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A quantitative model of universalization, serialization and modularization on equipment systems

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HIGHLIGHTS

- A heterogeneous information network with multi-layer, multi-dimension and multi-scale is proposed to describe the equipment system.
- Quantitative definitions of universalization, serialization and modularization indices based on heterogeneous information network are given in this paper.
- The defined metrics in the paper can reveal the objective standardization of equipment.

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ABSTRACT

Universalization, serialization and modularization are the three most important metrics in standardization of manufacturing. Developing with innovation of modern large-scale industrial production, a variety of methods were proposed to help enterprises to improve products' applicability, prevent trade barriers, and promote technical cooperation. Meanwhile, some metrics were designed to evaluate or optimize these standardized procedures. However, no systematically quantitative model has been proposed to evaluate the standardization of equipment so far. In order to break the barrier, a quantitative analysis based evaluation model of equipment system is proposed in this paper, in which, universalization, serialization and modularization indices are defined based on heterogeneous information network. Comparing the results performed by the proposed model with experts' evaluation, the metrics in proposed model can reveal the objective standardization of equipments.

1. Introduction

Standardization is the process of restraining repetitive things to a certain standard in social practice such as economy, technology, science and management. That makes it widely applied in many fields. Works like multiple reuse products, quotas, planning, requirements, methods, concepts, etc., can be regarded as standardized object. Standardization provides prerequisites for the rational development of product variety and the organization of specialized production, supports the improvement of product quality and efficient using of resources. Therefore, standardization came to be a significant research issue [1–3], especially in manufacturing fields [4–7].

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Universalization, serialization and modularization are the three most important metrics in standardization of manufacturing fields [8], such as aeronautics [9], motor [10] and electronics [11] for the industrial revolution, on account of their main contribution in product design shorten, grant saving, productivity improvement, product structure optimization, and so on. Universalization measures the interchangeability of components. Serialization aims at estimating the optimization of products' architecture. Modularization is designed to measure the ability of splitting and restructuring of equipments.

Interchangeable parts proposal was firstly presented by Whitney. Eli. That is the beginning of product universalization. According to the maximum physical and functional relations among components and maximizing the similarity of specifically modular driving forces, universalization makes components in product have great interchangeability [12]. Hence, many researchers [13,14] began to focus on standardization work to simplify the product design, to reduce the work preparation, and to improve the production organization. However, most of them focus on principles which are used to produce universalized products rather than metrics which are used to estimate the degree of universalization. Only few simple proportion based formulae were proposed [15].

Serialization is an advanced form of standardization that is on the basis of developed standardized production. Aiming at optimizing the product structure and productivity, serialization makes products and components versatile to meet business requirements and save costs [16]. Up to now, many significant researches [17–21] have been achieved in serialization process. Platform methods [22] were proposed to develop product families. And mathematical [23] and grouping [24] approaches were introduced as well. However, these methods payed attention to production process as well as research on universalization, while few methods were mentioned to estimate the degree of serialization quantitatively. Indeed, the cost calculation [25] was the most common one.

Unlike universalization and serialization, not only production methods but also estimating metrics of modularization have been widely discussed in references. For example, grouping methods [26–29], mathematical programming [30,31], genetic algorithms [12], heuristics [32,33] are traditional production methods and they have made significant contributions. However, manual labor on labeling universal parts is the essential work in estimating processes in which metrics are based on the statistics of the labels (series labels and universal parts labels) [34–36].

Although increasing number of commercial institutions have standardized their architecture of products and implementation based on quantitative metrics since the 1960s [15,37], there is no systematical evaluation model. As we know, heterogeneous information network is a kind of complex system, in which different types of entities are bound together to describe the associations between entities and the structure of system [38]. Because one type of entities can be constructed in one layer, one entity can associate with not only same type of entities but also different type of entities, and some type of small entities are part of other type of entities, heterogeneous information networks have multi-layer, multi-dimension, and multi-scale structure. As powerful as other complex network models [39–42], these characters enabled heterogeneous information network to describe the association between elements in equipment system clearly, since there are several types of entities (i.e. equipment modules, components, unit, etc.) and multiple relationships (i.e. citation relationships, inclusion relationships, and constraint relationships, etc.) in equipment system. Therefore, we propose a quantitative standardization evaluation model based on heterogeneous information network. In this model, universalization, serialization and modularization metrics are considered to measure the architecture of equipments. Benefiting from the consideration of network features of equipment system, the indices calculated by our model are in line with the logic in the real world. These indices can accurately reflect the degree of standardization of the equipment as shown in experiments.

2. Model and method

2.1. Framework

First of all, we use heterogeneous information network to describe the equipment system. Six topic layers are introduced to separate different types of elements in equipment system. The formal expression of topic layers is described as $T = \{T^{(t)}|t = 1, 2, 3, 4, 5, 6\}$ that contains six ordered layers: Equipment Class (EC) such as MT car, AT car, bus and truck; Equipment (EQ); Module (M) such as steering system, hauling system and protection system; Component (C) such as engine and brake; Unit (U) such as oil pump pack and transfer group; and Parts (P) such as screw and gear. The heterogeneous information network of equipment system used to support evaluation model is illustrated in Fig. 1. In which, the same type of elements stay in the same layer, and the directed edges from elements in layer $T^{(t)}$ to that in layer $T^{(t+1)}$ represent inclusion relationships.

For any adjacent layers , $T^{(t)}$ and $T^{(t+1)}$, the edges which represent the inclusion relationships between these two layers always from the entity in higher layer $T^{(t)}$ to that in lower one. So, every couple of neighboring two layers in the hierarchical network constructs a bipartite graph. Hence, the relationships between $T^{(t)}$ and $T^{(t+1)}$ can be described by an adjacent matrix, noted as $\mathbf{A}_{t\to t+1}$, where $T^{(t)}$ has n_t entities and $T^{(t+1)}$ has n_{t+1} entities.

Based on this network, three quantitative metrics, i.e., universalization, serialization, modularization, are designed to evaluate the standardization of equipment systems accurately.