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Expanding bottleneck management from manufacturing to product design and engineering processes

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ABSTRACT

Bottlenecks inhibit the performance of companies. Up to now, bottleneck management research has concentrated on manufacturing processes, while neglecting product design and engineering processes. This research fills this gap through developing and testing of a new bottleneck management concept for product design and engineering processes. The new concept is developed using a system theory modelling approach and comprises of four bottleneck management counter measures. Two propositions were developed to test the concept through an event-discrete simulation model. The simulation is grounded on empirical data from three design-driven companies and tests the impact of the four bottleneck management counter measures on the performance of product design and engineering processes. The findings from the simulation confirm the applicability of the newly developed bottleneck concept to improve the performance of product design and engineering processes. In doing so, this research study expands bottleneck management for the first time from manufacturing to product design and engineering processes.

1. Introduction

Bottlenecks have been investigated for decades to improve the performance of companies. The role of bottlenecks in a company was firstly described by Gutenberg (1951). He postulated the so-called 'Law of Minimum Sector Dominance', which states that every function has to be subordinated under the overall bottleneck of a company. This dominance of the bottleneck resource motivated Goldratt (1986) to develop the Theory of Constraints, which provides a toolset to increase the performance of company through a systematic bottleneck management. Different bottleneck resources can inhibit the performance of companies. These bottlenecks always appear when a capacity demand exceeds the supply of the respective resource (Cox & Blackstone, 2005). However, bottlenecks are not limited solely to insufficient capacity of workforce, but cover also sufficiency of other resources. Therefore, a large variety of bottleneck types can appear in practice, e.g. staff capacity (Vickery & Markland, 1985), parts (Kim, Davis, & Cox, 2003), raw material (Balakrishnan, Francis, & Grotzinger, 1996), layout (Stecke, 1992), information (Das, Edwards, Journet, & Newman, 1995) or budget (Schwartz, 1985). Causes for bottlenecks are manifold, e.g. overload with work (Byrne & Jackson, 1994), unexpected incidents (Thomas & Charpentier, 2005) or poor resource management (Chakravorty & Atwater, 2005). Many solutions have been suggested so far to cope with these bottlenecks.

Main focus of bottleneck management is the area of manufacturing and assembly. Although Theory of Constraints is not limited to manufacturing, it is deeply rooted in this area (Boyd & Gupta, 2004; Gupta & Boyd, 2008). Hence, it has become an accepted theory of Operations Management of manufacturing processes (Naor, Bernardes, & Coman, 2012). Besides, there is a plethora of other bottleneck management approaches. Examples are the shifting bottleneck detection approach (Adams, Balas, & Zawack, 1988; Roser, Nakano, & Tanaka, 2002) or the event discrete bottleneck analysis (Löffler, Wiendahl, Kapp, & Westkämper, 2002). All these approaches originated mainly from bottleneck management of manufacturing processes. This implies that previous research might have emphasised bottlenecks in manufacturing processes.

Product design and engineering processes have received less attention from bottleneck management than manufacturing processes. Franke, Discher, Kulick, and Stantchev (2009) report in their study that bottlenecks are a serious problem in product design and engineering processes. Pawar and Driva (1999) found that 24% of the companies from a European panel ranked bottleneck management as the most important approach to increase performance of product design and engineering processes. This led to several attempts to apply bottleneck management to product design and engineering processes. Mabin and Balderstone (2003, p. 574) mention the application of bottleneck management to heavy-engineering industries, but without any detail. Goldratt published another book in 1997, called 'Critical Chain', which also refers to product

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Table 1
Description of systematic literature review.

Selected journal	Key words	Analysis technique
• Journal of Operations Management • International Journal of Production Economics • Technovation • Production Planning and Control • International Journal of Production Research • International Journal of Operations and Production Management • IEEE Transactions on Engineering Management	• Bottleneck • Constraint • Product design • Engineering • New product development • Operations management • Drum buffer rope	• Repetition of the key words 'bottleneck' and 'constraint' • Context analysis of the key words • Clustering bottleneck management approaches ('Cutting and Sorting')

development projects (Goldratt, 1997, p. 1). However, he has not extended his ideas beyond single project management (Elton & Roe, 1998, p. 4). Based on this book, Steyn (2002) proposed a concept for multi-project environments, such as product design and engineering processes, but he does not provide any kind of test. Adler, Mandelbaum, Nguyen, and Schwerer (1995) present a concept to manage product development processes like manufacturing processes, but without a particular focus on bottleneck management. When looking closely at these studies, it appears that bottleneck management might be a potential solution to increase performance of product design and engineering processes. However, a comprehensive and tested bottleneck management concept for product design and engineering processes has been missing. Given the experiences from bottleneck management of manufacturing processes, this research study aims at investigating, if these well-known approaches can be used to increase the performance of product design and engineering processes.

In order to achieve this objective the paper is structured as follows: section two reviews the existing literature on bottleneck management of manufacturing and product design and engineering processes to identify the gap of knowledge. A new bottleneck management concept for product design and engineering processes is developed and described in section three. Simulation case studies with empirical data from three companies are utilised to test the new bottleneck management concept. This deployed research methodology is presented in the fourth section. The findings from these simulation case studies are described in section five. The feasibility of the new bottleneck management concept is discussed in section six. The paper concludes with the last section, which describes the contribution to scientific knowledge, managerial implications and further research directions.

2. Literature review

The existing literature about bottleneck management clusted into two categories; manufacturing and product design and engineering processes. Such classifications are particularly useful to determine the actual status of a research area (McCarthy, Ridgway, Leseure, & Fieller, 2000). A systematic literature review was conducted following the recommendations from Tranfield, Denyer, and Smart (2003), see Table 1. A key word search was used to identify relevant publications. Seven academic journals in the field of operations and engineering management were chosen by their ranking in the ABS Academic Journal Quality Guide[1] 2009. The hits from the keyword search were shortlisted and the relevance of the papers was evaluated. The analysis techniques by Ryan and Bernard (2003) were used to identify bottleneck types and counter measures. Firstly, the occurrence of different types of bottleneck is described, either in manufacturing or in product design and engineering processes. Secondly, existing counter measures against bottlenecks are presented, which will be used as a basis to develop a new bottleneck management concept for product design and engineering processes. The results from this literature review describe the actual status of bottleneck management research.

The different types of bottlenecks are described first. Two criteria are used to classify a bottleneck. The first criterion is the occurrence of a bottleneck either in manufacturing or in product design and engineering processes. The second criterion is the bottleneck resource itself. Altogether 49 potentially relevant papers were shortlisted and read. Four papers were discarded from the shortlist (Agarwal, 2008; Awate, Moorkanat, & Rangaraj, 2003; Schultz, McClain, & Thomas, 2003; Wang & Sarker, 2002), because bottlenecks are mentioned without any further description. The remaining papers are clustered according to the two criteria and two main findings can be drawn, see Table 2. Firstly, the main focus of bottleneck management literature is manufacturing, because 39 publications deal exclusively with this process. Five publications describe bottlenecks in product design and engineering processes. Only one publication mentions bottlenecks of both processes (Schwartz, 1985), but only in terms of research collaborations between public institutions and companies. This implies that bottleneck management research has concentrated on manufacturing so far, while neglecting the process of product design and engineering.

The second main finding is the emphasis of capacity bottlenecks. Capacity is the only type of bottleneck, which appears in both manufacturing and product design and engineering processes. It is the most often investigated type of bottleneck, as 37 publications deal with capacity bottlenecks (36 papers exclusively). Four publications consider capacity bottlenecks of product design and engineering processes. The six remaining types of bottleneck appear either in manufacturing or in product design and engineering processes. Three types of bottleneck could be found only in manufacturing processes: parts, flexibility and layout. These bottlenecks have been of minor research interest so far, because only four publications could be detected. Moreover, three other types of bottleneck could be identified exclusively in product design and engineering processes: budget, information and know-how. These have been also of minor interest in research, as only three publications describe these bottlenecks. All together, seven bottleneck types are identified in the literature, but capacity is the prevalent type.

A first gap of knowledge can be derived from the types of bottlenecks. Bottleneck management of product design and engineering processes is under researched in comparison with manufacturing processes. Capacity bottlenecks are the only type of bottleneck, which could be identified in both processes. Hence, the first gap is to find out, if capacity bottlenecks of product design and engineering processes can be managed like capacity bottlenecks of manufacturing processes.

[1] ABS Academic Journal Quality Guide of 2009 is online available at http://www.associationofbusinessschools.org/node/1000257.

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