine" so that the whole process of production is completed. In the whole production process, human and "machine" are affected by the environment, forming an environment man-machine interface.

3. Comprehensive Evaluation of Man-machine Relationship in Products
Based on the factors of man-machine-environment, the evaluation principle and system of man-machine relationship are put forward, and then the man-machine relationship is evaluated comprehensively.

3.1. Evaluation Principle of Man-machine Relationship
"Safety", "reliability" and "agreeableness" are the principles that should be followed in the evaluation of man-machine relationship of products. They are referred to as "three principles" for short. The "three principles" contain all the factors in the "man-machine-environment" as mentioned above.

3.1.1. Security
Safety includes objective, behavioral, physiological and psychological factors that cause accidents ("machines" and people). Objective factors mainly refer to comprehensive factors and machine factors, such as inappropriate distribution of human and "machine" functions; Design errors such as the use of tools and workplaces (such as inappropriate layout of displays and controllers, alarm devices in hard-to-see locations, etc.); Lack of necessary safety devices and protective measures. Behavioral factors mainly refer to human factors, including training and skills, memory ability, age and experience, life stress and so on. Physiological factors mainly refer to human factors and physiological and biological rhythms of human beings. Psychological factors mainly refer to the character of the person (introverted, extroverted or adventurous).

3.1.2. Reliability
Reliability mainly includes the use function of the machine, the service life of the machine and the working environment conditions of the machine. In addition, the manufacturing, assembly, management, maintenance, repair, transportation, packaging, inventory and so on of the machine are also factors to be considered for reliability.
3.1.3. Agreeableness
Agreeableness includes whether machine is easy to operate; Whether people are easy to fatigue when operating; Whether the design of machine conforms to man physiological characteristics; Whether the shape, color and texture of machine and its decoration meet human psychological requirements; And whether micro-climate (physical factors, such as temperature, humidity, lighting, noise, vibration, radiation, air pressure, etc. and chemical factors, such as toxic gases, industrial dust and smoke as well as water pollution) are suitable for people.

3.2. Evaluation System of Human Machine Relationship
According to the principle of product man-machine relationship evaluation, a good product man-machine relationship must be the combination of "safety", "reliability" and "agreeableness". The man-machine relationship evaluation system is shown in the following Fig.1

![Figure 1. Man-machine relationship evaluation system](image)

Explain: The values in brackets are the weights of a set of factors in the man-machine relationship that have been statistically processed for a CNC machine tool manufactured by a factory.

3.3. Basic Method of Fuzzy Synthetic Evaluation of Man-machine Relationship
Fuzzy evaluation is a method of evaluating things after fuzzy transformation according to the given evaluation system, and comprehensive evaluation is a general evaluation of things affected by multiple factors. The establishment of fuzzy comprehensive evaluation model can be summarized as follows:

1) We are given that a factor sets \( u = \{u_1, u_2, \ldots, u_n\} \);
   A evaluation sets \( v = \{v_1, v_2, \ldots, v_m\} \).

   A factor sets is a common set of various factors that affect the evaluation object, and a evaluation sets is a set of evaluation results that the judge may make on the evaluation object.

2) Establishing evaluation matrix
   A single factor constitutes a fuzzy evaluation vector: \( r = (r_{11}, r_{12}, \ldots, r_{1n}) \), the fuzzy evaluation vector of all single factors is composed of fuzzy evaluation matrix \( R \) [4]:

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \cdots & \cdots & \cdots & \cdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

3) Determining the weight of each factor in evaluation
   The degree of influence of different factors on evaluation objects are different. Therefore, when
evaluating, the importance of each factor is different. In order to make the evaluation more scientific, each factor should be assigned different weights.

$$A = (a_1, a_2, ..., a_n), \left(\sum_{i=1}^{n} a_i = 1, a_i \geq 0\right)$$

4) Carry out the compound operation of fuzzy matrix, get the result of fuzzy comprehensive evaluation, and normalize it.

$$B = A \cdot R = (b_1, b_2, ..., b_m)$$

Here, $$b_j = \bigvee_{i=1}^{n} (a_i \land r_{ij})$$

It is normalized fuzzy comprehensive evaluation index.

The above is a first level fuzzy comprehensive evaluation model. When a complex system is synthetically evaluated, there are many factors involved, and there are different levels among them. If the first-level evaluation can not reach a conclusion, it is necessary to establish a mathematical model of multi-level fuzzy comprehensive evaluation, see reference [5].

3.4. Weight Distribution

The determination of the factors that affect the weight plays an important role in the fuzzy comprehensive evaluation. Whether the weight is reasonable or not will directly affect the result of the evaluation. There are many ways to determine weights. In this paper, fuzzy statistics is used to distribute weights.

In order to assign weights to the comprehensive evaluation weight of man-machine relationship, first of all should organizes the relevant experts, technical personnel and management cadres who engaged in ergonomics for a long time to carefully analysis the designed "machine", to consider the influence degree of various factors for man-machine relationship. Each one is put forward a weight distribution for each factor; and then respectively carries on statistics, and remove excessive dispersed numerical values. Finally, according to a maximum value and a minimum value in the data groups, calculates their class interval and frequency within the group, to determine the factor's membership degree value.

The values in the brackets in the front figure are the weights of a group of factors in the man-machine relationship that have been statistically processed for a CNC machine tool manufactured by a factory. The weight of different products is different. The judgment set of each factor should be given by a considerable number of experts.

3.5. Application of Fuzzy Comprehensive Evaluation Method

Taking a CNC machine tool as an example, fuzzy comprehensive evaluation is made for its man-machine relationship.

The safety evaluation matrix, the reliability evaluation matrix and the agreeableness evaluation matrix are respectively:

$$R_1 = \begin{bmatrix} 0.18 & 0.52 & 0.28 & 0.02 \\ 0.16 & 0.64 & 0.17 & 0.03 \\ 0.24 & 0.69 & 0.07 & 0.00 \\ 0.54 & 0.36 & 0.10 & 0.00 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.35 & 0.30 & 0.25 & 0.10 \\ 0.32 & 0.38 & 0.20 & 0.10 \\ 0.36 & 0.40 & 0.20 & 0.04 \end{bmatrix} \quad R_3 = \begin{bmatrix} 0.45 & 0.35 & 0.10 & 0.10 \\ 0.44 & 0.35 & 0.21 & 0.00 \\ 0.46 & 0.48 & 0.06 & 0.00 \\ 0.30 & 0.35 & 0.30 & 0.05 \\ 0.28 & 0.56 & 0.16 & 0.00 \end{bmatrix}$$

Weight distribution:

$$A = \begin{bmatrix} 0.36, 0.30, 0.14, 0.20 \end{bmatrix} \quad b_j = A_i \cdot R_i = \begin{bmatrix} 0.18, 0.36, 0.28, 0.03 \end{bmatrix}$$

Normalization treatment:

$$b_j = \begin{bmatrix} 0.21, 0.42, 0.33, 0.04 \end{bmatrix}$$
Weight distribution:
\[ A_2 = \{0.56, 0.20, 0.24\} \quad b_2 = A_2 \cdot R_2 = [0.35 \quad 0.30 \quad 0.25 \quad 0.10] \]
Normalization treatment:
\[ b_2 = [0.35 \quad 0.30 \quad 0.25 \quad 0.10] \]

Weight distribution:
\[ A_3 = \{0.30 \quad 0.20 \quad 0.10 \quad 0.24 \quad 0.16\} \quad b_3 = A_3 \cdot R_3 = [0.30 \quad 0.30 \quad 0.16 \quad 0.16] \]
Normalization treatment:
\[ b_3 = [0.33 \quad 0.33 \quad 0.17 \quad 0.17] \]

According to the principle of maximum membership, the evaluation of safety is better; the evaluation of reliability is good; the evaluation of agreeableness is better.
Because the first grade judgement has a clear conclusion, there is no two level judgement.

4. Conclusion
Through the above analysis, we can draw the following conclusions:
1) The overall factors affecting the man-machine relationship of products are human factors, machine factors, environmental factors and comprehensive factors. Specifically, objective factors, behavioral factors, physiological factors, psychological factors, function, service life, working environment conditions, operability, fatigue, satisfying physiological, satisfying psychological and microclimate.
2) The principle of evaluating man-machine relationship is safety, reliability and agreeableness.
3) There are many factors involved in the evaluation of man-machine relationship of products, and most of the factors are fuzzy information, which can be quantitatively evaluated by fuzzy theory.
4) Applying the fuzzy comprehensive evaluation method to evaluate the man-machine relationship of the products can obtain more objective and fair conclusions.
5) The analysis of various factors in "man-machine-environment" and the comprehensive evaluation of man-machine relationship of products provide a more scientific basis for product design.

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6. Reference
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