Multiobjective optimization as a decision aid for managing build-to-order supply chains

S. Afshin Mansouri[1] and David Gallear

Brunel Business School, Brunel University,
Uxbridge, Middlesex UB8 3PH,
United Kingdom.

Abstract

This paper provides an overview of multiobjective optimization (MOO) as a decision aid in build-to-order supply chains (BTO-SC). The main features of BTO-SCs are discussed along with capabilities of MOO to enhance decision making at different points along the chain. Key decision points across a typical BTO-SC are identified and potential applications of MOO are discussed. A sample application is presented and future avenues for further research highlighted.

Key words: Build-to-order supply chains, multi-objective optimization, decision support

Introduction

A build-to-order supply chain (BTO-SC) is a production system that delivers goods and services based on individual customer requirements in a timely and cost competitive manner (Gunasekaran & Ngai 2009). Build-to-order and configuration-to-order markets driven by mass customization and e-commerce force retailers and manufacturers to shorten planning cycles, reduce manufacturing lead time, and expedite distribution (Tyan & Duc 2003). BTO allows for improved customer satisfaction and provides an opportunity for massive cost saving in the inventory costs (Sharma & LaPlaca 2005). BTO has significant business potential to promote sales and cost saving. According to a survey, 74% of car buyers in the U.S. would prefer to order a customized vehicle rather than buy from a dealers inventory if they could get delivery in less than 3 weeks (*Business Wire*, 2001 cited in Christensen et al. (2005)). In the same year, Nissan Motor estimates a full implementation of a BTO strategy could save up to $3600 per vehicle (*Economist*, 2001 cited in Christensen et al. (2005)). Dell generated a 160% return on its invested capital by allowing customers to order customized computers online, which were then manufactured and delivered within 5 days (*The Wall Street Journal*, 1999 cited in Ghiassi & Spera (2003)). Autoliv reduced 37% of their plant inventory by coordinating orders online with suppliers (The Wall Street Journal, 2001 cited in Swaminathan & Tayur (2003)).

---

[1] Corresponding author, Email: Afshin.Mansouri@brunel.ac.uk

Efficient management of BTO-SCs has attracted the attention of researchers and practitioners following successful implementation by companies like Dell, Compaq and BMW (Gunasekaran & Ngai 2005). Considering the growing importance of more informed and timely decision making in BTO-SCs, Gunasekaran & Ngai (2009) encourage further research on the modeling and analysis of such systems. Gunasekaran & Ngai (2009) classify the BTO-SC decisions into: *i.* configuration and *ii.* coordination levels. They emphasize on the importance of further research in several directions in BTO-SC including: developing suitable planning and scheduling models and techniques for managing the material flow, modeling and analysis of the coordination-level issues.

In order to expand BTO market share, several aspects of operations management need fundamental improvement. The German car industry for instance, has invested a lot of effort in recent years to further increase this share via shorter delivery times, high delivery reliability and a faster responsiveness (Meyr 2004). The current trend within the German automotive industry from build-to-stock (BTS) to BTO is mostly a shift in the 'order share' from retailers' forecast of market order towards real customers' order (Meyr 2004). In this way, major strategic goals include: shorter delivery lead times, more reliable promised due dates and flexibility in accepting change of customer options in very short time (Stautner 2001 cited in Meyr (2004)). The BTO market is not restricted to standard or premium products any more. In particular, it is becoming popular in the retail industry with rapid growth of internet shopping. For instance, Ewatchfactory [2] (a watch manufacturer) and timbuk2 [3] (a bag producer) allow customers to design their own products (Swaminathan & Tayur 2003).

With this trend, timely and informed decision making is becoming crucial for the long term success of businesses. However, different members of a BTO-SC may have their own preferences in response to dynamic customer orders which in many cases are conflicting. Efficient decision supports are thus essential to enable interested parties to evaluate the consequences of countless decisions being made across the whole supply chain, and in real time. This would help business opportunities to be exploited and help to solidify collaboration in the chain. The global economic downturn has further emphasized the importance of optimization to support managerial decision making to maintain competitive advantage towards business goals.

This paper introduces multiobjective optimization (MOO) as a decision aid in BTO-SC. The main features of BTO-SCs are discussed along with the attributes of MOO that make it a potentially very promising approach to enhance decision making across the chain. Key decision points in a typical BTO-SC are identified where MOO can be used as a decision aid. In this analysis, we make use of the classification scheme proposed by Gunasekaran & Ngai (2009). Configuration-level decision points (in product design, procurement and supplier selection, production configuration, distribution, and information technology/systems) will be overviewed. We will then focus on coordination-level decisions. These include decisions that deal with the operation of BTO-SCs, for instance: production scheduling, material requirements planning and inventory control. A sample application in trade-off analysis between price and delivery lead time will be provided as an extension to the earlier work of Moses et al. (2004) and Hegedus & Hopp (2001). The paper will also attempt to provide an

---

[2] www.ewatchfactory.com

[3] www.timbuk2.com

initial assessment of the likely boundaries (or limitations) to the use of MOO in this arena and highlight avenues for further research.

The main contributions of the paper are: *i.* introduction of MOO as a decision aid in BTO-SC and its potential benefits; *ii.* classification of key decision points across a BTO-SC with typical objectives to be considered and the way MOO can support managerial decisions; and iii. highlighting further research that is needed in order for this idea to be realized in practice.

BTO-SCM involves multiple decision criteria

A BTO-SC is primarily formed to create a sustainable competitive advantage for all members of the supply chain which is ultimately measured by success in the market (Christensen et al. 2005). However, the interests of all players are not necessarily in line with each other and therefore, cannot be fully satisfied all the time. As a result, management of BTO-SCs necessarily involves extensive compromise and trade-offs due to inherent conflict among the different parties. For instance, customers might look for reduced price and shorter delivery lead times while manufacturers try to enhance utilization of their facilities with reduced inventory and setup changeover. On the other hand, suppliers may favor smooth demand whereas logistic providers will look for high fleet utilization. It is obvious that all of these objectives cannot be attained at the same time. We argue that multi-objective optimization (MOO) has significant potential to facilitate decision-making in such instances by provision of insights as to the consequences of any action taken towards satisfying one performance metric on the rest of objectives. The key role of MOO in this scenario is to find the set of nondominated solutions from which decision makers can choose based on their preferences.

Key decision stages in BTO-SCs

Figure 1 shows a conceptual framework for decision making in a typical BTO-SC. The model is a simplified illustration of interfaces between a manufacturer and other parties, i.e: customer(s), supplier(s), logistic provider(s), distributer(s) as well as manufacturer itself where MOO can act as a decision support to facilitate better informed decision making. Other interfaces, for instance supplier, manufacturer and logistic provider could also be incorporated in the model. We ignored such interfaces at this stage for the sake of simplicity. We make part use of the classification of decision making areas in BTO-SCs proposed by Gunasekaran & Ngai (2009) adding complementary decision areas. We then categorize them based on the parties involved (customer, manufacturer, supplier, logistic provider, and distributer) in the decision making. From among all possible combinations of parties (customer-manufacturer, manufacturer-supplier, manufacturer-supplier-logistic provider etc.) we focus on a number of bilateral relations involving major parties and their immediate link in the chain. This leaves us with the following combinations at two levels: the configuration level (confg.) and the coordination level (coord.):

i. *customer-manufacturer interface*. This interface is where customers and manufacturer are dealing with important decisions with direct and/or indirect impact on other members of the chain. The followings are among the most common decisions (mostly at coordination level) being made by customer(s) or manufacturer separately or collaboratively at this stage:

- product configuration
- pricing
- delivery arrangements

ii. *manufacturer-supplier interface.* At this interface, a combination of strategic or configuration level decisions are made along with operational or coordination level decisions. These can be summarized as follow:

- procurement and supplier decisions (confg.):
    - make or buy decisions,
    - outsourcing, parts or components to be outsourced,
    - determining the number of suppliers,
    - supplier selection, and length of the contracts.
- short term order adjustments (coord.)
- delivery intervals (coord.)

iii. *manufacturer-logistic provider interface.* Long term agreements between the manufacturer and logistic providers are made through this interface. There are operational decisions which are to be made in response to dynamic changes in the production schedule(s). The followings are a selection of such decisions:

- long term inventory management strategies (conf.)
- delivery intervals and urgent replenishment policies (coord.)

iv. *manufacturer-distributer interface.* The decisions involved with physical distribution of finished products can be made through this interface. These would cover for instance the followings:

- the number and location of distribution centers (conf.)
- delivery arrangements with individual customers (coord.)
- after sales logistic services including collection of recycling items (conf.)

v. *manufacturer interface for internal decisions.* Internal departments of the manufacturer make their internal decisions using this interface. The following list introduce the main decisions at this interface:

- product design decisions (confg.)
- production decisions (confg.):
    - number of factories and their location,
    - capacity of each factory,
    - products to be manufactured at each factory, and

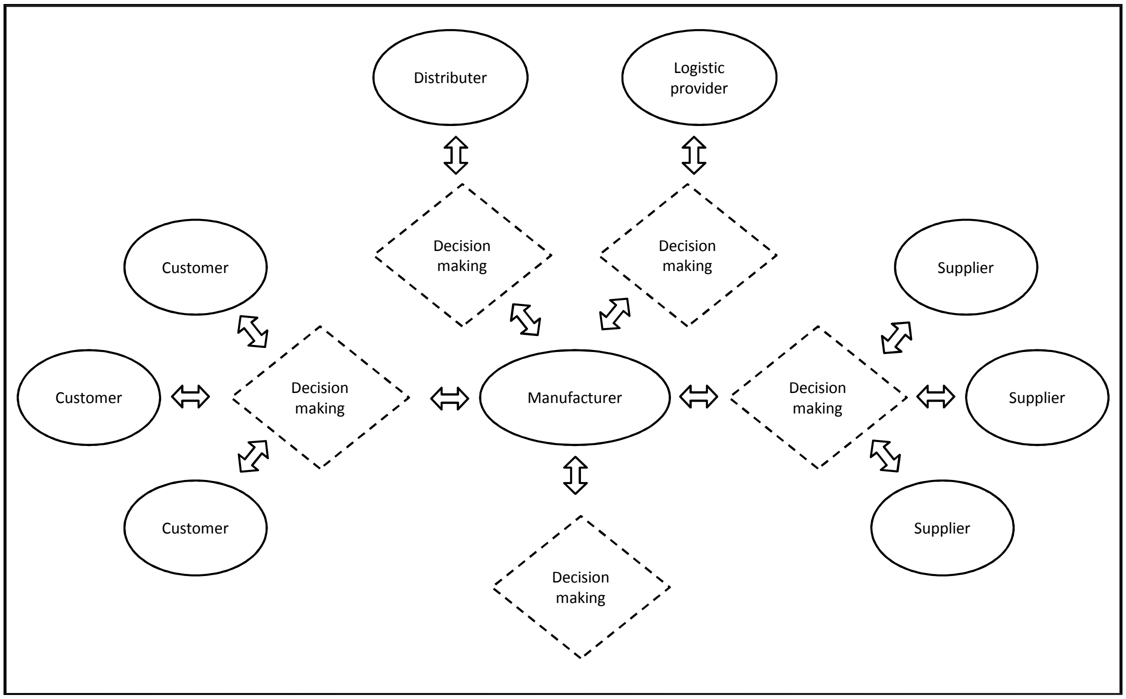

Figure 1: The conceptual decision model for BTO-SCs. The model illustrates interfaces between manufacturer and other parties of the chain, i.e: customer, supplier, logistic provider, distributer as well as manufacturer itself where MOO could be employed as a decision support to facilitate informed decision making.

  - and integration of the operations of all factories.
- material flow decisions (coord.):
  - inventory control,
  - purchasing,
  - master production scheduling,
  - material requirements planning,
  - scheduling and process control.

In the field of SCM and its related decision points, supplier selection has extensively been addressed as a multi-criteria problem in the literature, for instance by Dulmin & Mininno (2003), Amid et al. (2006), Xia & Wu (2007), Liao & Rittscher (2007) and Chou & Chang (2008). Karpak et al. (2001) apply VIG (A Visual Interactive Approach to Goal Programming) to assist multi-criteria decision making in materials purchasing.

Software packages for SCM

Single objective optimization has been implemented in a number of software systems to support supply chain decision making process, for instance by: LogicTools [4], MCA Solutions

---

[4] www.logic-tools.com

[5] and Manhattan Associates [6]. Biswas & Narahari (2004) introduced a decision support framework for SCM but there is no indication of multiobjective approaches to tackling the problems addressed in their paper. Wang et al. (2008) compared seven SCM software packages using an Analytic Hierarchy Process (AHP). These include: Aldata SCM, HighJump SCM, Infor SCM, Manhattan Associates' Integrated Logistics Solutions, Oracle E-Business Suite Supply Chain Management-R12, RedPrairie's E2e TM Suite, and SAP SCM.

Multi-objective optimization and decision support

The multi-objective optimization problem (MOOP) can be defined as the problem of finding a vector of decision variables $\widetilde{x}$, which optimizes a vector of M objective functions $f_i(\widetilde{x})$ where $i = 1, 2, \ldots, M$; subject to inequality constraints $g_j(\widetilde{x}) \geq 0$ and equality constraints $h_k(\widetilde{x}) = 0$ where $j = 1, 2, \ldots, J$ and $k = 1, 2, \ldots, K$.

The set of objective functions constitute a multi-dimensional space in addition to the usual decision space. This additional space is called the objective space, Z. For each solution $\widetilde{x}$ in the decision variable space, there exists a point in the objective space:

$$\widetilde{f}(\widetilde{x}) = Z = (z_1, z_2, \ldots, z_M)^T$$

In a MOOP, we wish to find a set of values for the decision variables that optimizes a set of objective functions. A decision vector $\widetilde{x}$ is said to dominate a decision vector $\widetilde{y}$ (also written as $\widetilde{x} \succ \widetilde{y}$) iff:

$$f_i(\widetilde{x}) \leq f_i(\widetilde{y}) \;\; \forall \; i \in \{1, 2, \ldots, M\};$$

and

$$\exists \; i \in \{1, 2, \ldots, M\} \mid f_i(\widetilde{x}) < f_i(\widetilde{y}).$$

All decision vectors that are not dominated by any other decision vector are called *non-dominated* or Pareto-optimal and constitute the Pareto-optimal front. These are solutions for which no objective can be improved without detracting from at least one other objective.

There are several approaches to find Pareto-optimal front of a MOOP. Among the most widely adopted techniques are: sequential optimization, ϵ-constraint method, weighting method, goal programming, goal attainment, distance based method and direction based method. For a comprehensive study of these approaches, readers may refer to Collette & Siarry (2004). Considering complexity of MOOPs, metaheuristics and in particular, Evolutionary Algorithms (EAs) have extensively been used to find approximations of Pareto-optimal frontiers of large-sized problems. Interested readers for detailed discussion on application of EAs in multiobjective optimization are referred to Coello Coello et al. (2002) and Deb (2001).

Multiobjective optimization and decision support

There are numerous examples of decision support systems in the literature. For example, Blecic et al. (2007) introduced a decision support system called BayMODE based on Bayesian

---

[5] www.mcasolutions.com

[6] www.manh.com

analysis and multiobjective optimization. Kollat & Reed (2007) presented VIDEO as an interactive visual decision support using evolutionary multiobjective optimization. They showed its application in a long-term groundwater monitoring design problem with up to four objectives. Lam et al. (2008) developed a multiobjective financial decision support for Chinese construction firms. The application of multiobjective optimization in the BTO-SC field however is largely absent from the literature.

Customer-manufacturer decision interface

This section elaborates on a key decision between customer and manufacturer when a potential customer is placing an order for a customized product. The manufacturer offers a selling price, possibly beyond the customer's budget, based on a fixed delivery lead time. The customer might not be happy with the combination of price-delivery lead time and decides not to buy the item. This would be a missed opportunity which could have been avoided due to the fact that price, potentially, could be negotiated at the expense of increased lead time. This scenario can be formulated as a MOOP with the following set of objectives:

$$Minimize\ (f_1 = cost,\ f_2 = delivery\ lead\ time)$$

Figure 2 shows a schematic representation of the Pareto-optimal front for this problem obtained via MOO. An option **b** is initially offered to the customer. However, based on the trade-off analysis, it is revealed that by only 10% increase in the delivery time at point **a**, a 30% reduction in cost could be offered to the customer. This might interest the customer and result in the purchase of the product. On the other hand, customers who desire a speedy delivery might be willing to pay extra to compensate for overtime working hours. Such scenarios could be evaluated on the trade-off curve. This example indicates how MOO can contribute to the long term business goals. Such decision aids need to be provided in a short time to meet the requirements of on-line shopping in a BTO-SC. For this, efficient solution tools are crucial to the success of MOO as a practical decision support.

Trade-off between due date and cost

Order promising is as an important measure for customer service. To this end, Moses et al. (2004) propose a methodology for due date promising in response to dynamic order arrivals in a build-to-order (BTO) environment. Nonetheless, to date it appears that BTO manufacturers while striving to provide promised completion dates to customers that are achievable, tight and computed in real time for dynamic order arrivals, still rely heavily on rough estimated lead times (Moses et al. 2004).

Moodie & Bobrowski (1999) address the tradeoff between cost and due date in a simple job shop when time allows for negotiations. This approach however does not seem practical in customer-manufacturer interface in a BTO-SC where time consuming negotiations cannot be afforded. Ruiz-Torres & Nakatani (1998) develop a simulation model to provide different due date and cost scenarios to customers in a manufacturing logistic network. In this way they make use of information from manufacturing, transportation and supplier elements.

Wang et al. (1998) address joint due date assignment and production planning under fuzzy assumptions. They develop a bargainer tool that can be used in customer-manufacturer

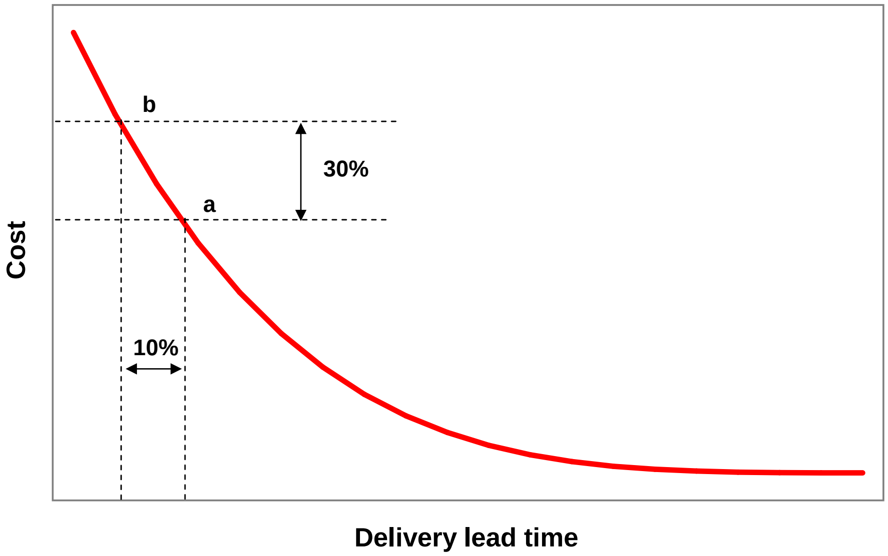

Figure 2: Trade-off between cost and delivery lead time in the form of the Pareto-optimal front. Shorter delivery can be promised at higher cost while lower cost can be offered with longer lead times.

interface to decide on delivery due date and cost for a make-to-order (MTO) manufacturing system. This tool works with 'sales management' and 'production planning' modules of a manufacturing resource planning (MRP-II) system. They propose a three phase solution approach assuming for a number of fixed orders at a given time. After initializing the system with near optimal due dates from the manufacturer's point of view, customers may start bargaining for shorter delivery lead times one at a time. In the bargaining process, alternative due dates are offered to the customers at the expense of extra cost required to pay for delayed delivery of already agreed due dates with other customers. The solution tool is tested on a small scale scenario where six orders were available for a MTO manufacturer. The authors conclude that the proposed solution approach requires fundamental improvement so it can be used for dynamic daily orders from several customers at the same time. As such, this approach seem not to be suitable for BTO-SC where theoretically thousands of customers can interact with manufacturers on a daily basis. Moreover, the current constraint of dealing with customers one-by-one needs to be addressed so that it can be used for global supply chains where customers interact with the sale management module virtually independent of each other, and often simultaneously.

Concluding remarks

In this paper we have discussed the role and capabilities of multiobjective optimization as a promising decision support for build-to-order supply chains. Most BTO-SCs are characterized by a high level of interactions among members, theoretically in real time, which further emphasizes on the importance of efficient decision support tools. Customer orders potentially impact all member parties in the supply chain, each of whom will undoubtedly have their own preferences regarding demand fulfilment. A multiobjective decision support can help decison makers to make more informed decisions towards business goals, and at the same time facilitate potentially higher levels of collaboration.

A conceptual framework was provided to highlight major decision points at the interfaces between main elements of a BTO-SC, centered around the manufacturer. The main decisions in each point were listed. A bicriteria decision problem in customer-manufacturer interface was discussed with potential applications in real time negotiation on cost and due date.

Identification of the most common set of decision criteria in each decision point across the whole chain requires extensive research through close collaboration of major companies involved in BTO-SC. Considering the widespread application of SCM software packages in global supply chains, further feasibility studies are needed to identify practical ways for implementing such decision supports on available software systems. Finally, efficient solution tools capable of finding good solutions in a very short time (a few seconds) are crucial for the wider application of this idea in practice. To facilitate these opportunities, further research on heuristic and metaheuristic solution tool development is of high importance.

References

Amid, A., Ghodsypour, S. H. & O'Brien, C. (2006), 'Fuzzy multiobjective linear model for supplier selection in a supply chain', *International Journal of Production Economics* **104**, 394–407.

Biswas, S. & Narahari, Y. (2004), 'Object oriented modeling and decision support for supply chains', *European Journal of Operational Research* **153**, 704–726.

Blecic, I., Cecchini, A. & Trunfio, G. A. (2007), 'A decision support tool coupling a causal model and a multi-objective genetic algorithm', *Applied Intelligence* **26**, 125–137.

Chou, S.-Y. & Chang, Y.-H. (2008), 'A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach', *Expert Systems with Applications* **34**, 2241–2253.

Christensen, W. J., Germain, R. & Birou, L. (2005), 'Build-to-order and just-in-time as predictors of applied supply chain knowledge and market performance', *Journal of Operations Management* **23**, 470–481.

Coello Coello, C. A., Van Veldhuizen, D. A. & Lamont, G. B. (2002), *Evolutionary Algorithms for Solving Multi-Objective Problems*, Kluwer Academic Publishers, New York.

Collette, Y. & Siarry, P. (2004), *Multiobjective Optimization: Principles and Case Studies*, Springer.

Deb, K. (2001), *Multi-Objective Optimization Using Evolutionary Algorithms*, Wiley, Chichester, UK.

Dulmin, R. & Mininno, V. (2003), 'Supplier selection using a multi-criteria decision aid method', *Journal of Purchasing & Supply Management* **9**, 177–187.

Ghiassi, M. & Spera, C. (2003), 'Defining the internet-based supply chain system for mass customized markets', *Computers & Industrial Engineering* **45**, 17–41.

Gunasekaran, A. & Ngai, E. W. T. (2005), 'Build-to-order supply chain management: a literature review and framework for development', *Journal of Operations Management* **23**, 423–451.

Gunasekaran, A. & Ngai, E. W. T. (2009), 'Modeling and analysis of build-to-order supply chains', *European Journal of Operational Research* **195**, 319–334.

Hegedus, M. G. & Hopp, W. J. (2001), 'Due date setting with supply constraints in systems using MRP', *Computers & Industrial Engineering* **39**, 293–305.

Karpak, B., Kumcub, E. & Kasuganti, R. R. (2001), 'Purchasing materials in the supply chain: managing a multi-objective task', *European Journal of Purchasing & Supply Management* **7**, 209–216.

Kollat, J. B. & Reed, P. (2007), 'A framework for Visually Interactive Decision-making and Design using Evolutionary Multi-objective Optimization (VIDEO)', *Environmental Modelling & Software* **22**, 1691–1704.

Lam, K.-C., Ning, X. & Gao, H. (2008), 'The fuzzy GA-based multi-objective financial decision support model for Chinese state-owned construction firms', *Automation in Construction* (in press), doi:10.1016/j.autcon.2008.10.004.

Liao, Z. & Rittscher, J. (2007), 'A multi-objective supplier selection model under stochastic demand conditions', *International Journal of Production Economics* **105**, 150–159.

Meyr, H. (2004), 'Supply chain planning in the German automotive industry', *OR Spectrum* **26**, 447–470.

Moodie, D. R. & Bobrowski, P. M. (1999), 'Due date demand management: negotiating the trade-off between price and delivery', *International Journal of Production Research* **37**(5), 997–1021.

Moses, S., Grant, H., Gruenwald, L. & Pulta, S. (2004), 'Real-time due-date promising by build-to-order environments', *International Jurnal of Production Research* **42**(20), 4353–4375.

Ruiz-Torres, A. J. & Nakatani, K. (1998), Application of real-time simulation to assign due dates onlogistic-manufacturing networks, *in* 'Simulation Conference Proceedings', Vol. 2, pp. 1205–1210.

Sharma, A. & LaPlaca, P. (2005), 'Marketing in the emerging era of build-to-order manufacturing', *Industrial Marketing Management* **34**(5), 476–486.

Swaminathan, J. M. & Tayur, S. R. (2003), 'Models for supply chains in e-business', *Management Science* **49**(10), 1387–1406.

Tyan, J. C. & Duc, F.-K. W. T. C. (2003), 'An evaluation of freight consolidation policies in global third party logistics', *Omega* **31**, 55–62.

Wang, D., Fang, S.-C. & Hodgson, T. J. (1998), 'A fuzzy due-date bargainer for the make-to-order manufacturing systems', *IEEE Transactions on Systems, Man, and Cybernetics - Part C: Applications and Reviews* **28**(3), 492–497.

Wang, Z., Yan, R., Hollister, K. & Xing, R. (2008), 'A relative comparison of leading supply chain management software packages', *International Journal of Information Systems and Supply Chain Management* **2**(1), 81–96.

Xia, W. & Wu, Z. (2007), 'Supplier selection with multiple criteria in volume discount environments', *Omega* **35**, 494–504.