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Int. J. Production Economics 91 (2004) 1–15
international journal of production economics
www.elsevier.com/locate/dsw

Product-driven supply chain selection using integrated multi-criteria decision-making methodology

Ge Wang[a], Samuel H. Huang[b,*], John P. Dismukes[a]

[a] Center for Manufacturing Value Chain Science, University of Toledo, Toledo, OH 43606, USA
[b] Intelligent CAM Systems Laboratory, Department of Mechanical, Industrial and Nuclear Engineering, University of Cincinnati, Cincinnati, OH 45221, USA

Received 1 November 2001; accepted 1 June 2003

Abstract

Effective supply chain design calls for robust analytical models and design tools. Previous works in this area are mostly Operation Research oriented without considering manufacturing aspects. Recently, researchers have begun to realize that the decision and integration effort in supply chain design should be driven by the manufactured product, specifically, product characteristics and product life cycle. In addition, decision-making processes should be guided by a comprehensive set of performance metrics. In this paper, we relate product characteristics to supply chain strategy and adopt supply chain operations reference (SCOR) model level I performance metrics as the decision criteria. An integrated analytic hierarchy process (AHP) and preemptive goal programming (PGP) based multi-criteria decision-making methodology is then developed to take into account both qualitative and quantitative factors in supplier selection. While the AHP process matches product characteristics with supplier characteristics (using supplier ratings derived from pairwise comparisons) to qualitatively determine supply chain strategy, PGP mathematically determines the optimal order quantity from the chosen suppliers. Since PGP uses AHP ratings as input, the variations of pairwise comparisons in AHP will influence the final order quantity. Therefore, users of this methodology should put greater emphasis on the AHP progress to ensure the accuracy of supplier ratings.

Keywords: Supply chain; Analytic hierarchy process; Product life cycle; SCOR model

1. Introduction

A supply chain is "an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials/components, (2) convert these raw materials/components into specified final products, and (3) deliver these final products to retailers" (Beamon, 1998). This chain is traditionally characterized by the flow of materials and information both within and between business entities. Supply chain management is the use of information technology to endow automated intelligence to the planning and control of the flow of supply

*Corresponding author.
E-mail address: shuang@gauss.mie.uc.edu (S.H. Huang).

0925-5273/$ - see front matter
doi:10.1016/S0925-5273(03)00221-4

chain to speed time to market, reduce inventory levels, lower overall costs and, ultimately, enhance customer service and satisfaction. The ultimate goal of supply chain management is to meet customer's demand more efficiently. Briefly speaking, for a manufacturing enterprise, it is to make the right product, for the right customer, in the right amount, at the right time.

Current research on supply chain management covers conceptual issues and managerial themes (Cox and Lamming, 1997), frameworks for strategy implementation (Harland, 1996), social aspects of supply chain management (Price, 1996), coordinated management of the supply chain (Thomas and Griffin, 1996), the application of inter-organizational information systems in supply chain (Holland, 1995), design and analysis of supply chain models (Beamon, 1998), etc. It has been realized that individual investigation of various processes of the supply chain is not sufficient. Rather, the design and analysis of the supply chain as a whole is critical to achieve efficient supply chain management. In other words, effective supply chain design and integration is the key to reducing costs.

Research in the design category involves contributions from different disciplines. Design of the supply chain determines its structure, i.e., it focuses on the location of decision spots and the objectives of the design (Arntzen et al., 1995; Berry and Naim, 1996; Mourits and Evers, 1995; Revelle and Laporte, 1996; Towill et al., 1992). Design of the chain should be able to integrate the various elements of the chain and should strive for the optimization of the chain rather than the entities or group of entities. Information sharing and its control play a vital role in integration of the different elements of the chain and require highly coordinated efforts of both engineers and managers (Fisher and Raman, 1996; Lee et al., 1997; Moinzadeh and Aggarwal, 1997; Srinivasan et al., 1994). Design needs to focus primarily on the objectives and not just the development of tools used in decision making. This paper primarily deals with the design/selection of an appropriate supply chain configuration to achieve optimal performance, which is measured using a standard set of metrics.

2. Background

Due to shortened product life cycles, rising manufacturing costs, and the globalization of market economies, increasing attention has been placed on supply chain management. In the United States, annual expenditures on non-military logistics are estimated at $670 billion, which is over 11% of the gross national product (GNP). For US manufacturing firms, it is common that logistics costs account for 30% of cost of goods sold (Bigness, 1995). With improved supply chain management, product costs can be reduced significantly while excellent product quality and customer services are maintained.

2.1. Product characteristics and supply chain strategy

Generally, products can be categorized into three types, namely, functional, innovative, and hybrid (Huang et al., 2002). Functional products' demand can be forecasted quite accurately and their market share remains fairly constant. They enjoy a long life cycle with superficial design modification leading to different product types. Innovative products are new products developed by organizations to capture a wider share of the market. They are significantly different from the available product types and are more adapted to the customer requirements (mass customization). They, at times, represent a breakthrough in product design. Innovative products are the result of customer designs, which indicate his/her ever-changing requirements. Hybrid products can consist of either (a) different combinations of functional components, and (b) mix of functional and innovative components. All products have a life cycle, typically depicted as a curve of unit sales for a product category over time (Wiersema, 1982), which can be classified into four discrete stages: introduction, growth, maturity and decline.

Typically, supply chain can be classified into three categories: *lean supply chain* (LSC), *agile supply chain* (ASC), and *hybrid supply chain* (HSC). An LSC employs continuous improvement processes to focus on the elimination of waste or non-value stops across the chain. It is supported by the reduction of set-up times to allow for the economic production of small quantities, thereby achieving cost reduction, flexibility, and aiming for external responsiveness by responding to customer requirements. The LSC can provide higher profits and internal manufacturing efficiency when product demand is stable and can be accurately forecasted. If necessary, it may sacrifice customer responsiveness to achieve cost efficiency.

An ASC basically focuses on responding to unpredictable market changes and capitalizing on them. It tries to achieve a speedier delivery and lead time flexibility. It deploys new technologies and methods, utilizes information systems/technologies and data interchange facilities, puts more emphasis on organization issues and people (knowledge and empowered employees), integrates the whole businesses process, enhances innovations all over the company, and forms virtual companies and production based on customer designed orders.

Along with the lean and ASC, the existence of an intermediate chain known as the HSC was proposed (Huang et al., 2002). An HSC generally involves ‘‘assemble to order’’ products whose demand can be quite accurately forecasted. The chain helps to achieve mass customization by postponing product differentiation until final assembly. Both lean and agile techniques may be utilized for component production. The company–market interface has to be agile to understand and satisfy customer requirements by being responsive, adaptable and innovative. Different product types at different stages of life cycle might need different supply chain strategies. Table 1 summarizes the supply chain classification based on product type and life cycle. Table 2 provides a comparison of different types of supply chains.

2.2. *Analytic hierarchy process (AHP)*

AHP is a decision-making tool that can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, subcriteria and alternatives (Saaty, 1990). Applications of AHP have been reported in numerous fields such as conflict resolution, project selection, budget allocation, transportation, health care, and manufacturing (Harker, 1989). More and more researchers are realizing that AHP is an important generic method and are applying it to various manufacturing areas (Andijani and Anwarul, 1997; Chan et al., 2000; Liu et al., 1999; Jiang and Wicks, 1999; Lin and Yang, 1996). In addition to the wide application of AHP in manufacturing areas, recent research and industrial activities of applying AHP on other selection problems are also quite active (Tam and Tummala, 2001; Lai et al., 1999; El-Wahed and Al-Hindi, 1998; Schniederjans and Garvin, 1997; Tummala et al., 1997).

AHP’s hierarchic structure reflect the natural tendency of human mind to sort elements of a system into different levels and to group like elements in each level (Saaty, 1982). From a human factor point of view, AHP can be a very effective tool to assist human decision making. A study conducted by Lehner and Zirk (1987) show that when a human being and an intelligent machine cooperate to solve problems, but where each employs different problem-solving procedures, the user must have an accurate model of how that machine operates. This is because when people deal with complex, interactive systems, they usually build up their own conceptual mental model of the system. The model guides their actions and helps them interpret the system’s

Table 1
Supply chain classification based on product type and product life cycle

Product life cycle	Product type		
	Functional	Innovative	Hybrid
Introduction	Lean supply chain	Agile supply chain	Hybrid supply chain
Growth	Lean supply chain	Agile supply chain	Hybrid supply chain
Maturity	Lean supply chain	Hybrid/lean supply chain	Hybrid supply chain
Decline	Lean supply chain	Hybrid/lean supply chain	Hybrid supply chain

Table 2
Comparison of lean, hybrid, and agile supply chains

Category	Lean supply chain	Hybrid supply chain	Agile supply chain
Purpose	Focuses on cost reduction, flexibility and incremental improvements for already available products Employs a continuous improvement process to focus on the elimination of waste or non-value added activities across the chain	Interfaces with the market to understand customer requirements, maintaining future adaptability Tries to achieve mass customization by postponing product differentiation until final assembly and adding innovative components to the existing products	Understands customer requirements by interfacing with the market and being adaptable to future changes Aims to produce in any volume and deliver into a wide variety of market niches simultaneously Provides customized products at short lead times (responsiveness) by reducing the cost of variety
Approach to choosing suppliers	Supplier attributes involve low cost and high quality	Supplier attributes involve low cost and high quality, along with the capability for speed and flexibility, as and when required	Supplier attributes involve speed, flexibility, and quality
Inventory strategy	Generates high turns and minimizes inventory throughout the chain	Postpone product differentiation till as late as possible. Minimize functional components inventory	Deploys significant stocks of parts to tide over unpredictable market requirements
Lead time focus	Shorten lead-time as long as it does not increase cost	Is similar to the lean supply chain at component level (shorten lead-time but not at the expense of cost). At product level, to accommodate customer requirements, it follows that of an agile supply chain	Invest aggressively in ways to reduce lead times
Manufacturing focus	Maintain high average utilization rate	It is a combination of lean and agile, where the beginning part is similar to lean and the later part is similar to agile	Deploy excess buffer capacity to ensure that raw material/components are available to manufacture the product according to market requirements
Product design strategy	Maximize performance and minimize cost	Components follow the lean concept (cost minimization) at the beginning. Modular design helps in product differentiation towards the latter stages	Use modular design in order to postpone product differentiation for as long as possible

behavior. Such a model, when appropriate, can be very helpful or even necessary for dealing successfully with the system. However, if inappropriate or inadequate, it can lead to serious misconceptions or errors (Young, 1981). Therefore, it is very important for decision makers to be able to understand the decision-making model structure, while AHP just provides such a simple, easily understood, and flexible model structure.

2.3. Brief review and analysis of supplier selection methodologies

The problem of supplier selection is not new. Before supply chain management becomes a buzzword, the problem of supplier selection is called vendor selection. First publications on vendor selection can be traced back to the early 1960s. These early research activities are summarized in a literature review by Weber et al. (1991). Ghodsypour and O'Brien (1998) also provided a short but insightful overview of supplier selection research. Interested readers should refer to these two papers for more information. Here, we classify research on supplier selection into three major categories and listed a few representative publications in Table 3.

From Table 3, one can see that quite a few researchers treat the supplier selection problem as an optimization problem, which requires the formulation of an objective function. Since not every supplier selection criterion is quantitative, usually only a few quantitative criteria are included in the optimization formulation. This problem is recognized by Ghodsypour and O'Brien (1998), which proposed an integrated method that use AHP and linear programming to deal with both qualitative and quantitative criteria. Our methodology follows this philosophy but has a distinctive feature, namely, it is guided by a product driven supply chain design strategy.

It is well known that problem formulation is critical to the success of optimization. Therefore, we should first answer the following questions: (1) what supplier selection criteria to use? (2) How to use them? The first question is relatively easy to answer. We should use a set of criteria that are well accepted. The second question is often ignored by researchers since they usually assign fixed weights to the criteria. However, researchers in strategic supply chain design (Huang et al., 2002; Fisher, 1997) have established that different products require different suppliers and this can only be accomplished through appropriate use of the selection criteria. We believe we are the first to integrate this strategy into a quantitative supplier selection methodology.

3. Problem definition and SCOR model

Supplier selection is an essential step in supply chain design. Typically, supplier selection involves multiple criteria and usually, it is quite difficult to

Table 3
Summary of supplier selection research

Category		Author(s)
Criteria	Identification	Stamm and Golhar (1993), Ellram (1990), Roa and Kiser (1980)
	Analysis	Choi and Hartley (1996)
Strategy	Three-stage model	Davidrajuh (2003)
	Product-driven model	Huang et al. (2002), Fisher (1997)
Optimization	Linear programming	Pan (1989), Kingsman (1986), Anthony and Buffa (1977), Moore and Fearon (1973)
	Mixed integer programming	Rosenthal et al. (1995), Chaudhry et al. (1993), Turner (1988), Narasimhan and Stoynoff (1986), Bender et al. (1985), Gaballa (1974)
	Goal programming	Sharma et al. (1989), Buffa and Jackson (1983)
	Multi-objective programming	Liu et al. (2000), Weber and Current (1993)
	Non-linear programming	Hong and Hayya (1992), Benton (1991)

find an optimal solution. Traditional techniques in operations research mainly deal with quantitative measures, while vagueness and uncertainty, which is described by qualitative measures, exists everywhere within the supply chain. A technique that can deal with both quantitative and qualitative measures is needed to better model such situation.

3.1. Problem definition

Generally speaking, the manufacturing supply chain design decision-making process, from a manufacturing company's standpoint, could be described as follows: A typical manufacturing company A lies in a common manufacturing supply chain, which includes its suppliers, distributors, and final customers. Company A produces m products. For each product P_i (product index $i = 1, 2, \ldots, m$), it may consist of n_i major components, which need to be outsourced (Company A might have capacities to produce the other components by itself). For each outsourced component C_{ij} (component index $j = 1, 2, \ldots, n_i$), there are k_{ij} potential suppliers to choose from. Each potential supplier S_{ijx} (supplier index $x = 1, 2, \ldots, k_{ij}$) has a known production capacity R_{ijx}. According to the production plan, company A will purchase T_{ij} units of component C_{ij} from one or more suppliers out of the whole set of potential suppliers for component C_{ij} based on company A's predefined supplier selection criteria considering each supplier's production capacity. In summary, company A will make decision:

- to choose *most favorable supplier(s)* for various outsourced components to meet its supplier selection criteria
- to order various quantities from the chosen *most favorable supplier(s)* to meet its production plan

3.2. Supply chain operations reference (SCOR) model

Supply Chain Council (SCC) constructed a descriptive framework called SCOR (SCC, 1999). SCOR is a standard supply chain process reference model designed to embrace all industries. SCOR enables companies to communicate supply chain issues, measure their performance objectively, identify performance improvement objectives, and influence future SCM software development. It includes all the metrics that might exist in a supply chain, the formulae associated with the metrics, a reference to best practices vis-à-vis the metrics, and technology that can contribute to achieving best practices.

Operating a supply chain is far different from running a stand-alone company, so are the metrics. The SCOR model endorses 12 performance metrics, which fall into four defining categories:

1. Delivery reliability:
   1.1. delivery performance (DR1),
   1.2. fill rate (DR2),
   1.3. order fulfillment lead time (DR3),
   1.4. perfect order fulfillment (DR4).
2. Flexibility and responsiveness:
   2.1. supply chain response time (FR1),
   2.2. production flexibility (FR2).
3. Cost:
   3.1. total logistics management cost (CT1),
   3.2. value-added productivity (CT2),
   3.3. warranty cost or returns processing cost (CT3).
4. Assets:
   4.1. cash-to-cash cycle time (AT1),
   4.2. inventory days of supply (AT2),
   4.3. asset turns (AT3).

These performance metrics are adopted as the standard criteria for evaluating a company's performance. It should be noted that the solution methodology (described in Section 4) is generic and does not depend on the metrics used. In other words, the same methodology can be used if a company decides to either remove or add metrics.

4. Solution methodology

The developed methodology is based on AHP and preemptive goal programming (PGP), incorporating both quantitative and qualitative factors. It applies a *decomposition–synthesis* approach to solve the supplier selection problem. Fig. 1

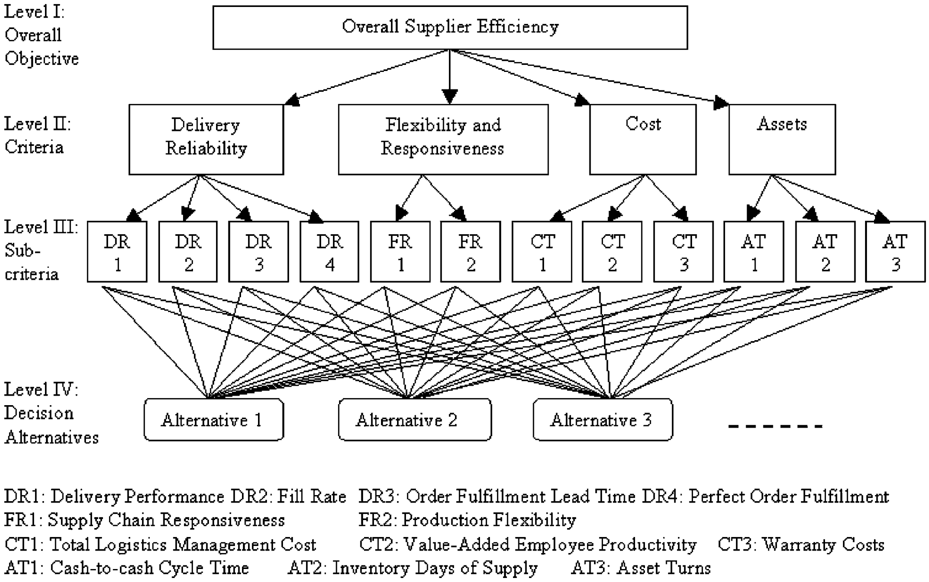

Fig. 1. Proposed AHP Model for SCOR Level I performance metrics hierarchy.

schematically illustrates the developed AHP-based model for SCOR level I performance metrics hierarchy.

The model presented in this paper applies the AHP, which uses pairwise comparison, to make the trade-off between tangible and intangible factors and calculate a rating of suppliers. By applying these ratings as coefficients of an objective function in PGP, the model can allocate order quantities among the favorable suppliers such that the manufacturing organization (customer) can choose the most favorable and least number of suppliers to achieve maximum efficiency. Fig. 2 shows the integrated AHP–PGP algorithm for supplier selection. Steps of the algorithm based on AHP and PGP are briefly summarized as follows:

Part A. Apply decomposition-synthesis approach using AHP.

Step 1. Decompose problem: The underlying multi-criteria decision-making problem is decomposed according to its main components. The overall goal of supplier selection is to achieve optimal supplier efficiency. The efficiency measure consists of four categories, namely, delivery reliability, flexibility and responsiveness, cost, and assets. Each category consists of a number of specific performance metrics, which are identified in Step 2.

Step 2. Define criteria for supplier selection: SCOR model level I performance metrics are used as the criteria for supplier selection. This is a set of standard performance measures endorsed by SCC, which is intended to be a standard for the supply chain industry.

Step 3. Design the hierarchy: The hierarchy consists of the overall goal, criteria, sub-criteria (could have several levels), and the decision alternatives. Fig. 1 schematically illustrates the proposed hierarchy based on SCOR metrics.

Step 4. Perform pairwise comparison and prioritization: Once the problem has been decomposed and the hierarchy constructed, prioritization procedure starts in order to determine the relative importance of the elements within each level. The pairwise judgment starts from Level II and continues on to Level III (Fig. 1). Based on product characteristics and corresponding supply chain strategies, the relative importance of the criteria and sub-criteria (performance metrics) is determined by experienced managers.

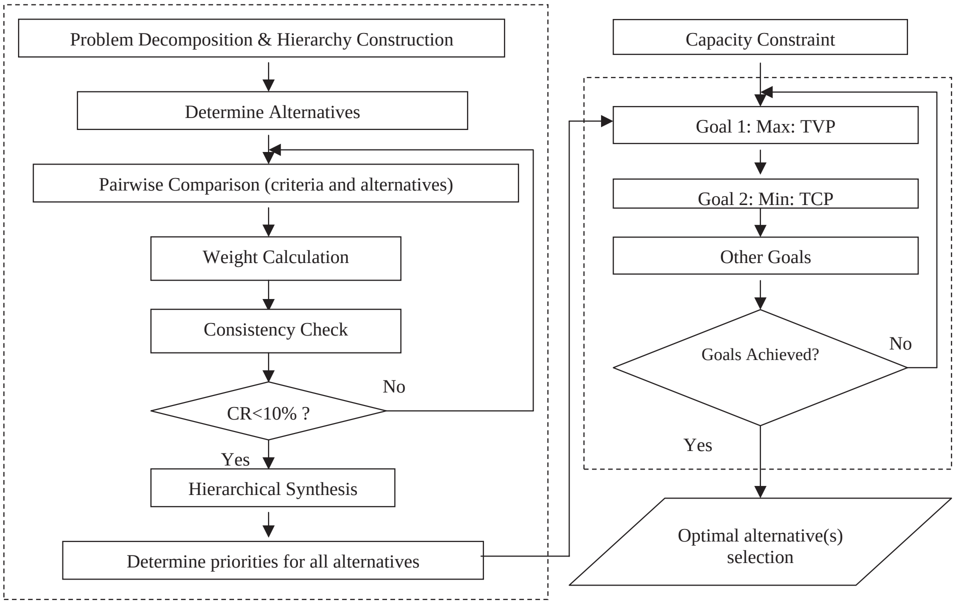

Fig. 2. An Integrated AHP–PGP algorithm for supplier selection.

Step 5. Rate the alternative suppliers: Similar to Step 4, the decision alternatives should be compared pairwisely. The comparison is made with respect to each of the 12 sub-criteria at level III.

Step 6. Calculate the weights of the criteria: Generally, given a pairwise comparison matrix, the priority weights for each attribute can be calculated based on standard methods provided by Satty (1980).

Step 7. Compute the overall score of each supplier/hierarchical synthesis: By integrating the assigned weights of criteria and supplier's rating, the final score of each supplier is determined in order to develop an overall evaluation process.

Step 8. Make overall decision: The supplier (decision alternative) that has the highest rating is the best choice. If there are no capacity constraints, this supplier is chosen to satisfy all the product demand. Otherwise, suppliers with lower ratings need to be considered. The decision process is presented in Part B.

Part B. Build the PGP model considering the constraints.

If there are some constraints, such as supplier's capacity, number of suppliers required, etc., then we should use the supplier's rating as coefficients of an objective function in PGP to assign order quantities to the selected suppliers. The PGP problem formulation for supplier selection within a manufacturing supply chain is shown step by step as follows:

Step 9. Define decision variables for goal programming:

Q_x Purchasing quantity from supplier x
E_f Amount of over-achievement for Goal f
U_f Amount of underachievement for Goal f

where

x Supplier index, $x = 1, 2, 3, \ldots, k_{ij}$
f Goal (priority) index, $f = 1, 2, 3, \ldots, F$

Step 10. Define the parameters:

T_{ij} Customer demand for component j or product i
TVP Total value of purchase
TCP Total cost of purchase
D_x Unit purchasing cost of supplier x
R_x Production capacity of supplier x
F Number of goals (priorities), which is defined in Step 12

k_{ij} Total number of potential alternatives for component j of product i
W_x AHP weight for supplier x

Step 11. State the constraints:

$$R_x \geqslant Q_x, \tag{1}$$

$$Q_x \geqslant 0, \tag{2}$$

$$\sum_{x=1}^{kij} Q_x = T_{ij}. \tag{3}$$

Step 12. Determine the preemptive priorities incorporating AHP weights:

Priority 1. Maximize the TVP,

$$\sum_{x=1}^{kij} W_x^* Q_x + U_1 - E_1 = \text{TVP}. \tag{4}$$

Priority 2. Minimize the total cost of purchase,

$$\sum_{x=1}^{kij} D_x^* Q_x + U_2 - E_2 = \text{TCP}. \tag{5}$$

Step 13. Determine the detrimental deviation:

$P1 : U_1,$
$P2 : E_2.$

Step 14. State the priority objectives:

$$P1 : \min U_1, \tag{6}$$

$$P2 : \min E_2. \tag{7}$$

The priority objectives are to minimize detrimental deviation $P1$ and $P2$ defined in Step 13.

Step 15. Find the optimal solution:

By using commercial software tool for goal programming, such as WinQSB®, Lingo®, etc., the optimal solution to the goal programming can be obtained. The optimal solution will decide which supplier(s) will be chosen (any x, where $Q_x > 0$) and how many items they need to supply (Q_x^*).

5. Illustrative example

GW Inc. is a hypothetical car manufacturer that can produce various functional components, such as, engine, body, glass components, etc. Only three components for GW Inc. need to be outsourced, i.e. tires, electronics, and peripherals. Considering the supplier selection criteria defined in Section 3.2, some observations can be made. The 12 performance metrics are classified into four categories. It is very difficult for a supplier to achieve excellent performance in all the categories. Therefore, it is necessary for GW Inc. to prioritize the performance category based on component characteristics and customer needs. Consider tires first, they are functional products where customer demands are stable. Therefore, the focus should be on reducing costs, while flexibility and responsiveness are not so important. Now consider peripherals, to satisfy customers' personal preference, GW Inc. plans to offer a large variety of combinations. In the mean time, new peripherals (such as navigation systems) appear due to rapid technology changes. Therefore, peripherals are considered innovative products where customer demands are difficult to forecast. In this case, flexibility and responsiveness become the priority, while cost issues are secondary. Finally, electronics require mass customization, yet its aggregated demand is stable. Therefore, they are considered hybrid products where the concept of postponement can be used—differentiate late in the manufacturing process with short lead time items, and standardize long lead time items to be processed early in the supply chain. In this case, a more balanced view towards cost and flexibility requirements should be taken.

For each of the three components, there are several potential suppliers that have been certified by the Quality Assurance Department of GW Inc. It is a common practice for manufacturing companies to use certain quality criteria (such as ISO 9000 certification) to identify a limited number of potential suppliers. This pre-selection process reduces the number of decision alternatives. It can be carried out based on strategic quality management practices, such as those presented by Tummala and Tang (1996). Our proposed AHP–PGP methodology does not deal with this process and assumes immediate availability of this information.

It is assumed that only three potential suppliers are qualified to supply each outsourced component, respectively. A_1, A_2 and A_3 represent the three potential suppliers for tires, A_4, A_5 and A_6 represent the three potential suppliers for electronics, and A_7, A_8 and A_9 represent the three potential suppliers for peripherals. Furthermore, A_1, A_4 and A_7 are assumed to be lean-oriented suppliers, A_2, A_5 and A_8 are assumed to be agile-oriented suppliers, and A_3, A_6 and A_9 are assumed to be hybrid-oriented suppliers. GW Inc. is considering to select the best supplier(s) for each outsourced component to meet its production plans. Table 4 lists the supplier information for each component and the OEM demand information for P_1. The data is modified from a published example (Ghodsypour and O'Brien, 1998). In order to simplify the process, the same supplier patterns (i.e. Defect rates, Unit production cost, Fill rate) for three different components of one product are applied to both products. Fig. 3 describes this supplier selection problem in a hierarchical tree.

As indicated in Section 3.1, GW Inc. will make the following decisions:

1. To choose *most favorable supplier(s)* from the potential suppliers (A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8 and A_9) for the three outsourced components, namely, tires, electronics and peripherals, for product P_1, to meet the company's supplier selection criteria—SCOR Model Level I performance metrics.

Table 4
Supply and demand information for GW's product P1

Component	Tires			Electronics			Peripherals		
Supplier	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
Capacity (units)	400	700	600	100	300	200	150	200	150
Defect rate	1%	3%	2%	1%	3%	2%	1%	3%	2%
Unit purchasing cost ($)	0.6	2.4	1.2	0.6	2.4	1.2	0.6	2.4	1.2
Fill rate	80%	90%	98%	80%	90%	98%	80%	90%	98%
OEM demand (units)	1000			250			250		
Max. acceptable defect rate	2%			2%			2%		

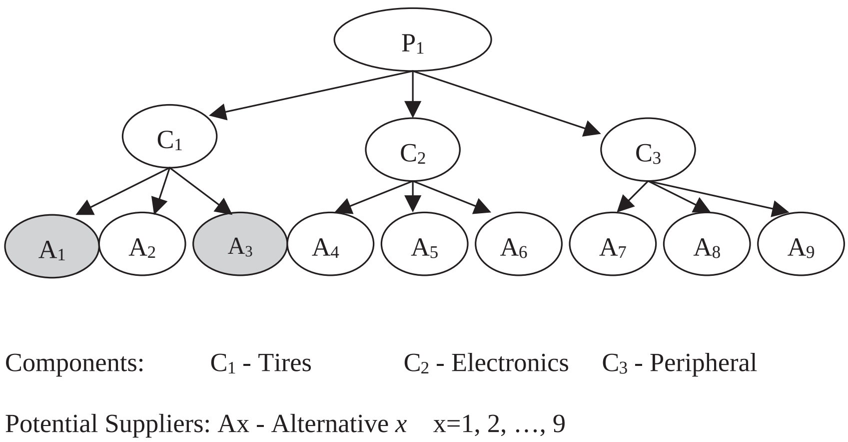

Fig. 3. Hierarchical tree illustration of supplier selection for P1.

2. To order various quantities from the chosen *most favorable supplier(s)* to meet its production plan shown in Table 4.

When using the proposed methodology, company managers need to first prioritize the performance metrics based on the three different supply chain strategies. This is done by using pairwise comparison with Saaty's 1–9 scales. The final AHP ratings for lean, agile, and HSC strategies are shown in Tables 5–8, respectively. Note that pairwise comparison involves subjective ratings. Good understanding of the fundamental concepts discussed in Section 2 is the key to fill out all these rating tables accurately, which will eventually affect the final ratings of potential suppliers by the way of synthesis process. In other words, this decision-making process should be carried out by an experienced corporate manager that has good

Table 5
AHP rating for lean supply chain strategy

Overall objective	DR	FR	CT	AT
DR 0.243	DR1 0.200	FR1 0.500	CT1 0.500	AT1 0.333
FR 0.046	DR2 0.200	FR2 0.500	CT2 0.250	AT2 0.333
CT 0.640	DR3 0.200		CT3 0.250	AT3 0.333
AT 0.072	DR4 0.400			

Table 6
AHP rating for agile supply chain strategy

Overall objective	DR	FR	CT	AT
DR 0.187	DR1 0.200	FR1 0.667	CT1 0.333	AT1 0.333
FR 0.647	DR2 0.200	FR2 0.333	CT2 0.333	AT2 0.333
CT 0.082	DR3 0.200		CT3 0.333	AT3 0.333
AT 0.057	DR4 0.400			

Table 7
AHP rating for hybrid supply chain strategy

Overall objective	DR	FR	CT	AT
DR 0.198	DR1 0.200	FR1 0.667	CT1 0.500	AT1 0.333
FR 0.387	DR2 0.200	FR2 0.333	CT2 0.250	AT2 0.333
CT 0.275	DR3 0.200		CT3 0.250	AT3 0.333
AT 0.140	DR4 0.400			

Table 8
AHP rating for potential suppliers

	DR1	DR2	DR3	DR4	FR1	FR2	CT1	CT2	CT3	AT1	AT2	AT3
*A*1	0.581	0.299	0.557	0.557	0.110	0.110	0.571	0.557	0.545	0.110	0.164	0.164
*A*2	0.110	0.336	0.123	0.123	0.581	0.581	0.143	0.123	0.182	0.309	0.297	0.297
*A*3	0.309	0.366	0.320	0.320	0.309	0.309	0.286	0.320	0.273	0.581	0.539	0.539

Table 9
Selection decision-making results

Results	Suppliers		
	AHP rating (weight)	PGP result (quantity)	Final decision
Component tires			
A_1	0.499	400	Choose supplier A_1 with 400 units and A_3 with 600 units
A_2	0.171	—	
A_3	0.320	600	
Component electronics			
A_4	0.318	25	Choose supplier A_4 and A_5, each with 25 units and A_6 with 200 units
A_5	0.340	25	
A_6	0.342	200	
Component peripherals			
A_7	0.221	125	Choose A_7 and A_8, each with 125 units
A_8	0.436	125	
A_9	0.317	—	

knowledge about the suppliers and their performance.

After prioritizing the performance metrics, pairwise comparison is conducted to evaluate all the potential suppliers. Good evaluation is based on deep understanding of SCOR Model Level I performance metrics and accurate supplier information. Variations of pairwise comparison rating of alternative suppliers may affect the final ratings of suppliers. In other words, the final ratings depend on the pairwise evaluation provided by the decision maker. The decision maker's personal preference is a critical factor. To make sure that the decision maker does not make mistakes that cause conflicting ratings, a final inconsistency checking is applied. If inconsistency is detected, the decision maker is required to re-evaluate the pairwise comparisons made. Table 8 shows the final AHP ratings for all the potential suppliers. The final ratings for A_1, A_2, and A_3 are 0.499, 0.171, and 0.320, respectively. Since A_1 has the maximum rating, it is chosen as the main supplier. However, since A_1 only has a production capacity of 400 units, which cannot satisfy the demand, the decision process continues on to PGP.

The decision variables for GPG are as follows:

$x = 1, 2, 3,$
$f = 1, 2,$
$F = 2,$
$K_{ij} = 3.$

The constrains are:

$R_1 = 400 \geqslant Q_1$ (Capacity constraint)
$R_2 = 700 \geqslant Q_2$ (Capacity constraint)
$R_3 = 600 \geqslant Q_3$ (Capacity constraint)
$Q_1 + Q_2 + Q_3 = 1000$ (Demand constraint)
$1000 \times 0.02 \geqslant Q_1 \times 0.01 + Q_2 \times 0.03 + Q_3 \times 0.02$ (Quality constraint)
$R_1 \geqslant 0,$
$R_2 \geqslant 0,$
$R_3 \geqslant 0,$
$Q_1 \geqslant 0,$
$Q_2 \geqslant 0,$
$Q_3 \geqslant 0.$

The priorities are as follows:

Priority 1. Maximize TVP,

$$Q_1 \times 0.499 + Q_2 \times 0.171 + Q_3 \times 0.320 + U_1 - E_1 = \text{TVP}.$$

Priority 2. Minimize total cost of purchase (TCP),

$$Q_1 \times 0.6 + Q_2 \times 2.4 + Q_3 \times 1.2 + U_2 - E_2 = \text{TCP}.$$

A commercially available optimization software, WinQSB®, is used to facilitate the goal programming optimization process. Optimal solution can be decided: supplier A_1 and A_3 are chosen with 400 and 600, respectively. Table 9 shows the selection results of the three outsourced components.

6. Conclusion

The case study presented above illustrated how multiple criteria (e.g. SCOR Model Level I performance metrics) can be included in the AHP approach to permit a more flexible and inclusive use of this data in a decision on supplier selection. It has also been demonstrated how the AHP weighting can be combined in a PGP model to include the capacity constraints in the supplier selection process. The integrated AHP–PGP methodology can select the best set of multiple suppliers to satisfy capacity constraint.

As defined in Section 3.1, suppliers A_1, A_4 and A_7 are lean-oriented, suppliers A_2, A_5 and A_8 are agile-oriented, and A_3, A_6 and A_9 are hybrid-oriented. Recall that component tires could be considered as the functional products, component electronics as the hybrid products, and component peripherals as the innovative products. Component tires are in the maturity stage within its product life cycle. Component electronics and peripherals are both in the growth stage within their product life cycle. According to Table 1, it can be concluded that LSC strategy should be deployed for component Tires, ASC strategy should be deployed for component peripherals, and HSC strategy should be deployed for component electronics. Therefore, theoretically A_1 will be the choice for component tires, since A_1 is lean-oriented supplier based on the above analysis. Similarly, A_5 will be the choice for component electronics, and A_9 will be the choice for component peripherals. The mathematical results from the AHP model perfectly match the above theoretical analysis.

Recall that the AHP results are only applied to the situation without considering the capacity constraints. There are capacity constraints for the case study illustrated in the previous sections; therefore, the PGP model is applied by taking the AHP final ratings as coefficients.

It can be found from Fig. 2 and the above case study that variations of pairwise comparison of both criteria/sub-criteria ratings and alternative ratings affect the suppliers' ratings, which are the coefficients of the objective function of the PGP, and they can have an influence on order quantities, which are optimized through the solution of the PGP.

Acknowledgements

This research work is funded partially by the National Science Foundation under grant DMI-9713743, and Pilkington North America (formerly Libbey-Owen-Ford Co.) and eSourceWorld.com under an industrial grant.

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