Research on Product Quality Control Based on Multi-Agent Modeling

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ABSTRACT

This paper explores a new approach to product quality control based on Agent-Based Modeling and Simulation (ABMS). Addressing the limitations of traditional methods in dealing with multi-factor coupling and dynamic changes, this study constructs a multi-agent system model that simulates the impact of factors such as human, machine, material, method, and environment on product quality loss. Utilizing the Netlogo simulation platform, a dynamic analysis is conducted to assess the contribution of each factor to quality loss, offering a fresh perspective on quality control. Additionally, this paper proposes a product structure optimization strategy based on the model, identifying key parameters through sensitivity analysis to provide a scientific basis for performance optimization. This research not only enriches the application of ABMS in the field of quality control but also provides effective tools for quality improvement and structure optimization in actual production, carrying significant theoretical and practical implications.

Keywords: Agent-based modeling and simulation (ABMS), product quality control, netlogo simulation, structure optimization strategy

1. INTRODUCTION

With the continuous progress of science and technology and the rapid development of industry, complex system analysis plays an increasingly important role in many fields, especially in product quality control and structural optimization.[1] The multi-agent modeling and simulation (ABMS) method reveals the internal mechanism of complex systems by simulating the interactions between autonomous agents in the system. This method has been widely applied in supply chain management, ecosystem simulation, and other fields, and has achieved significant results. As a powerful tool, it can deeply reveal the internal mechanism of complex systems by simulating the behaviors and interactions of various agents in the system. In the field of product quality control and structural optimization, multi-agent system modeling can provide a more comprehensive and in-depth analysis perspective, providing scientific evidence for decision makers.

At present, product quality control and structural optimization are facing many challenges, such as multi-factor coupling, dynamic change, etc.[1] Traditional methods are often difficult to effectively deal with these complex problems, resulting in unstable product quality and limited structural optimization effect. Multi-agent system modeling can reflect the complexity of the system, and dynamics in the actual production process, and provide new solutions for product quality control and structure optimization.

2. LITERATURE REVIEW

2.1 Multi-agent system modeling

Multi-agent system modeling is a modeling method based on distributed artificial intelligence. It reveals the operation rules of the complex system by dividing it into multiple autonomous agents (Agents) and simulating the behavior and the interaction of the whole system.2 Multi-agent system modeling is highly flexible and scalable, and can deal with nonlinearity and uncertainty in complex systems.

2.2 Quality control

The main methods of current product quality control include statistical process control (SPC), comprehensive quality management (TQM), etc. These methods improve the product quality to some extent, but still have limitations, such as the

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inability to effectively respond to multi-factor coupling, dynamic changes and other problems. Multi-agent system modeling can be simulating each link and subject behavior in the actual production process, which can more accurately reflect the influencing factors and their interaction mechanism, providing new ideas and methods for product quality control.

2.3 Structure optimization

Structural optimization refers to the process of optimizing the performance indexes of products by changing their structural parameters under certain constraints. Commonly used structure optimization algorithms include genetic algorithms, particle swarm algorithm, etc. However, these algorithms often struggle to consider the interactions and dynamic changes between multiple factors when dealing with complex systems. Multi-agent system modeling can provide a more comprehensive and in-depth analysis perspective and optimization strategy for the structure optimization by simulating the behavior and mutual influence of each subject in the system.

3. MULTI-AGENT SYSTEM MODELING APPROACH

3.1 Modeling framework

This paper uses the multi-agent modeling and simulation method to construct the product quality loss emergence model. First of all, according to the overall quality management theory, the five main factors affecting the formation of quality (human, machine, material, method and ring) are summarized. Then, the Netlogo simulation platform is used to dynamically simulate the degree and trend of these factors on the product quality loss. The quality impact factor analysis is shown in Figure 1

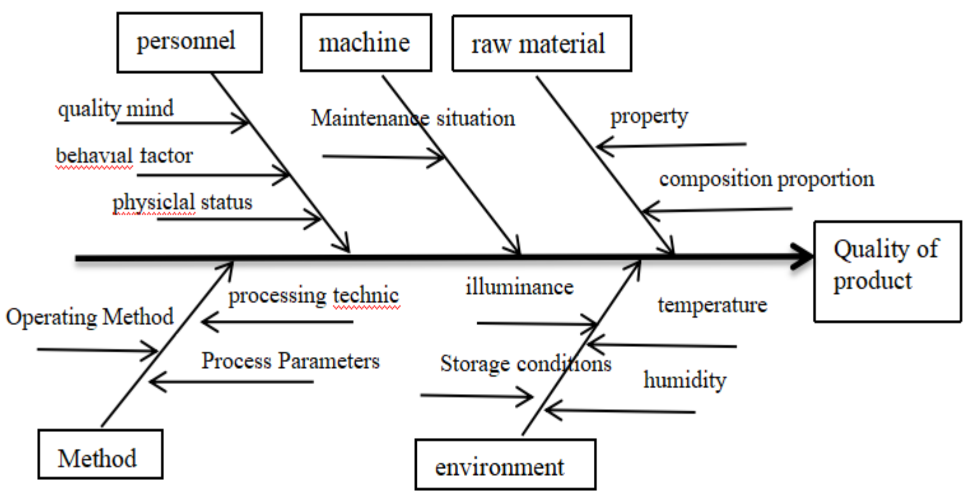

Figure 1. The causality diagram of product quality indicators

3.2. modeling technique

In the modeling process, Agent-Based Modeling (Agent based modeling) and other technologies are used.3 Agent-based modeling builds the system model by simulating the behavior and interaction of each subject; the system dynamics describes the dynamic equation.

4. MODEL BUILDING

4.1 Multi-agent CGP modeling

(1)Equipment subject: the equipment quality level is affected by the equipment operation status and the equipment maintenance level, then

$$F(X_i) = \sum_{i=1\sim 2} \alpha_i X_i + \omega_1 \quad (1)$$

Where X_1 represents the equipment operating health, X_2 represents the equipment maintenance level, α_i is the correlation degree between X_i and $F(X_i)$, and ω_1 is the remaining item.

(2)Method subject: The method treatment level is affected by the processing technology, parameter setting and operating procedures, then

$$F(Y_i) = \sum_{i=1\sim 3} x_i Y_i + \omega_2 \quad (2)$$

Where Y_1 is the processing process, Y_2 is the parameter setting, Y_3 is the operation process, and the method quality level is $F(Y_i)$, where x_i is the correlation degree between Y_i and $F(Y_i)$, and ω_2 is the remaining item.

(3) Raw material main body：Raw material quality level hand raw materials composition, packaging material composition and product type characteristics, then

$$F(S_i) = \sum_{i=1\sim 3} \gamma_i s_i + \omega_3 \quad (3)$$

Where S_1 raw material ingredient, S_2 packaging material composition, S_3 product class characteristics, γ_1 is the correlation degree between S_i and $F(S_i)$, and ω_3 is the remaining item.

(4)Personnel subject：The quality level of personnel is affected by quality awareness, behavioral factors and physical condition, then

$$F(W_i) = \sum_{i=1\sim 3} \beta_i w_i + \omega_4 \quad (4)$$

Where W_1 is the quality awareness, W_2 is the behavioral factor, W_3 is the physical condition, β_i is the correlation degree of $F(W_i)$, and ω_4 is the remaining term.

(5)Environmental subject：The environmental quality level is affected by the temperature, humidity, lighting degree and storage conditions, then

$$F(D_i) = \sum_{i=1\sim 4} \delta_i D_i + \omega_5 \quad (5)$$

Where D_1 is the temperature, D_2 is the humidity, D_3 is the illumination degree, D_4 is the storage condition, δ_i is the correlation degree of $F(D_i)$, and ω_5 is the remaining term.

4.2. Product quality loss

Quality loss is interpreted in quality cost management as the sum of all the losses caused to producers, consumers and even the society in the whole product life cycle, involving various interests.5 Further analysis shows that the occurrence of product quality loss can be attributed to multiple aspects, including equipment, methods, raw materials, personnel, and environmental quality level impact.then

$$P = dF(X_i) + fF(Y_i) + gF(S_i) + hF(W_i) + jF(D_i) + p \quad (6)$$

In the formula，The “dfghj ” is the correlation coefficient between product quality loss and equipment, method, personnel, principle and environmental quality level respectively; p is the remaining item.

5. STRUCTURAL OPTIMIZATION MODEL

5.1 Model optimization

Based on the constructed multi-agent system model, further refine the internal structure and interaction mechanism of each agent. In particular, for key structural parameters that affect performance, clarify their representation and action paths in the model.5

Parameter sensitivity analysis: Through preliminary simulation, identify several key structural parameters that have the greatest impact on performance. Conduct sensitivity analysis on these parameters to understand their impact and trend on performance indicators within different ranges of values.

(2) Optimization target setting: According to the results of sensitivity analysis, the optimization target is clarified. That is, the performance indicators that need to be maximized or minimized are determined, as well as the quantitative relationship between these indicators and key structural parameters.

(3) Optimization model construction: Based on the optimization objectives and key structural parameters, construct a specific optimization model. The model should be able to describe the behavior of the system under different combinations of structural parameters and predict the corresponding performance metrics.

5.2 Simulation was run and the data collection

To evaluate the impact of the structural parameters on the system performance, we performed a rigorous simulation analysis. First, the simulation parameters are set according to the optimization requirements, including the value of structural parameters, simulation time, etc. Subsequently, the simulation tools are used to record the system status and performance indicators in real time. After data collection, conduct strict verification to ensure the accuracy of the data. Finally, the relationship between parameters and performance is revealed through data analysis and makes optimization suggestions.

6. CONCLUSION AND FUTURE PROSPECTS

6.1 Conclusion

(1) Through the analysis of the process of product quality formation, the fishbone map is summarized the five factors affecting the quality formation of human, machine, material, method, ring and ring from the perspective of comprehensive quality management. Through questionnaire survey, data processing and analysis, the index system of factors affecting product quality loss is established.

(2) Based on the multi-agent modeling and simulation (ABMS) method, and the product quality loss emergence model is constructed according to the index system of influencing factors of product quality loss.4 Using Netlogo simulation platform, we dynamically simulate the influence of uncertain factors of human, machine, material, method, ring and five aspects on the emergence degree and trend of product quality loss, and obtain the functional interaction rules between uncertain factors by analysis.

6.2 Future Prospects

(1) Integration of advanced technologies: In the future, the integration of multi-agent modeling and simulation methods with big data and AI technology should be deepened, model parameters should be optimized through data mining, prediction accuracy and robustness should be improved, and AI technology should be used to realize model automation and intelligence, so as to promote the application of methods in complex systems.

(2) Strengthen interdisciplinary cooperation and practical application: promote cooperation in computer science, systems engineering, management and other fields, solve research problems and deepen theoretical research. At the same time, we cooperate with enterprises and industries to apply the research results to the actual production, verify their effectiveness, improve the social value and economic benefits, and provide practical support for the analysis and optimization of complex systems.

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REFERENCES

[1] Zhang, M., Zhao, J, P. and Sun, Y, L., “Quality control and Structure optimization of digital resources in university libraries,” Journal of Xi'an University of Arts and Sciences: Natural Science Edition, 11 (4): 120-122 (2008).

[2] Wang, Y, X., “Research on product quality control based on multi-agent modeling and quantifier constraint satisfaction,” Southwest University of Science and Technology, 1-2, (2019).

[3] Helbing, D., Social Self-Organization: Agent-Based Simulations and Experiments to Study Emergent Social Behavior. Berlin, Heidelberg: Springer Berlin Heidelberg, 25-70 (2012).

[4] Liu, Y, J., "Public opinion modeling and simulation research based on multiple subjects," Journal of the University of Shanghai for Science and Technology, 33 (4), 331-336 (2011).

[5] Cheng, G, P., and Yuan, F, L., Quality Management (2nd edition), Wuhan University of Technology Press, Wuhan, (10-20) 2011.