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A multi-criteria approach to robust outsourcing decision-making in stochastic manufacturing systems

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ABSTRACT

Manufacturing outsourcing is a key industry trend towards greater operations effectiveness and is related to the discussion of strategic core competencies. We study the issue of contract manufacturing at the strategic–tactical level aiming for robust decisions to accommodate stochastic manufacturing environments and immanent uncertainty of planning parameters. The topic is approached from a multi-criteria decision-making perspective, since service, cost, quality, and more long-term value-related aspects need to be considered to arrive at well-balanced decisions. Our contribution is twofold: first, we develop a scenario-based non-parametric ranking approach to determine beneficial outsourcing options at the strategic level. The ranking method uses both model-based Key Performance Indicators (KPIs), which are obtained from a tactical planning model, and non-model-based KPIs that are derived in an independent assessment from multiple stakeholders. Second, we provide an enhanced aggregate planning approach at the tactical level in order to evaluate the performance implications of the strategic outsourcing decisions which in turn serve as the model-based KPIs for the ranking method. A queuing network-based approach is incorporated in the aggregate planning model to anticipate the stochastic behavior of manufacturing systems. An industry-derived case example with distinct outsourcing options is used to highlight the benefits of the approach and to investigate tactical trade-offs when coordinating internal and external manufacturing decisions.

1. Introduction

In the 1980s, a marked trend towards the reduction of internal added value was observable primarily in the automotive and service sectors (Helper, 1991; Gottfredson, Puryear, & Phillips, 2005). Nowadays, in a more volatile world, corporate strategists talk about focusing on core competencies and see manufacturing outsourcing as a lever for increasing efficiency while managing operations risk. While in 1988 outsourcing in the pharmaceutical industry accounted for only around 20% of total production, in the 2000s about every 6 in 10 goods were supplied externally (van Arnum, 2000). Similarly, in 2000 outsourcing covered 10% of global electronics production (Plambeck & Taylor, 2005). Recent data reveal that the top 25 contractors earned 342 bn USD in global sales in 2013, corresponding to some 30% of the total electronics manufacturing market (Manufacturing Market Insider, 2014) further confirms the relevance of manufacturing outsourcing.

Contract manufacturing (CM) agreements commission the contractor to provide on-demand manufacturing of variable production volumes. In this study, we focus on turnkey CM that covers the provision of finished goods in contrast to selective outsourcing at the component level (consignment CM) (see Kim, 2003). The contractee transfers manufacturing obligations to the contractor, which increases its flexibility and can lead to cost efficiencies as well as service improvements. Moreover, operations risk with respect to quality and compliance issues can be transferred to the contractor. Despite these benefits, some fundamental strategic concerns remain. The contractee might lose critical know-how regarding manufacturing procedures and might struggle to retain expertise in-house, while the contractor increases bargaining power and can even turn into a future competitor (Arruñada & Vázquez, 2006). Furthermore, outsourcing entails reputational or ethical risks such as poor working standards or the violation of worker participation rights. As a consequence, manufacturing outsourcing has moved away from its purely financial focus towards a

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more broadly evaluated manufacturing approach. In this respect, the topic touches some fundamental lines of the business policy and thus requires comprehensive multi-dimensional decision support.

In this paper, we study the issue of selecting beneficial outsourcing options at the strategic level considering multiple financial and non-financial measures such as service, quality, and risk. More specifically, we use the example of turnkey CM as mentioned above and evaluate several contractors that could differ in manufacturing capabilities with respect to producible product range and available production capacity. When evaluating the outsourcing options, one needs to consider the impact on tactical operations performance with respect to costs and lead times since optimal capacity levels and volume/mix decisions for the internal production change according to the capabilities of the external manufacturing option. These effects are reinforced by the dynamics of stochastic manufacturing systems regarding workload-dependent lead times given the volume/mix decisions. To account for these multiple facets involving such decision-making, a decision support system needs to tackle the problem from a combined strategic–tactical perspective and must balance both qualitative and quantitative factors. While costs and lead times can be derived using quantitative models, qualitative factors such as quality or risk must be assessed by subject matter experts. Finally, a corresponding approach needs to provide robust decisions that lead to reasonable results irrespective of future developments, accommodating the strategic and partly irreversible character of outsourcing decisions.

The existing literature covers only selective aspects of the aforementioned problem, but mainly in isolation. For instance, Dotoli and Falagario (2012) apply Data Envelopment Analysis (DEA) for supplier selection, while Merzifonluoğlu, Geunes, and Romeijn (2007) consider subcontracting options in a tactical planning model and Asmundsson, Rardin, Turkseven, and Uzsoy (2009) study congestion phenomena in stochastic manufacturing systems. Moreover, robust decision-making has received increasing attention in the operations management context (see e.g., Hahn & Kuhn, 2012). With this paper, we close a current gap in the literature by integrating strategic outsourcing decision-making with tactical operations planning to anticipate the impact of sourcing decisions on operations performance in a stochastic manufacturing environment. These inter-dependencies can have significant impact and thus influence optimal decision-making substantially as we will show below.

Our contribution lies in the integration of the strategic and the tactical planning levels while addressing the multi-dimensionality of outsourcing decision-making. At each point, we use state-of-the-art methodology complemented with the necessary extensions for the decision problem in focus. In our approach, we also emphasize the issue of robust decision-making to accommodate the impact of parameter uncertainty in this context. To solve the multi-criteria decision problem and to ensure robust solutions, we build on DEA to evaluate and construct the ranking of sourcing options at the strategic level given multiple scenarios. An Aggregate Production Planning (APP) model is applied at the tactical level in order to coordinate volume/mix decisions between internal and external production. In contrast to previous simulation-based approaches (see, e.g., Hung & Leachman, 1996), we integrate a queuing network model to capture the non-linear behavior of a stochastic manufacturing system. Although we present a strategical–tactical decision framework for outsourcing decision-making, the approach is generic and can be adapted to any multi-dimensional decision problem that involves the selection of discrete design options while considering the impact on the tactical level.

The remainder of the paper is structured as follows: we review the existing literature on multi-criteria decision-making in supplier selection and aggregate production planning of stochastic manufacturing systems in Section 2. In Section 3, we develop an approach for robust outsourcing decision-making in a stochastic manufacturing environment. An industry-based case example is presented in Section 4 to illustrate the benefits of this approach and to investigate general implications of CM decision-making on stochastic manufacturing systems. We end the paper with concluding remarks on our findings and suggest directions for future research in Section 5.

2. Literature review

The relevant literature for this research follows three streams: (i) aggregate production planning with subcontracting options, (ii) production planning with an emphasis on workload-dependent lead times as well as stochastic manufacturing systems, and (iii) multi-criteria decision-making in supplier selection.

As far as the first stream is concerned, an overview of deterministic and stochastic APP approaches can be found in Nam and Logendran (1992), Mula, Poler, García-Sabater, and Lario (2006), and Díaz-Madroñero, Mula, and Peidro (2014), most recently. Díaz-Madroñero, Peidro, and Mula (2015) provide a related survey on tactical optimization models for integrated production and transportation routing problems. Building on this, Merzifonluoğlu et al. (2007) integrate subcontracting options and introduce sales price decisions as well as economies of scale using concave revenue and cost functions. Similarly, Atamtürk and Hochbaum (2001) propose a model for balancing capacity expansion, subcontracting, internal manufacturing, and inventory holdings in a setting with non-stationary demand. The work of Carravilla and de Sousa (1995) features subcontracting embedded in a hierarchical framework that distinguishes aggregate planning, master production scheduling, and operational loading. The issue of advanced planning and scheduling in manufacturing supply chains with an outsourcing option is considered in Lee, Jeong, and Moon (2002). Finally, Kim (2003) proposes an optimal control model to investigate outsourcing with two contractors that provide a range of price levels and improvement capabilities for future cost savings. While these approaches incorporate subcontracting, they omit the implications of variability and assume fixed lead times irrespective of the workload in the system. The latter will be explicitly taken into account in our approach using workload-based lead times.

The second stream of literature addresses the aforementioned deficits of conventional APP models. Armbruster and Uzsoy (2012) summarize corresponding approaches including clearing functions and discrete-event simulation (DES). An overview of clearing functions approaches that aim at capturing the non-linear relationship between work-in-process (WIP) and the maximum output can be found in Pahl, Voß, and Woodruff (2007) and Missbauer and Uzsoy (2011). Asmundsson et al. (2009) extend the basic clearing functions formulations of Graves (1986) and Karmarkar (1987) and develop a multi-stage multi-product planning approach. Similarly, Selçuk, Fransoo, and De Kok (2008) apply clearing functions in a hierarchical supply chain planning framework to predict lead times among other operational performance metrics. However, current clearing functions-based approaches fall short of capturing the impact of lot-sizing on the performance of stochastic manufacturing systems (Missbauer & Uzsoy, 2011).

DES represents an alternative approach to anticipate the performance of stochastic manufacturing systems in production planning which allows for a more detailed modeling of the shop floor level. Simulation-based approaches have received increasing attention since the early work of Hung and Leachman (1996), which is confirmed by a series of case studies from the semiconductor industry (see, e.g., Kacar, Irdem, & Uzsoy, 2012). Additionally, Almeder,