European Journal of Operational Research 000 (2017) 1–16

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Supplier quality improvement: The value of information under uncertainty

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A R T I C L E I N F O

Article history:
Received 8 January 2016
Accepted 21 May 2017
Available online xxx

Keywords:
Supply chain management
Risk analysis
Uncertainty modelling
Decision analysis
Manufacturing

A B S T R A C T

We consider supplier development decisions for prime manufacturers with extensive supply bases producing complex, highly engineered products. We propose a novel modelling approach to support supply chain managers decide the optimal level of investment to improve quality performance under uncertainty. We develop a Poisson–Gamma model within a Bayesian framework, representing both the epistemic and aleatory uncertainties in non-conformance rates. Estimates are obtained to value a supplier quality improvement activity and assess if it is worth gaining more information to reduce epistemic uncertainty. The theoretical properties of our model provide new insights about the relationship between the degree of epistemic uncertainty, the effectiveness of development programmes, and the levels of investment. We find that the optimal level of investment does not have a monotonic relationship with the rate of effectiveness. If investment is deferred until epistemic uncertainty is removed then the expected optimal investment monotonically decreases as prior variance increases but only if the prior mean is above a critical threshold. We develop methods to facilitate practical application of the model to industrial decisions by a) enabling use of the model with typical data available to major companies and b) developing computationally efficient approximations that can be implemented easily. Application to a real industry context illustrates the use of the model to support practical planning decisions to learn more about supplier quality and to invest in improving supplier capability.

1. Introduction and industrial motivation

Our research is motivated by engagement with major manufacturing companies that make complex, high value engineered products. The companies with which we have collaborated are responsible for the design, manufacture and assembly of parts but, given the nature of their final products, are also systems integrators of parts that are procured from global supply chains. The responsibilities of supply chain management within these organisations include selecting and developing suppliers, as well as ensuring a sufficient supply of parts to the required specification to meet production demands. These supply bases are extensive and often there is a long lead time with initial contracting of new suppliers happening 3–5 years ahead of the delivery of supplied parts.

Company operations are underpinned by large databases containing information on suppliers (e.g. commodity grouping, technology maturity, geographical location), items (e.g. unit price, lead time, design ownership), and orders (e.g. volumes, delivery status, quality conformance). Routine management reports include data analysis to provide information about supplier performance. Company cultures encourage and embrace rational analysis for operational decision-making. These include decisions to undertake different kinds of activities for poorly performing suppliers and to plan interactions with some suppliers to avoid future problems. Supplying parts at the required quality level is fundamental to achieve the desired level of performance. Supplier development is a costly activity for the companies because it requires deployment of skilled personnel for substantial periods of time. The deployment of such resources requires consideration of the costs and effectiveness of activities. It is within this industrial context that we seek to help management (1) to assess how much it is worth spending to improve supplier quality performance and (2) to understand whether there is value in learning more about supplier quality capabilities.

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http://dx.doi.org/10.1016/j.ejor.2017.05.044
0377-2217/

Krause, Handfield, and Scannell (1998) describe supplier development as *"any set of activities undertaken by a buying firm to identify, measure and improve supplier performance and facilitate the continuous improvement of the overall value of goods and services supplied to the buying company's business unit"*. In considering the two challenges posed by our industry problem, we distinguish between two types of activity: those that primarily will help us learn more about the state of a supplier's current capabilities, such as plant visits, auditing (Handley & Gray, 2013; Mayer, Nickerson, & Owan, 2004); and those interventions primarily designed to improve supplier quality, such as supplier training, allocating buyer personnel to improve the supplier's technical base and operations (Krause, Handfield, & Scannell, 1998; Krause, Handfield, & Tyler, 2007). We can then conceptualise a modelling approach that incorporates a two stage decision process, considering how much should be invested in supplier quality improvement activities and whether it is valuable to make an investment now or after learning more about the supplier. These decisions are made under uncertainty about the true quality level that a supplier will achieve. The degree of uncertainty will be influenced by how much experience the buying firm has with a supplier. For established suppliers with whom the buyer has a long history about quality achieved, the uncertainties may be less than for a supplier who is more recently integrated into the buying firm's supply base.

To build a meaningful model we need to understand the nature of uncertainties affecting supplier quality performance. Our general model is developed with parameters to reflect quality uncertainties. A distinctive feature of our approach is that we distinguish between aleatory and epistemic uncertainties, which relate respectively to those uncertainties that are regarded as irreducible and those that are reducible if more information is collected (Hoffman & Hammonds, 1994). Generally, epistemic uncertainty represents some degree of ignorance or incomplete information about the system or aspects of the system of interest, and importantly such uncertainty can be reduced as information is collected. In contrast, aleatory uncertainty describes the inherent random variation that is a property of the system and is therefore not considered reducible (Bedford & Cooke, 2001). In operational quality systems an improvement in capability would be realised by a reduction in the process variation resulting from a decision to develop a supplier's quality performance (Kotz & Lovelace, 1998). Epistemic uncertainty in this context is concerned with the a priori state of knowledge about a supplier's process capability and is expressed before making the decision to develop a supplier or not. Learning by the buyer about a supplier's true quality capability reduces epistemic uncertainty.

We develop a stochastic model within a Bayesian framework to capture both the epistemic uncertainty associated with true supplier quality performance as well as the aleatory uncertainty associated with the inherent randomness in a supplier's performance such as that observed in quality performance data. Our approach is grounded in the value of information concept that data has value if, once analysed, it can result in a change of decision (Ketzenberg, Rosenzweig, Marucheck, & Metters, 2007; Wagner, 1969). We consider value to be a combination of the likelihood of changing a decision and the magnitude of its consequence. By formulating an appropriate stochastic model we can estimate the uncertainty associated with the decision consequences, assign likelihoods to possible data and update the stochastic model in view of data.

We consider a context where we have a dominant prime entity (the buyer), such as one of the major manufacturers with which we work, that relies on an extensive base of suppliers. We therefore assume a single buying organisation with multiple suppliers that have been selected according to the buyer's standard procurement process. Thus, for a new supplier there is insight into anticipated quality performance based on evidence from, for example, quality process reviews, quality certification, quality achieved for similar parts, or first article inspections. For those suppliers that have supplied parts to the buyer, data will also exist on quality performance achieved historically. Our model is intended to be most useful for those suppliers whose relationship with the buyer is relatively new and for whom a proactive approach to development will be taken, for example, during the period between signing a contract and delivery of the regular supply of orders. This is because in such cases epistemic uncertainty is likely to be greater than for suppliers with whom the relationship is more mature.

We do not consider the choice of activity beyond the two classes of development noted above; learning and improvement. Our model requires as inputs an expression of the buyer's assessment of epistemic uncertainty in the true supplier quality, as well as the financial value of production losses that will be incurred by the buyer if sub-standard parts are supplied, and an assessment of the effectiveness of development activity. The model provides the level of the optimal investment in a supplier improvement activity with an upper bound on the amount it is worth spending to reduce the epistemic uncertainty about the supplier quality by targeting learning activities before investing in improvement. Such results help the manager to screen suppliers to assess whether it is worth conducting additional plant visits, audits or other learning activities first, or whether it is more appropriate to invest directly in, for example, training, deployment of buyer resources into the supplier, root cause analysis or other activities aimed at directly making quality improvements.

In this study we address the challenge posed by a practical industry problem by developing and evaluating an innovative and applicable modelling solution using a sound mathematical methodology. Our principal contribution is a new modelling framework for supplier development taking into account the value of information. The model is grounded in the theory of decision analysis and statistical inference, and is aligned with an important industrial supply management problem for which we develop a methodology to support implementation with real data. Our model addresses gaps in the existing literature in relation to research on supplier development and the value of information within a supply chain quality management context. The existing literature tends largely either to develop mathematical models for assumed scenarios providing insightful thinking tools, or to discuss the theory and practice of supplier development in an operational supply management context.

We examine the literature relevant to our problem context and position our work in relation to existing empirical knowledge and models on supplier development in Section 2. Our scientific modelling contribution is described in Section 3. We explain how we formulate the stochastic model based on assumptions about the probabilistic representation of uncertainties and present a number of propositions related to properties of the model. We develop an exact solution for the expected value under perfect information, which is the limiting case of buying down epistemic uncertainty through learning activities. To support practical implementation, we derive a computational approximation and evaluate the conditions under which it is accurate. Section 4 presents an application of our model to real, albeit de-sensitised, industry data on supplier non-conformance rates for a set of key tier 1 suppliers to a large industrial prime. We present an empirical Bayes method to estimate the prior distribution representing the epistemic uncertainty in supplier performance using typical data contained in industry databases. After discussing the reasonableness of our assumptions given the industry problem and data, we present a selection of ways in which the findings of our model can be communicated to supply chain managers. Section 5 presents our conclusions and discusses the implications of our findings for practice and theory,