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A review of cost estimation models for determining assembly automation level

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ABSTRACT

The aim of this research is to support early phase cost estimation for assembly systems design and automation decision. During this phase, various alternatives of assembly systems with different automation levels can be generated. The alternatives generation is performed using available information on product design, assembly sequences, and planned production information. The issue is to assess given alternatives, identify, and opt for the most appropriate one. Several criteria have to be considered in this decision. The economic aspect represents one of the most preponderant, including cost and profitability prediction. The importance and challenges of this complex issue are highlighted in this paper with feedbacks from manufacturers and the literature. The literature in the field is reviewed, presented, and analyzed. For this sake, a selection of cost models is performed covering a wide chronological range, journals, and fields including assembly and manufacturing models. Classification techniques of cost estimation works are presented and exploited in the proposed review. It is used to filter and discuss models suitability for the defined assembly automation decision issue. The most appropriate models are more thoroughly reviewed and discussed. Useful literature costing techniques, features, and relevant cost drivers are also identified. They cover multiple aspects as production information, resources features or performances. Finally, the review findings are illustrated by a cost estimation outline proposal to support early phase cost prediction for assembly systems design and automation decision.

Introduction

Manufacturers are aware that an increased usage of automation does not necessary result in increased benefits (Bainbridge, 1983; Boothroyd, Dewhurst, & Knight, 2011; Gorlach & Wessel, 2008). After having experienced high levels of automation, the result of a survey in German companies about automation shows that more than a third of 355 surveyed companies planned to reduce the level of automation within their plants (Lay & Schirrmeister, 2001). The usefulness of automation is highly dependent on finding appropriate distribution of tasks between the human and the technical system (Frohm, Lindström, Winroth, & Stahre, 2006). A multitude of criteria have to be considered to lead to the best process. Our interest in this paper is focused on the cost criterion because revealed as one of the most preponderant criteria to consider in such decisions as will be explained in the motivation section. The purpose is to support cost estimators in assembly, particularly deciders and designers of assembly systems, in early phase cost predicting. The target is to be able to objectively predict the cost using a model as complete as possible, with significant information that can be available during such crucial phase. The purpose is also to support automation choices consideration in the assembly system to design. This can help in comparing automation choices to increase the profitability and optimize the cost during assembly system design. For this sake, we perform a deep review in the field of cost estimation in assembly and manufacturing as well. We present a state of the art with characterizations and classifications of the different cost estimation approaches that can be encountered in the literature and we evaluate their suitability to support Level of Automation (LoA) decision. Several models are then provided to support cost estimators with regard to different aspects in the process of cost predicting. We identify and present also most impacting cost drivers, commonly used in the literature and less commonly ones, with references and models, to support the cost estimation.

The paper is organized as follows: in a first section the motivations are presented. In Section 2, expectations for cost estimation with consideration of assembly and LoA purposes are presented.

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Literature in cost estimation is reviewed in Section 3. In Section 4, the literature cost models suitability is studied and analyzed with regard to classifications and criteria. This leads to most promising models identification that are more deeply described and analyzed. In Section 5, an illustration with most important strengths of different models is summed up with cost drivers identification into an integrated method with references to support cost estimation for different axes and cost targets. Finally, the paper is concluded in Section 6 with perspectives and future works proposals.

1. Motivation: Importance of early cost estimation in assembly automation decision making

In this section, elements motivating us to tackle the problem of cost estimation for the sake of LoA decision making are highlighted. We mean by early assembly cost estimation the prediction of assembly costs during an early phase which anticipates the final detailed system design performing. This is defined by an assembly cost per product estimate computation.

Two major motivations can be distinguished. The first one consists in the importance of the cost criterion itself in the long-term scale of future industrialization projects, particularly those necessitating heavy investments, for both manufacturing and assembly. The second is related to the difficulties and specificities caused by the particular phase of estimating the cost: the early phase anticipating final system design. These two elements are detailed through the two following sub-sections.

1.1. Cost predicting: an issue of a wide interest for manufacturers

1.1.1. Importance for manufacturers

The cost represents one of the most important decision criteria and an essential ingredient in the process of creating support for business decisions within manufacturing operations for every manufacturer (Gayretli & Abdalla, 1999; Pehrsson, Ng, & Stockton, 2013). It is also admitted that it represents a focal point for design and operational strategies and a key agenda for managerial policies and business decisions (Niazi, Dai, Balabani, & Seneviratne, 2006). The estimation of costs is also a vital concern of every manufacturing firm and is tackled in every organization with a need to predict the costs as accurate as possible (Downs & Trappey, 1992; Eklin, Arzi, & Shtub, 2009; Winchell, 1989). The prediction can make a manufacturing project feasible with a satisfactory profitability or to be renounced. Having a reliable cost estimation system involving most preponderant cost information and activities becomes an increasingly important competitive issue (Jahan-Shahi, Shayan, & Masood, 1999).

Cost estimation can be useful for widely concerned stakeholders within manufacturers' services, particularly for managers and deciders such as manufacturing responsible, automation engineers and specialists, consultancy and engineering offices. This can provide a support to decide about manufacturability, feasibility and profitability of a given future production or a given manufacturing project (Jha, 1996). In fact, quantitative information on a system's cost can be helpful and useful for every production manager needs for the purpose of economic decision making (Jha, 1996). This notion matches with "Design to Cost" aiming at estimating the cost of a design before deciding and fixing the final design. Being able to estimate the cost of an assembly system during the design phase can offer an interesting opportunity to optimize the system design as well as a feedback to improve the product design for best and most profitable issue to enhance competitiveness.

When considering the factors that decide a product's success in today's market, it becomes clear that cost is as crucial as quality and functionality (Layer, Brinke, Houten, Kals, & Haasis, 2002). In fact, among the main economic factors that influence competitiveness of companies is the product cost criterion (Roy, Souchoroukov, & Shehab, 2011) where manufacturing and assembly costs represent important investments to be amortized, sometimes exceeding more than 50% of the whole product cost. Making sure that target costs can be met and guaranteeing competitive prices can be realized since the design phase of new products becomes a priority (Ping, Yongtong, Bode, & Shouju, 1996). A reliable cost estimation has a direct bearing on the performance and effectiveness of a business enterprise because overestimation can result in loss of business and goodwill in the market preventing the company from remaining competitive, whereas underestimation may lead toward financial losses to the enterprise (H'mida, Martin, & Vernadat, 2006; Niazi et al., 2006). An appropriate estimation, even during the early phase, has to be consequently enough accurate. It should then include as much as possible of available information and cost drivers that can be exploited for the sake of a meaningful prediction.

1.1.2. Importance for assembly systems automation decision

The relationship between the cost and Level of Automation (LoA) decision was evoked in different literature works in the field of automation deciding. The majority of this literature on LoA considers the cost as one of the most important and preponderant criteria (Boothroyd et al., 2011; Frohm et al., 2006; Gorlach & Wessel, 2008; Lay & Schirrmeister, 2001; Parasuraman, Sheridan, & Wickens, 2000; Windmark, Gabrielson, Andersson, & StŒhl, 2012). Some of them are focused on existing processes and are questioning on the possibility of improving the system. Others are focused on new systems design and are then predicting the cost of new productions. This corresponds more to our objective. These different models are reviewed through literature sections of this paper.

Concerning cost estimation involving in the automation decision, Windmark et al. (2012) noted that partial automation is introduced since some elements involved in the production can be costly or particularly difficult to automate. In the same way, other researchers pointed out in Gorlach and Wessel (2008) that a balanced combination of manual and automated processes allows reducing manufacturing costs. It was also underlined that the two dominant factors motivating automating are: first cost efficiency, then reducing negative effects of working environment that can represent danger to health (Windmark et al., 2012). Concerning the cost, the authors mentioned that be particularly profitable, high automation generally requires a high production volume. Profitability curves of three automation levels (manual, automatic, and robotic) costs with regards to number of product parts to assemble in a DFA perspective were drawn since the first DFA works of Boothroyd (1987). Most important results of this Boothroyd's study show that automatic is the most profitable when the number of parts is high or medium. The profitability margins between the different technologies decrease when the number of parts decreases and converge to a same value for a two parts assembly product. Multiple critics can be addressed to these results. They are less credible nowadays because of the significant technological progress compared to manufacturing systems of that period (1987). Also, the basically experimental results without any demonstration, proof, or model, needs to be updated or justified using a concrete and generic model supporting the bases of decision approaches. The only consideration of the number of parts as an automation decision criterion or profitability parameter represents also a weakness, while multiple criteria should be taken into account (Salmi, David, Blanco, & Summers, 2015b). In another work, Gorlach and Wessel (2008)) pointed out that an optimal level of automation of manufacturing systems can only be obtained if all relevant aspects of the manufacturing process are taken into