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Pareto optimization for informed decision making in supply chain management

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Abstract: This paper discusses application areas of Pareto optimization (PO) to support informed decision making in supply chain management (SCM). The main features of supply chain decisions are discussed and the capabilities of PO as a support to enhance decision making across the chain are examined. Two sample applications from online purchasing and supermarket retailing are leveraged to illustrate typical support that can be provided to customers and retailers in the process of decision making. In the first application, an online retailer deals with trade-off analysis between total purchase/delivery cost and delivery due date. The second application concerns inventory management in a supermarket where inventory cost and lost sale conversely correlate. The key decision points in a typical supply chain are then identified and mapped to potential applications of PO. Based on the preceding analyses, the paper concludes with the elaboration of salient avenues for further research.

Key words: Supply chain management, Pareto optimization, Decision support

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1. Introduction

Supply chain management involves extensive compromise and trade-offs due to inherent conflict amongst interests and preferences of the supply chain players. In other words, the goal of supply chain management is to meet the challenge of conflicting objectives by evaluating the tradeoffs (Ellram et al. 1999). In a retail supply chain for instance, the retailer desires high customer service and product variety via an adequate supply of a wide range of products. Suppliers on the other hand, need stable production runs of individual products to achieve economies of scale. Rather than resolve the conflict directly through better planning and communication, the historical approach has been to use buffer inventory to meet customer service goals as a cushion for conflicting objectives (Ellram et al. 1999). As another example, in a build-to-order supply chain (BTO-SC) a customer looks for reduced price and shorter delivery lead time while the manufacturer tries to enhance utilization of their production line and minimize inventory cost and setup changeovers. On the other hand, suppliers favor smooth demand and less order changes while logistic providers interest minimum order changes and high fleet utilization. It is obvious that all of these objectives cannot be attained at the same time so multi-objective optimization (MOO) need to be applied to provide a set of nondominated or Pareto-optimal solutions from which the decision maker can choose based on their preferences.

2. Pareto optimization

Pareto optimization (PO) is to find a vector of decision variables \tilde{x} , for a multi-objective optimization problem (MOP). Without loss of generality, such decision vector minimizes a

vector of M objective functions $f_i(\tilde{x})$ where $i = 1, 2, \dots, M$; subject to inequality constraints $g_j(\tilde{x}) \geq 0$ and equality constraints $h_k(\tilde{x}) = 0$ where $j = 1, 2, \dots, J$ and $k = 1, 2, \dots, K$. A decision vector \tilde{x} to dominate a decision vector \tilde{y} (also written as $\tilde{x} \succ \tilde{y}$) iff: $f_i(\tilde{x}) \leq f_i(\tilde{y}) \forall i \in \{1, 2, \dots, M\}$; and $\exists i \in \{1, 2, \dots, M\} \mid f_i(\tilde{x}) < f_i(\tilde{y})$.

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

The set of objective functions constitute a multidimensional space in addition to the usual decision space. This additional space is called the objective space, Z . For each solution \tilde{x} in the decision variable space, there exists a point in the objective space $f(\tilde{x}) = Z = (z_1, z_2, \dots, z_M)^T$. The reflection of Pareto-optimal set in the objective space is called *Pareto front*. Figure 1 illustrates the Pareto front for the following MOP as proposed by Deb (1999):

$$\text{Min } f_1(x_1, x_2) = x_1$$

$$\text{Min } f_2(x_1, x_2) = \left[2.0 - \exp \left\{ - \left(\frac{x_2 - 0.2}{0.004} \right)^2 \right\} - 0.8 \exp \left\{ - \left(\frac{x_2 - 0.6}{0.4} \right)^2 \right\} \right] / x_1 \quad (1)$$

$$\text{Subject to: } 0.1 \leq x_1, x_2 \leq 1.0.$$

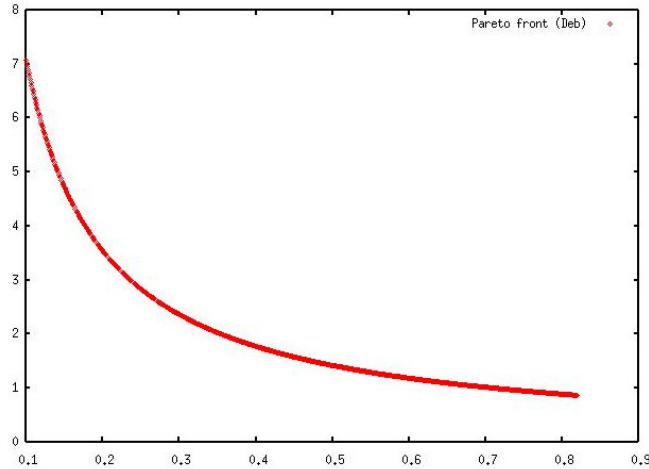


Figure 1. Pareto front for problem 1 (adapted from Deb, 1999)

There are several approaches to find Pareto-optimal front of a MOP. 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).

3. Pareto front and decision support

There are numerous examples of decision support systems based on MOO in various applications, for instance in Blečić et al. (2007) and Kollat & Reed (2007). However, the application of MOO as a decision support in the SCM field however is largely absent from the literature. An initial report of potential applications of MOO as a decision support for BTO-SCs can be found in Mansouri & Gallear (2009).

A decision support system (DSS) is a model-based set of procedures to assist managers in making informed decisions (Little, 2004). Generally speaking, a DSS contains four main

components: data base (DB), model base (MB), knowledge base (KB), and a graphical user interface (GUI) (see Figure 2). The database stores the data, model and knowledge bases store the collections of models and knowledge, respectively, and the GUI allows the user to interact with the database, model base, and knowledge base. The knowledge base may contain simple search results for analyzing the data in the database. In this paper we elaborate on Pareto optimization as part of the MB.

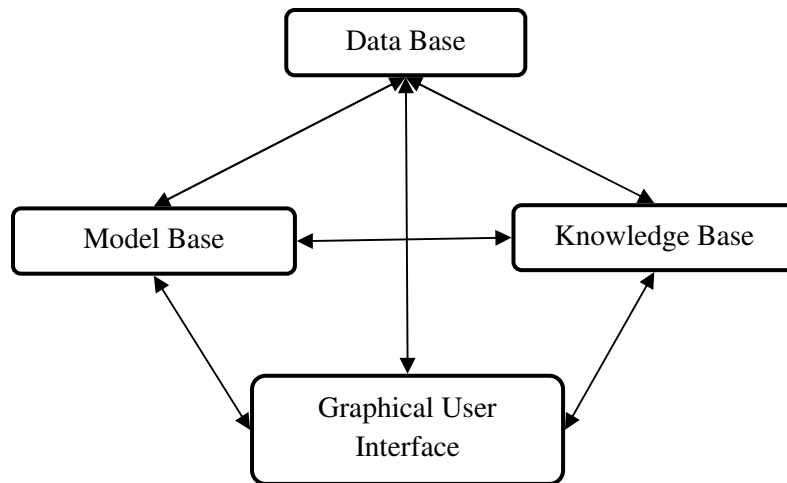


Figure 2. The main components of a typical decision support system

4. Trade-off analysis in price-delivery decisions

In this section we discuss potential applications of trade-off analysis as a decision aid in company ABC's supply chain; a major online retailer of home appliances in the UK. The main parties involved in ABC's supply chain include: *i.* the ABC; *ii.* customers; *iii.* the logistics service provider; and *v.* manufacturers.

There are three delivery options are available to customers. These include:

- normal delivery within 7-10 days (at normal price);
- next day delivery (at higher price);
- long (more than two weeks) delivery (free of charge).

The varied prices are due to the following three scenarios for stock availability:

- the item is available in the ABC warehouse (will be distributed from the main DC directly to customer);
- the item is not available in appliances online warehouse but is available in manufacturers' warehouse (just-in-time delivery is possible);
- the item is not available in ABC warehouse nor in manufacturers' but can be promised for a later delivery based on prior agreement with manufacturers.

A PO-based decision aid can be designed for trade-off analysis in customer interface to provide customer with alternative options as to overall cost and delivery due date. The system will take into account the current status of orders, inventory levels in the warehouse, inventories available in manufacturers' warehouses (for just-in-time deliveries), planned routes for the trucks, etc. and provide customer with various options as to delivery time and cost. It is assumed that under this scenario, order placing, routing and truck allocation and purchase orders to manufacturers (in case the item is not available in stock) are integrated and can be done simultaneously. The result of such trade-off will specify: the route, truck, source of supply and delivery date along with

associated total cost of purchase and delivery to be paid by customer. Table 1 represents the Pareto-optimal solutions for a given product. The purchase and delivery plans referred in this table will contain the following details for ABC:

- the source of supply (own warehouse, manufacturer’s warehouse) for items available on the given dates;
- purchase order to the manufacturer for out-of stock items. Such orders can be made at discount price (advance purchasing) or at higher price (for fast supply). Such agreements need to be made in advance with manufacturers;
- the route and truck for the delivery.

The above information will be available to ABC; the customer only sees the final outcome as price and delivery time to choose from. These solutions are depicted in Figure 3. Looking at this figure, a customer can make an informed decision and balance the delivery date and price based on their preferences.

5. Trade-off analysis for inventory management

This section outlines a potential application of PO for inventory management decisions for a retailer who carries about 4000 stock keeping units (SKU). Based on the forecasted demand, PO can provide trade-off solutions indicating the best combination of safety stock for the SKUs along with their associated average in stock inventory and expected lost sale. Table 2 represent the results of such analysis using synthetic data. In this table, each row represents an inventory

Table 1: Prices of product X to be delivered to customer Y in different days

Purchase/delivery plan	Total purchase and delivery cost (£)	Delivery due (day)
1	450	1
2	440	2
3	438	3
4	435	4
5	430	5
6	430	6
--	N/A	7
8	430	8
9	430	9
10	428	10
11	428	11
12	425	12
13	425	13
14	N/A	14
...
30	410	30-44
45	400	45-59
60	385	60-90

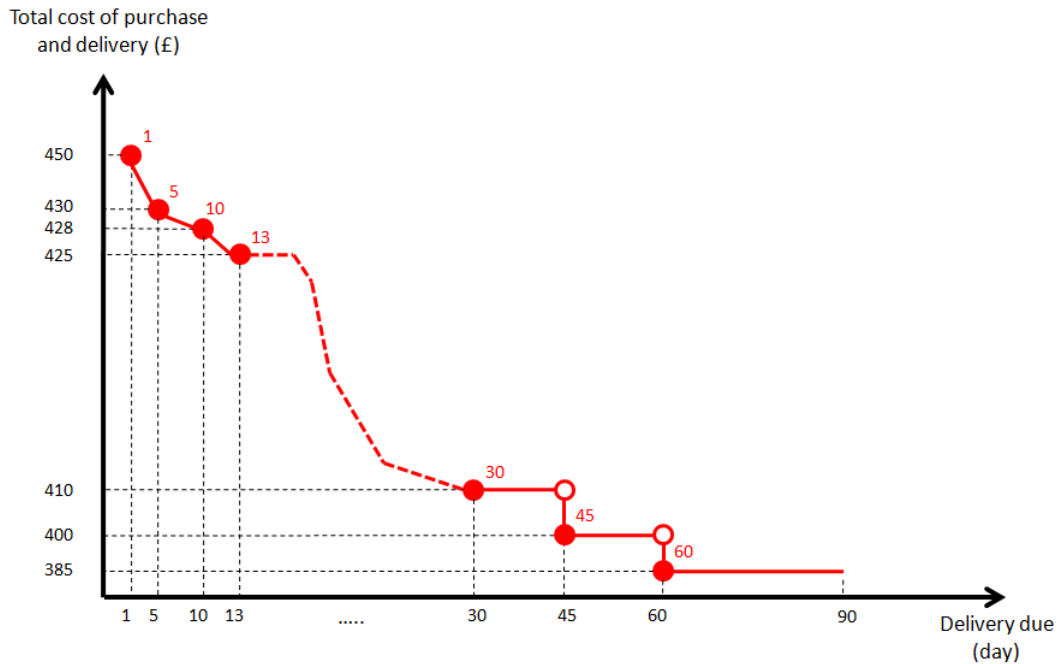


Figure 3. Trade-off between total purchase/delivery cost and delivery due date

plan outlining the level of safety stock for each SKU and its associated average inventory and expected lost sale. Figure 4 depicts similar results in the form of a trade-off curve which visualises the shape of trade-off. This curve provides further insight as to the correlation between inventory cost and lost highlighting the areas in which significant improvements can be made.

Table 2: Best inventory plans at different levels of expected lost sale

Inventory plan	Average in stock inventory (£1000)	Expected Lost Sale%
1 (SKU ₁ =5,...SKU ₄₀₀₀ =3)	15,000	5.5
2 (SKU ₁ =3,...SKU ₄₀₀₀ =4)	10,000	6.0
3 (SKU ₁ =6,...SKU ₄₀₀₀ =2)	8,500	7.2
...
100 (SKU ₁ =2,...SKU ₄₀₀₀ =0)	2,000	67.5

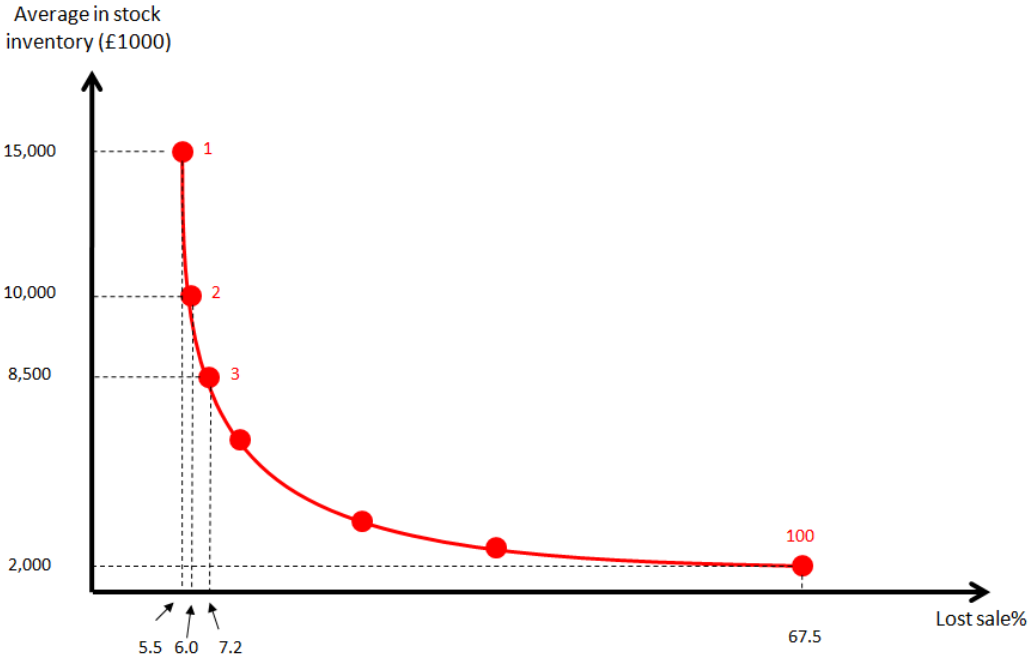


Figure 4. Trade-off between average inventory and lost sale

For instance, in the left side of the curve, massive savings in inventory levels is achievable if some minor extra lost sale can be tolerated. On the other hand and in the right hand side of the graph, one can see that lost sale can be massively decreased by some minor increment in inventory levels. In short, the trade-off analysis will assist decision makers in choosing an inventory plan that suits their marketing strategies, customer service and financial circumstances.

6. Key decision points in supply chains

There are major decision interfaces in a typical supply chain where decision making involves multiple criteria and/or multiple parties. Customers, manufacturers, retailers, distributors, logistic providers and suppliers are the main parties of a generic supply chain. There are several interfaces for which similar PO-based decision aids can facilitate negotiation, mediation and decision making. For instance: customer-manufacturer, retailer-supplier, retailer-distributer-customer, manufacturer-supplier, manufacturer-logistics service provider, distributor-logistics service provider. Figure 5 illustrates a set of potential decision interfaces.

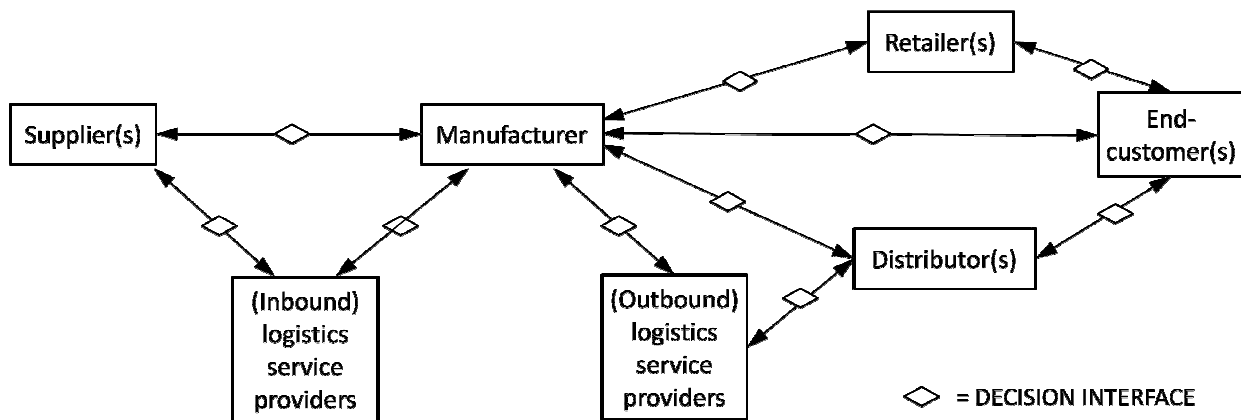


Figure 5. Decision interfaces in a typical supply chain

A number of supply chain related optimization problems in which more than two parties are involved have already appeared in the literature. For example, assuming the manufacturer as the focal point of a supply chain as is generally common practice is SCM research, on the supply side of the chain Kawtummachai and Hop (2005) developed and tested a solution algorithm for order allocation in a multiple-supplier environment. In their application, the decision problem concerned the allocation of products to suppliers and the respective order quantities, such that the total cost of purchasing is minimized at a specified service level. More recently, Amodeo et al. (2009) demonstrated multi-objective simulation based optimization for inventory management using metaheuristics. On the demand side of the chain Chen et al. (2007) examined coordination mechanisms for distribution systems. Specifically, they studied a distribution channel where a supplier distributes to retailers a single product who then sell the product to retailers, and presented an optimal strategy where total system wide profits are maximized in a centralized system. Zhou et al. (2003) used genetic algorithm to find Pareto optimal solutions in a short period of time for bi-criteria allocation decision problem of customer to warehouses with different capacities. Selim et al. (2008) considered the problem of collaborative production-distribution planning in supply chains using a multi-objective linear programming model. Applications have also extended beyond the dyadic perspective. A case in point is Xue et al. (2005), who applied a MOO algorithm based on the principles of multi-objective differential evolution (MODE) to design-supplier-manufacturer (DSM) planning in the in the context of printed circuit board assembly (PCBA) industry. These applications are not meant to be an exhaustive list, but collectively they clearly demonstrate the range of potential applications for Pareto optimization techniques.

7. Concluding remarks

This paper has examined the capabilities of Pareto optimization as a support tool to enhance decision making in the management of supply chain activities. Two application examples have been demonstrated in different contextual settings. We are interested in identifying and exploring further application possibilities. Our starting point has been to recognize the different decision interfaces where decision making takes place and decision aids can be applied. Against this conceptual schema, an initial examination of the literature supports the proposition that Pareto optimization is a viable tool that managers can use for better informed decision making.

With the increasing complexity of supply chains (and networks), our goal is to extend these existing applications and provide a comprehensive framework describing Pareto optimization alternatives at the various supply chain interfaces that can be tested through future research in real-life settings. Perhaps the biggest challenge to exploiting Pareto optimization techniques is convincing practitioners of their value. This is likely to require demonstrated success over an extended period of time, and hence gaining access to open-minded trial firms will be a key stage in the application and exploitation of Pareto optimization in supply chain decision making.

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