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A hybrid cost estimation framework based on feature-oriented data mining approach ☆

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ABSTRACT

This paper presents an informatics framework to apply feature-based engineering concept for cost estimation supported with data mining algorithms. The purpose of this research work is to provide a practical procedure for more accurate cost estimation by using the commonly available manufacturing process data associated with ERP systems. The proposed method combines linear regression and data-mining techniques, leverages the unique strengths of the both, and creates a mechanism to discover cost features. The final estimation function takes the user's confidence level over each member technique into consideration such that the application of the method can phase in gradually in reality by building up the data mining capability. A case study demonstrates the proposed framework and compares the results from empirical cost prediction and data mining. The case study results indicate that the combined method is flexible and promising for determining the costs of the example welding features. With the result comparison between the empirical prediction and five different data mining algorithms, the ANN algorithm shows to be the most accurate for welding operations.

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1. Introduction

Due to increasing manufacturing product complexity, variations, as well as dynamic supply chain management, manufacturing companies need to coordinate their order acceptance process dynamically; hence, they must estimate costs based on timely information resources among their business partners. The customer inquiry management has to be done accurately and quickly to provide effective feedback.

Currently, different computer-aided systems are used for collaborative manufacture and aimed to increase efficiency and flexibility of information flows while also keeping sensitive collaboration loops with the different business partners. Enterprise Resource Planning (ERP) is the most important information management technology that supports order-fulfillment and is capable of creating the links between product documents, schedules, and other forms of communication. Different ERP software tools are used to share information among different partners for daily manufacturing activities, through which many of the process functions are available to support collaborative manufacturing, such as

customer order product configuration, process planning, financial decision making, accounting, and supply chain coordination; ideally, all of which are unified and managed from a single system [1]. However, ERP packages do not have the sufficient functions for market-oriented cost estimation processing with dynamic production scenarios, even though such functions play a main role in business success [2]. Cost estimation (CE) is one of the key factors that create integration between internal production management system and market-oriented dynamic informatics functions.

Manufacturing costs, in many companies, are not accounted for systematically and accurately due to the complexity and the constant changes of the processes involved in production and the lack of data collection schemes. The process model in an ERP package contains certain details of manufacturing processes, such as the types and setups of machining features, cutting conditions, expected productivity, past costs, and status of job completion. Most ERP systems can estimate process costs based on the required time for the machining process (i.e., labor cost), materials, and power consumption. However, preparing the complete information for a specific manufacturing process is difficult. Developing a generic and comprehensive data model for manufacturing processes in ERP has been a major issue that is being studied to achieve the expected production performance [2]. One limitation of most ERP systems is that the actual variations of processes, such

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as the different welding jobs, are not well defined and documented. Such technical challenges are particularly true in companies with small batches and high variations of product models, which cause overwhelming difficulties in accurate cost estimation. Even with a complete set of process definitions, using the historical data from similar operations requires an expert judgment to determine the factors that correlate to the respective costs.

Traditionally, the cost of a product is calculated based on the cost of product development, time spent on manufacturing processes and equipment used, and the energy and materials consumed. In turn, these factors are influenced by the parts' geometrical relations, accuracy of dimensions, as well as material and surface characteristics. On the other hand, the modern cost paradigm focus on customer inputs, product similarities among configurations, and flexible markups [3]. There has been a considerable amount of research available on cost estimation for manufactured goods, specifically about the manufacturing processes, such as turning and milling cost estimation. However, many process costs have not been consistently defined yet, such as the cost of welding operations in variation workshops. Empirical methods are commonly used for manufacturing cost estimation. Such methods are difficult to adapt to different jobs and estimation can only be given by experienced personnel [2].

2. ERP solutions

ERP systems have certain financial functions for cost management. A typical ERP system records and tracks product and process related data, such as raw material, set-up time, run time, number of machines and labor time for cost calculation. A disadvantage of this data tracking method is that many detailed features and parameters are not fully considered in cost calculations; therefore, the accuracy of the cost results is questionable. In addition, many cost items can only be calculated when all of the parameters are in place. This constraint requires a lot of time to obtain the necessary data and even makes timely cost estimation too expensive to be realistically implemented.

To solve such problems, ERP vendors are developing more accurate costing functions. For example, EPICOR™ [4] is working on the development of cost forecasting and planning in addition to the calculation of manufacturing costs; the budget process is defined based on the manufacturing process plan in multiple cost-calculation scenarios. Then, the financial planner uses different methods, such as examining history and trends and making a depreciation analysis, to do the forecasting [4].

In an ERP system like EPICOR™, the cost estimation module still uses the traditional method for quotation generation and final cost determination for a company's manufacturing products and processes. An ERP system conducts cost calculation based on four categories: labor, material, overhead, and service, which can provide the general information necessary to determine cost. To have a more accurate cost estimation and calculations, customization of the software tool is required because more attributes need to be extracted. As an example, Figs. 1 and 2 show the cost attributes of a specific part in EPICOR™ and Visual Info™ [34] from a company which has gone through a transition of ERP package change from one to another.

3. Literature review on cost estimation methods

Although product cost estimation has important roles in company decision-making, it usually remains as a key issue in the manufacturing industry. The time required to collect data and the available information limitations impose essential constraints in choosing the most suitable cost estimation method.

Many cost estimation techniques can be initially categorized into qualitative and quantitative methods [5]. Qualitative cost estimation uses a heuristic method in the case of difficulty in finding the accurate cost based on parametric product data [6]. Usually, this technique requires historical cost data and cost engineering experts to identify the similarity of products. The most common qualitative techniques for product cost estimation are implementations of a case-based methodology, a decision support system, and analogical cost estimation.

The quantitative cost estimation approach is typically focused on analytical cost calculation functions and the exact parameters summarized from the records of business transactions for costing purpose [5]. Analytical cost estimation can be very detailed and accurate for complex products. This method, basically, decomposes product manufacturing processes into cost factors based on their operation methods, features, surface quality requirement, key process dimension and geometrical tolerances, and supporting activities. In order to manage the tedious cost elements more efficiently and yet to keep the accuracy of cost estimation, the correlated cost patterns can be identified and categorized with product configuration variations and predefined procedures. In other words, analytical analysis can be extended to a feature-based approach.

In this paper, a feature-based cost estimation approach is proposed as the cost estimation mechanism to identify cost-related patterns that are associated with certain functions and manufacturing processes [5]. The following review sections are focused on the research works related to this approach.

The first research about feature recognition goes back to Lyc Kyprianou's PhD thesis (Shape Classification in Computer-Aided-Design) at University of Cambridge in 1980 [35]. By the end of the 1980s, Shah and Rogers [7] introduced the feature-based modeling system and its requirements conceptually because feature concept mapped very well with engineering semantics with software engineering object-oriented approach. Features have been widely used by the process planning community since that time. One year later, Emmerik and Jansen [8] introduced a set of graphical user interfaces for feature-based modeling. The feature-based engineering informatics approach has gained more and more penetration into computer-aided software tools, such as those in CAD and CAM domains. However, the feature concept had not been used for determining cost purpose until Wierda [9,10], who was one of the first researchers, used the concept of the feature in qualitative and quantitative cost estimation. In 1990, he introduced a new tool that supported users to effectively control costs. He defined the "life cycle cost" by three phases in the model; including conceptual design, materialization, and detailed design. He also defined two types of cost information: design rules and manufacturability information. Design rules refer to the historical design information used to describe a framework for a current design. Manufacturability information refers to the current design information and geometry information of a product; this information is used to extract the product cost data. In his cost model, the target cost was considered in each phase. As a result, the design was based on cost, and the cost was based on information generated from the feature reorganization program [9]. In 1991, Wierda expanded "life cycle cost" to include feature-based cost modeling to fill the gap between the design and the process plan. In addition, he described the advantages of calculating the costs per feature [10].

By the end of the 1990s, more techniques were introduced for using the feature-based cost estimation. Zhang et al. [11] launched the feature-based cost estimation by using back-propagation neural networks, especially for packaging products. They introduced the definition and quantification of the cost-related features, and then used the back-propagation neural networks to figure out the relationship between the cost-related features of product