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Research and Analysis of Opportunities in Product Development Cost Estimation Through Expert Systems

Rafael VOLTOLINI[a,1], Kaio VASCONCELOS[a], Milton BORSATO[a] and Margherita PERUZZINI[b]

[a] *Programa de Pós-Graduação em Engenharia Mecânica e de Materiais (PPGEM) – Universidade Tecnológica Federal do Paraná (UTFPR)*
Rua Dep. Heitor Alencar Furtado, 5000 – 81280-340 – Curitiba – PR – Brasil

[b] *Dipartimento di Ingegneria "Enzo Ferrari" (DIEF) – Università degli Studi di Modena e Reggio Emilia (UNIMORE)*
Via Vivarelli 10, 41125 Modena - Italy

Abstract. The early stages of product development are characterized by uncertainties and assumption of parameters that directly affect the product and project costs, the development time, and the quality of the manufacturing process. Designers must deal with challenges that arise unexpectedly in an agile and responsive manner. Expert information systems based on ontological models are a promising approach to capture knowledge and rationale of domain specialists, either for decision making or knowledge reuse. The present study presents a bibliometric analysis on the use of ontologies in product development for cost estimation. It identifies trends and research opportunities that can orient future works. From a general search in scientific databases that originally listed thousands of entries, 31 articles were found and selected based on criteria established using the Proknow-C method. The outcome of the present study can help researchers in the search of relevant research gaps to guide future scientific investigations in the area of knowledge-based cost estimation for product development. Results indicate that there are several possibilities for solutions using ontological and hybrid, transdisciplinary approaches. In the search for solutions that support the product cost estimation in the early stages of development, the use of intelligent systems is not only promising, but is also challenging as a new and real transdisciplinary research area of interest.

Keywords. Proknow-C, Product development, Ontology, Cost, Review

Introduction

The early stages of product development are full with uncertainties and complex parameters, as they directly affect the estimation of product and project costs, such as development time and manufacturing process [1]. Experts in different areas, with or without industry and market experience, must deal with the challenges that arise unexpectedly in an agile and responsive manner. For the development of new products,

[1] Corresponding Author, Mail: voltolini@alunos.utfpr.edu.br

in the initial stages of the design process, the uncertainties and the lack of knowledge on the subject may reveal serious risks for the future project execution [2]. Collecting tacit knowledge, storing and applying solutions intelligently is a way to avoid forgetting information for future projects [3]. Knowledge management is described by knowledge-based engineering (KBE) as a way to manage implicit knowledge and make it explicit for reuse and search for solutions [4]. Expert systems are approaches that simulate the knowledge of a specialist in a certain area of knowledge. In this context, ontological approaches are characterized as a way of capturing knowledge, storing and generating solutions or reusing knowledge later [5]. It is a way of making the process flexible and responsive to the demands of the market and customer requirements [6]. With the evolution of the use, the instrument tends to increase the interoperability, making the instrument continuously refined and increased with the knowledge, increasing its applicability power [7].

The concept of Industry 4.0 arises from the process of linking the semantic web with intelligent solutions such as artificial intelligence, fuzzy front end, ontology and other forms of knowledge management [8]. Being spread rapidly by connecting technology autonomously and making the process intelligent, collaborative and agile [9]. Thus, this study presents a literature review based on an ontological approach in product development with emphasis on costs. In order to identify which proposals are being developed in the last years and which solutions are proposed, as well as to identify gaps pointed out by the authors of the theoretical references. The ProKnow-C process (Knowledge Development Process - Constructivist) [10] was used as an intervention tool in a structured way to achieve the main objective.

This research is relevant to build a solid knowledge about the topic of research, and an explicit information on articles relevant to the scientific community to identify characteristics of these publications. The paper is organized into five sections. The first section consists of the introduction; in the second section, the methodology ProKnow-C is presented; in the third section, the methodological aspects of the research are described; the fourth section analyses the main findings; finally the fifth section contains the paper conclusions.

1. Methodological Aspects

This research is classified as exploratory and descriptive [11]. According to Yilmaz 2013 [12], it can be classified as a qualitative and quantitative research, since it systemically distinguishes data in the systemic analysis and, at the qualitative stage, reflects about the understanding of the bibliographic content. In addition, it is characterized by generating the opportunity to apply knowledge and bibliographic to join fragments of scientific publications [13].

The tool used on this research is Proknow-C [10], which acts on knowledge capture in a structured way from the scientific literature as demonstred in Figure 1. The process consists of four steps: i) selection of a portfolio of articles on the research theme; ii) bibliometric analysis of the portfolio; iii) systemic analysis and; iv) definition of the research question and research objective.

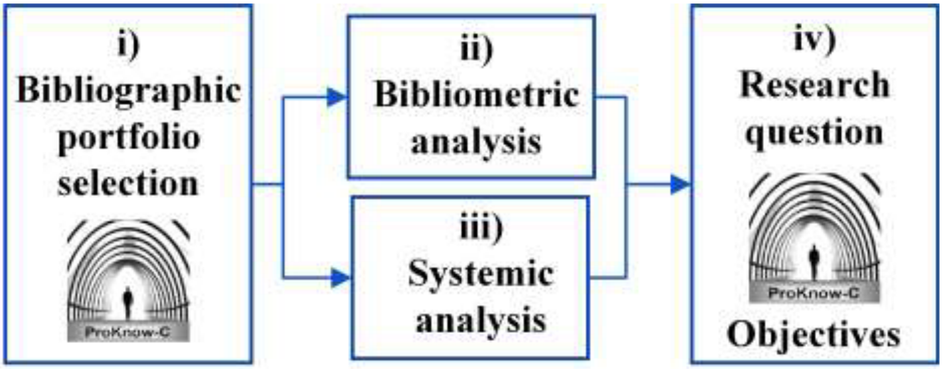

Figure 1. Steps of the systemic review process.

The softwares Mendeley 1.17.11 and Microsoft Excel 2016 were used to manage the collected references. Mendeley support storing references and Microsoft Excel was used for managing the article bank.

2. Bibliographic portfolio selection

The first stage of the research consists of the selection of the bibliographic portfolio (BP) that has scientific recognition, aligned with the theme and available for reading in full. The article selection of the raw article bank followed the definition of research axes. The main topics of the research are cost estimation and product development. Three axes were defined:

1. The cost management axis, that supports the general article overview;
2. the product development axis, that includes all phases to define and design a certain product;
3. and the knowledge management axis, that describes how to systematically work with the human knowledge and the company expertise in an intelligently way.

In the sequence, each search axis gives rise to keywords. For the cost management axis, the selected keywords are: design to cost (DTC), design for cost (DFC), cost engineering, cost modeling, and cost estimation. For the product development axis, the selected keywords are: product development, new product development, collaborative product development, and fuzzy front end. For the third axis related to knowledge management, the selected keywords are: ontology (ies), expert system, intelligent system, artificial intelligence (AI), collaborative knowledge, and protégé.

The databases used for the research are available in the Portal de Periódicos da CAPES in the areas of engineering and computation. In particular, EBSCO, Emerald, IEEE, Science Direct, Scopus, Springer, Village Engineering, Web of Science and Wiley were selected for this study. The search process used the followed terms are: ("design to cost" OR "DTC" OR "design for cost" OR "DFC" OR "cost engineering" OR "cost modeling" OR "cost estimation") AND ("ontolog*" OR "expert system" OR "intelligent system" OR "artificial intelligence" OR "AI" OR "collaborative knowledge" OR "protégé").

The research was carried out in October 2017, and was restricted to articles published on journals in the five previous years (from 2012 to 2017). The searches resulted in a total of 1659 articles. The redundant ones were found and excluded, remaining 1559. With the reading of the titles, there were 183 aligned with the theme of the research. After verifying the alignment with the theme, 47 were selected and the authors were identified. The full text reading started with 54 articles. Of these, 31 were considered aligned and completed the process of filtering.

3. Bibliometric analysis

The 31 published articles selected from the BP were found on different international journals, but the most frequent were the "Knowledge-Based Systems" journal and the "Computers in Industry" journal namely, with three publications each. The most cited journal in the references of the BP was the "International Journal of Production Research", that stands out with 32 publications. Following, the research highlighted the "Expert Systems with Applications" journal (30 citations), the "International Journal of Production Economics" (30 citations), the "International Journal of Advanced Manufacturing Technology" (29 citations), "Advanced Engineering Informatics" (23 citations), and "Computers in Industry" (22 citations).

Figure 2 represents the relevance of journals to the research topic. They follow a line of study with cutting-edge technology and great complexity still in the Academy.

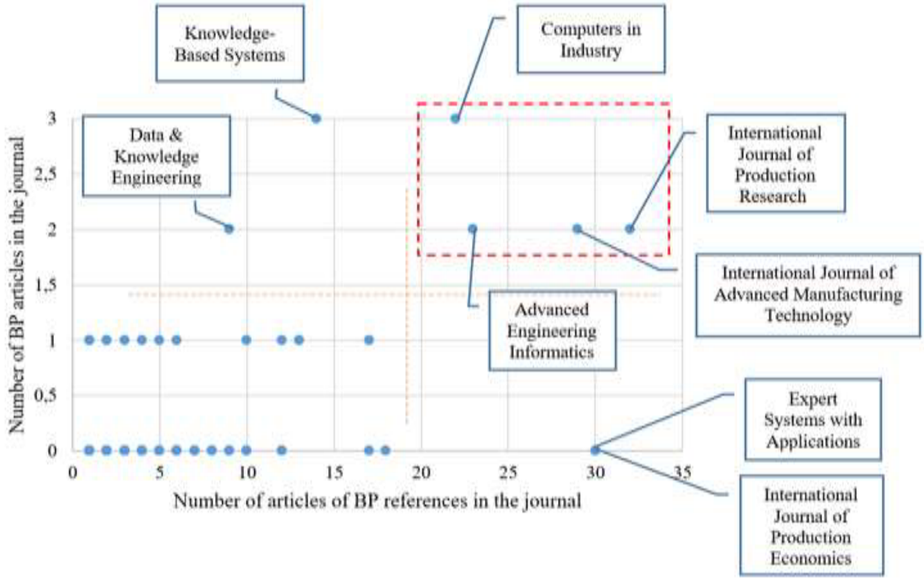

Figure 2. Results about the exploited research topic on international journals.

The most relevant journal, according with the Journal Citation Reports (JCR), is "Knowledge-Based Systems", with an impact factor of 4,529.

The authors with the most prominence, of the 107 authors of BP, is Prof. Essam Shehab with 4 published researches. Also Pablo Bermell-Garcia, Olasubomi Sanya and Yuchun Xu are relevant authors, with respectively 2 and 2 papers. A similarity between the most cited authors is the link with the University of Cranfield, in the United Kingdom, and to work in the development of products and engineering projects.

From the three axes, some keywords initially defined appear among the 16 most representative found keywords, that are ontology, knowledge, cost and product.

4. Systemic analysis

The systemic analysis helps identifying gaps in the literature about the desired topic based on the author's own criteria and vision of what is relevant [14]. The approaches used by the proposted method are called “lenses” and collaborate in the identification of evidence and knowledge gaps presented in the selected articles [10] . For this work, the adopted lenses are: 1) identification of problems, 2) features described, 3) research opportunities (gaps).

4.1. Identification of problems

With the analysis of articles in the BP, problems are identified in the following contexts.

Knowledge management: Verhagen et al. 2012 [15] describe that KBE has not yet matured enough to become a solid industry tool, especially in aerospace and automotive. This evidence emerges in [16], which describe the complexity of human behavior to replicate it in an intelligent system to simulate the decisions of an expert. Lee et al., 2014 [17] presents the case study where information must be systematized through ontologies to be consulted during the development of the projects.

Costs estimation: When using CAD tools, raw schemas are created, which provide insufficient information for cost estimation. Hongzhuan et al., 2013 [18] describe the challenges of developing complex products such as Boeing 787, where cost estimating can become subjective decisions and appropriate methods are needed to manage knowledge. Mousavi et al., 2015 [19] describe that the costs of new products tend to increase uncertainties and should be considered in the early stages of product development.

Product development: The ability to detect so much data and information requires the help of intelligent systems to become efficient, which takes into account the knowledge of the experts and the team's experience [20]. Even more so in such a competitive market, where creativity is decisive as much as the ability to reuse knowledge by an apprentice industry with the same challenges as professionals with years of experience [21]. Sanya and Shehab, 2014 [22] report that it is necessary to avoid wasting time with repetitive tasks and to focus on the capture, formalization of knowledge and codification.

4.2. Solutions described

The complexity of the subject still challenges researchers and encourages the search for literature reviews such as the work of Ensslin et al., 2012 [14] on the identification of KBE theoretical foundation in search of research problems, such as the deficiency in reporting costs and benefits from KBE and in the reuse of knowledge. In order to investigate approaches in the development of KBE systems that offer a high level of knowledge reuse, Sanya and Shehab, 2014 [22] have achieved results regarding the portability of the KBE system in the ontology engineering disciplines (MDA, OOP, UML) such as OWL and SWRL, ontology-based languages. Quintana-Amate et al., 2015 [4] investigated the learning gain in industry and identified, through interviews, that there is a gap between KBE development processes where artificial intelligence tools can be integrated with the interventions of experts in a more systematic and modeled way. Other studies in the scope of knowledge management evidence the applicability and benefits as [20] and [23].

In the scope of ontology the approaches are broad and demonstrate dynamism in the applications. Fortineau et al., 2013 [7] started from a literature review related to the ontology of inference for product lifecycle management and found that most of the knowledge capture, instantiations or mapping are still done manually in the inference models. Furthermore, Saa et al., 2012 [24] propose a fuzzy ontology to support imprecision and uncertainties and conclude that the use of a fuzzy approach overcomes existing problems where it was not allowed uncertainties, example in the the software Protégé (ontology editor).

Within the context of construction field, Verhagen et al., 2012 [15] developed an ontology to capture the tacit knowledge and return an unique solution. Zhang et al., 2012 [25] describes a source of information and knowledge that can be used throughout the product life cycle by engineers with or without experience. Xu et al., 2016 [26] have researched rule-based semantics in the production of BIM models for the purpose of estimating costs to construct the estimation process for specialists. In a railway infrastructure, Lee et al., 2014 [17] proposed an approach to calculate complex data, automatically incorporate expert knowledge and proposes efficient design solutions. Moreover, Simperl et al., 2012 [27] presents ONTOCOM, a method of estimating costs in ontology engineering project. First a framework is defined to reduce the complexity of monetary planning, then a cost model is developed to identify cost factors that correspond to classes.

Aerospace engineering requires good structured practices or methods to develop the available ontologies. In this context Sanya and Shehab, 2015 [5] seek to present a structure that encourages a modular architecture and knowledge reuse with the help of 11 specialists. In the first phase the knowledge was captured, the second phase was the formulation of the ontology structure, in phase three the iterative development and refining of ontology engineering and in phase four the validation. The experts evaluated the approach with 82% applicability in the industry, 65% in ontology comprehension, 67% scalability and 78% in ontology structure modularity encouragement.

Beydoun et al., 2014 [28] sought to develop an approach to identify relevant ontologies in three stages: mapping models, checking for consistency and comparing with domains of ontologies. In this way it is possible to develop an ontology from a repository of different reusable ontologies in the early stages of product development. [29] also contributed with ontology reuse techniques and developed a guide on how to reuse them.

Another research front identified in the BP is a fuzzy technique to reach the determined objectives. Achiche et al., 2013 [30] focused on the decision support to managers in evaluating costs by using tools in the Fuzzy Front End core in complex situations. Agard and Barajas, 2012 [31] opted to present a review of the literature on podium development topics in the fuzzy logic context and identified opportunities for fuzzy application in the process.

Fazlollahtabar and Mahdavi-Amiri, 2013 [32] presented a cost estimation model for the autonomously guided vehicle-based automated manufacturing system, where the rules were used to minimize costs. Renzi and Leali, 2016 [33] proposed a project platform between a series of alternatives through a fuzzy approach and reached 6 solutions generated in the initial stages in the generation of the concept. Relich, 2016 [3] developed a cost estimating model of a new product with the aid of fuzzy computational intelligence techniques to identify relationships between new product development costs and stored product parameters.

In the artificial intelligence context, Mousavi et al., 2015 [19] sought to improve prediction performance with the development of new products using hybrid artificial intelligence techniques, called PSO, CV and SVR. Khodakarami and Abdi, 2014 [2] opted to study the Bayesian networks to make cost estimation with many uncertainties. The results indicated that Bayesian networks are very complex in terms of efficiency in the process of inference and construction of the model.

Taking into account the premises of the three research axes, Wasim et al., 2013 [34] investigated aspects related to LeanPDP in the development of a model for estimating manufacturing costs in support of certain decisions still in the early stages of development of products. Through the C# language the model was developed and resulted in improvements such cost estimation time from 25 days to 12-15 days and response time of quote from 3 months to 1 month. And yet several contributions by mathematical approaches to cost estimates from literature review were found by [35]. Other examples of application of an ontological approach can be seen in [36], [37] and [38].

4.3. Research opportunities

The main approach detected is the ontological one. It is necessary to develop an ontology from a script systemically and methodologically to make it more robust [23]. This approach may have connection with semantic web services [36], where tacit knowledge is formally collected and reusable collaboratively on the web [15] or maintained in a restricted environment [38], such as within a company.

Currently, ontological approaches encompass free data, in large-scale and with flawed technical communication, where the proposal could be restricted to specific business needs to increase applicability. An important factor is the need for interoperability [7], with layered solutions where the artifact is continuously absorbing expert knowledge and proposing solutions in real time. Over time, knowledge must be captured systematically, stored and reused from existing production lines or results obtained in the industry with automatic techniques [6].

Simple solutions are the beginning, with definitions of concepts to support the specialists [20] advancing to project recommendations for costs, for example, involving scalability and knowledge assessment with quantifications of success factors [22]. Regardless of the context, an ontological approach can be shaped for knowledge management success cases [37] or more specifically in the cost domain [5]. Depending on the complexity of the project involved, other approaches can be applied together, such as the Bayesian object-oriented network [2] in which complex models can be structured in an interrelated way in a probabilistic risk analysis of complex problems with uncertainties of cost analysis in the project.

Several authors describe the use of databases and structuring of data [15]. The differential when linked to ontologies is the inclusion of systems that incorporate knowledge automatically when the expert describes it and proposes design solutions. Data gathering may be the key for experts to find solutions and tools appropriate to situations from an interface with specific end-user data based on the expertise [30].

Approaching knowledge management also emerges the window for artificial intelligence, which contemple a knowledge gap and needs the development process of knowledge-based engineering for integration and interventions [4]. Still, fuzzy is discussed where there are many uncertainties from past project data. Detecting these patterns requires mining techniques that can be achieved by a cost estimation model with computational intelligence to identify relationships and product parameters [3].

5. Conclusions

The paper deepen the use of ontologies in product development for cost estimation by a bibliometric analysis. It identified the most relevent trends and research opportunities that can orient future works. Given the large amount of information available and the challenges of finding research related to the research axes cited in this study, it confronted with the problem of how to search by identifying and analyzing information on product development in the costs area. This research carried out the investigation from relevant articles on the subject by the Proknow-C intervention instrument to form the theoretical reference on the subject.

Three research axes were defined: (i) cost management, (ii) product development process and (iii) cost management. Following, from a search in article banks, articles were found and selected from criteria established by the Proknow-C method resulting in 31 articles for the BP. Authors also analyzed the impact factor of the journals, the scientific recognition of the articles and the most cited authors, and the main keywords used to describe the studies performed. Subsequently, a systemic analysis assisted in the identification of problems, description of the resources and methods adopted by the authors in the investigation and identification of gaps on the subject.

The main research opportunity lies in ontological approaches to estimate costs in product development according to defined axes. Several studies have been developed and there are still difficulties to work with uncertainties, such as in the early stages of the product development process, where there are few parameters to develop the process. The study highlighted that the use of ontologies can help to capture such knowledge, properly strcutured into databases, and allows to add new data that is not in the system. As experts add tacit knowledge into the ontology, it is possible to reuse this information by other experts or in solutions generated by the artifact itself.

According to the study, there are many possibilities for future studies with an ontological and / or hybrid approaches. In order to find solutions that describe the product costs during the product development process, preferably from the early stages where the challenges are greater as well as the uncertainties and shortage of parameters to base and systematize the understanding, the use of expert systems certainly open the way to new studies.

The use of proknow-C reveals the uncertainties of the topic and allows to delve into the desired topic with filters that increase the quality of scientific research. It is recommended to include relevance analysis of featured articles by comparing the number of times the article is cited in the bibliographic portfolio references. Another recommendation is to repeat the process considering new keywords, journals and authors discovered in the first research, this iterative process demands time but increases the level of knowledge of the researcher on the subject.

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