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Evaluating petroleum supply chain performance

Application of analytical hierarchy process to balanced scorecard

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Abstract

Purpose – Performance evaluation in supply chain management (SCM) is not a straightforward task. This becomes even more complicated while evaluating a process industry supply chain because of its inherently different characteristics. The purpose of this paper is to suggest a method to evaluate the performance of one such process supply chain, namely the petroleum industry supply chain.

Design/methodology/approach – The paper uses a combination of analytical hierarchy process (AHP) and balanced scorecard (BSC) for evaluating performance of the petroleum supply chain. The choice of factors determining supply chain performance under the four perspectives of BSC has been validated using opinion from subject matter experts (SMEs). In order to determine relative importance of criteria opinion of SMEs has been collected in the form of pairwise comparisons. Using these comparisons, the AHP technique has been applied to determine the relative weights of various perspectives as well as the factors under each perspective.

Findings – The importance of four perspectives with respect to petroleum supply chain performance in descending order of importance comes out as: customer, financial, internal business process, innovation and learning. Within these perspectives, the following factors seem to be most important respectively: purity of product, market share, steady supply of raw material and use of information technology.

Practical implications – Most research work has focused on discrete part manufacturing supply chains. Process industry supply chains deserve a different treatment due to their inherently different characteristics. The methodology suggested in this paper tries to include these characteristics and can help in comparing performance of supply chains of different petroleum companies.

Originality/value – The value of this paper lies in the unique approach towards determining the performance of process industry supply chains. By using BSC, non-financial factors have also been taken into account. Opinion of SMEs has been quantified using the AHP technique thus converting qualitative data to quantitative data.

Keywords Performance measurement (quality), Analytical hierarchy process, Balanced scorecard, Supply chain management, Petroleum

Paper type Research paper

Introduction

Performance evaluation is an important activity for the survival and growth of any firm. As the old adage goes: "you can't improve what you can't measure". Given the magnitude of the organizational changes, there is a need for performance measures to gauge progress towards organizational goals, to provide feedback on efforts for continuing improvement, and to guide the transformation through successive stages (Chan, 2006). Performance measurement is related to strategic intent, and the broad set of metrics used by managers to monitor and guide an organization within acceptable and desirable parameters (Morgan, 2004). Organizations may need to carry out

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performance measurement for various kinds of reasons: identifying success, identifying whether they are meeting customer requirements, helping them understand their processes, identifying where problems bottlenecks, waste, etc., exist and where improvement are necessary, ensuring decisions are based on fact, not on supposition, emotion or intuition; and showing if improvement planned, actually happened (Parker, 2000). Management gurus have long argued that a key to continuous improvement is to measure, measure and measure (Lapiede, 2000). Companies that have won the Baldridge Award or similar state awards have extensive measurement systems. Over a five year period ending in 1998, the winners of Baldridge Award and similar awards did two to three times better than comparable companies in terms of growth in sales and operating income (www.balancedscorecard.org). Performance measures have two main effects. First of all, they can be used as a good description for the as is situation. Secondly, they can be used to set performance goals (Myer *et al.*, 2000). The firm must have comprehensive set of measures to assess progress towards achieving company wide goals, improving core business processes and aligning the firm with the needs of the market (Lockamy *et al.*, 2000). Measures and metrics are needed to test and reveal the viability of strategies without which a clear direction for improvement and realization of goals would be highly difficult (Gunasekaran *et al.*, 2001). Organizations need to ensure achievement of their goals and objectives, therefore, purpose of performance measurement is to evaluate, control and improve operation processes (Ghalayini and Noble, 1996).

Supply chain managemet and its performance measurement

Supply chain management (SCM) is the practice of co-coordinating the flow of goods, services, information and finances as they move from raw material to wholesaler to retailer to consumer (Russell, 2001). It is more than a simple tool to evaluate and optimize a supply chain; it is a complex, structured business relationship model. It takes into consideration all aspects of the events required to produce your company's product in the most efficient and cost effective manner possible (Quiett, 2002). One of the most significant paradigm shifts of modern business management is that individual businesses no longer compete as solely autonomous entities, but rather as supply chains (Lambert and Cooper, 2000). SCM is being heralded as a value driver because it has such wide ranging effect on business success or failure (Farris II and Hutchison, 2002).

The main reason for poor performance of supply chains is the lack of a measurement system (Morphy, 1999). The purpose of measurement and control in the supply chain is to provide management with a set of actions that can be taken in improving performance and planning competitiveness enhancing efforts (Hoek, 1998). Organizations need to measure not only the final output but also the processes involved in reaching the final output in order to locate the problem which is causing variance between the target and actual specification of the final product.

Many researchers have studied the performance measurement aspect of supply chains. Measurement of supply chain may use integrated measures that are cross functional and can be applied to the entire process (Bechtel and Jayaram, 1997). The problem that could be faced in practice is that existing and widely published measurement systems like total cost of ownership and direct product profitability are focused at particular portions of the supply chain instead of being used as chain wide measurement (La Londe and Pohlen, 1996). Another suggested system includes resource, output and flexibility measures (Beamon, 1999). Modern measurement

systems should support innovative strategies and non-financial measures should be developed further (Scapens, 1998). Different types of systems require specific measurement system characteristics, and therein lay the difficulty in creating a general approach to performance measurement (Beamon, 1999). Traditionally, firms have focused on financial indices for measuring performance. However, survival of the company does not depend on profitability alone and managers have learnt that unequalled focus on financial health can result in adverse consequences (Pandey, 2005). To understand value drivers, managers must have in place, a performance measurement system designed to capture information on all aspects of business not just the financial results (Bryant *et al.*, 2004). In order to overcome short range orientation of accounting-based reward system, firms are implementing compensation plans that supplement financial metrics with additional measures to assess performance that is not accepted in short-term financial results (Ittner *et al.*, 2003). Financial accounting measures are insufficient to measure supply chain performance for the following reasons (Lapiede, 2000): they tend to be historically oriented, lacking a forward looking perspective; they do not relate to strategic performance, they are not directly tied to operational effectiveness/efficiency. Most research has concentrated on supply chains of concerned with discrete manufacturing. But process industry supply chains are no less important. Process industry supply chains like the one in the petroleum industry operate at massive scales which makes it all the more important to bring about efficiency in the supply chain. But companies must not view SCM for improving efficiency but also a way to bring about increase in sales, boost competitive advantage and create shareholder value (Vlasimsky, 2003).

Distinguishing characteristics of the petroleum supply chain

Petroleum has the several characteristics that justify a separate treatment of its supply chain. Some of these prominent features are listed below:

- *Process industry*: petroleum is a result of the process industry, which is very different from discretely manufactured items like television sets or automobiles.
- *Inflammability*: petroleum products are highly inflammable and so the risk in handling the product is much higher than in case of other products.
- *Contamination*: petroleum products can be contaminated easily, e.g. by mixing kerosene with diesel. This is especially true for a country like India where subsidies provided by government on petroleum products like kerosene encourage mixing of petrol or diesel with kerosene by dealers.
- *Bulk volumes*: petroleum products are produced and moved in bulk leading to high inventory carrying costs. There is no volume flexibility either in terms of production or distribution.
- *High transportation costs*: transportation costs represent a much higher fraction of total costs than the in case of other products made by the discrete manufacturing.
- *Long supply chain*: much of the crude required by the petroleum industry in India is outsourced. Transportation of crude by ship is very time-consuming, which means that the supply chain is very long starting from the sourcing of crude to delivery of the finished product to the customer.

- *Volatility of raw material prices*: crude prices keep fluctuating in the international market. This is generally not so in case of conventional supply chains producing discrete units of product.

Balanced scorecard and analytical hierarchy process

The balanced scorecard (BSC) suggested by Kaplan and Norton (1996) can provide a comprehensive measurement system for supply chains by including four different perspectives while measuring performance, viz, customer, financial, internal business process and learning and innovation. These four perspectives cover different aspects of the supply chain performance.

(1) the customer perspective tries to look at how an organization likes to present it to its customers;

(2) the financial perspective looks at how the firm presents it to its stakeholders;

(3) the innovation and learning perspective looks at how an organization learns and carries out innovation in order to sustain itself in the future; and

(4) the internal business perspective tries to find out how well the firm is performing its internal business processes.

A BSC could be used for measuring supply chain performance because it takes care of financial and non-financial measures (Brewer and Speh, 2000; Lapiede, 2000). The BSC enables management reports to focus on measures specifically selected to represent the organizations strategy (Kaplan, 2005). Many organizations have found the BSC to be a useful technique in performance and strategic management (Maisel, 1992; Hoffecker and Goldenberg, 1994).

The analytical hierarchy process (AHP) provides a framework to cope with multiple criteria situations involving intuitive, rational, quantitative and qualitative aspects (Alberto, 2000). Hierarchical representation of a system can be used to describe how changes in priority at upper levels affect the priority of criteria in lower levels (Chan, 2003). It organizes the basic rationality by breaking down a problem into its smaller and smaller constituent parts and then guides decision makers through a series of pairwise comparison judgments to express relative strength or intensity of impact of the elements in the hierarchy (Saaty and Kearns, 1985).

The AHP method can support managers in a broad range of decisions and complex problems – including supplier-selection decisions, facility-location decisions, forecasting, risks and opportunities modeling, choice of technology, plan and product design, and so on (Fariborz *et al.*, 1989). Some of the areas in which AHP has been applied are: benchmarking the performance of a postal company against its competitors (Chan, 2006), automating the design of a material handling equipment selection system and providing artificial intelligence in the decision-making process (Chan *et al.*, 2001), evaluating political candidates (Saaty and Bennett, 1977), allocating energy resources (Saaty and Mariano, 1979), and evaluating organizational effectiveness (Chan and Lynn, 1993). It has also found application in decisions pertaining to SCM: evaluating risk in the supply chain (Gaudenzi and Borghesi, 2006), selection of vendors (Hemaida and Schmits, 2006). The AHP has also been used in combination with BSC, e.g. to align BSC to a firms strategy (Searcy, 2004).

The research problem

In India, the administered price mechanism through which the prices of petroleum products were controlled by the government has been dismantled. Though the pricing is still not completely free of government control, in the coming years, one can expect complete decontrol of prices. In such, a situation wherein prices would be completely determined by market forces, the performance of the supply chain shall become an important factor in determining success or failure of a company in the market.

Most work done in the area of supply chain performance evaluation till now has focused on supply chains of discrete part manufacturing. Process industry supply chains have not received the same importance that they deserved. The petroleum industry supply chain is one such process industry supply chain, which has features that distinguish it from other supply chains. Besides other characteristics of the petroleum supply chain, there is extreme standardization, material is moved in bulk, risks involved are high, and adulteration of product can be a major problem (Varma *et al.*, 2006a, b). Conventional measures of supply chain performance like cost or lead time may not be adequate to measure their performance. There may several other factors which affect supply chain performance, many of which may be non-financial in nature. All these criteria need to be accounted for while evaluating the performance of the supply chain. How does one rate the supply chain performance in such a case? The objectives of this paper are:

(1) To validate the importance of criteria to be used for measuring supply chain performance which have been identified in earlier research.

(2) To formulate an AHP framework applied to the BSC for evaluating the performance of the petroleum supply chain, based on the above criteria.

(3) To determine the relative weights of the different perspectives, viz, customer, financial, internal business process and innovation and learning, and also the weights of criteria under each of the perspectives on the basis of opinions collected from subject matter experts (SMEs).

Methodology

In the current research problem, there is no basis available for quantification of relative weights of different criteria that affect petroleum supply chain performance. In such a case, The AHP presents a good technique to determine the weights. The methodology used here is a combination of AHP and the BSC. The criteria for determining performance of petroleum supply chain under the four perspectives of the BSC (customer, financial, internal business and innovation and learning) have already been identified in earlier research work (Varma *et al.*, 2006a, b). This particular research study had identified the generic issues in petroleum SCM and mapped these to the four perspectives of the BSC. Since these are generic issues in managing petroleum supply chains they have been treated as objectives of any petroleum supply chain. The effectiveness of the supply chain can be measured by how well an organization achieves these strategic objectives and they have been treated as the criteria for measuring petroleum supply chain performance. In order to further revalidate the criteria so chosen, industry experts were asked to rate the importance of the criteria in the questionnaire. The experts were also given the option of suggesting any other criteria, which they thought would be important in the petroleum supply chain. However, no particular additional criteria came out strongly from the responses obtained from experts. The AHP technique was applied to it to determine the relative weights of the four perspectives as also weights of the criteria under each

perspective. The hierarchy for AHP applied to the BSC has been schematically shown in Figure 1. Figure 1 shows the formulation of the AHP framework and three different supply chains being compared at the lowest level.

Usefulness of the proposed AHP model

The usefulness of the suggested AHP structure to evaluate the performance of the petroleum supply chain can be justified in the following manner.

(1) The AHP approach is able to use criteria, which are not easy to quantify. As we all know, there are always aspects in performance management that may not be easily quantifiable. This model can take care of such criteria.

(2) The AHP model can help in determining relative importance of criteria in the shape of weights taking into account the views of different experts. This is done by asking experts to do pairwise comparisons and taking the geometric means of such comparisons in order to arrive at a single figure for the pairwise comparisons.

(3) The criteria used in the model are robust in nature because they have been derived from generic issues relevant to petroleum SCM. Even though the

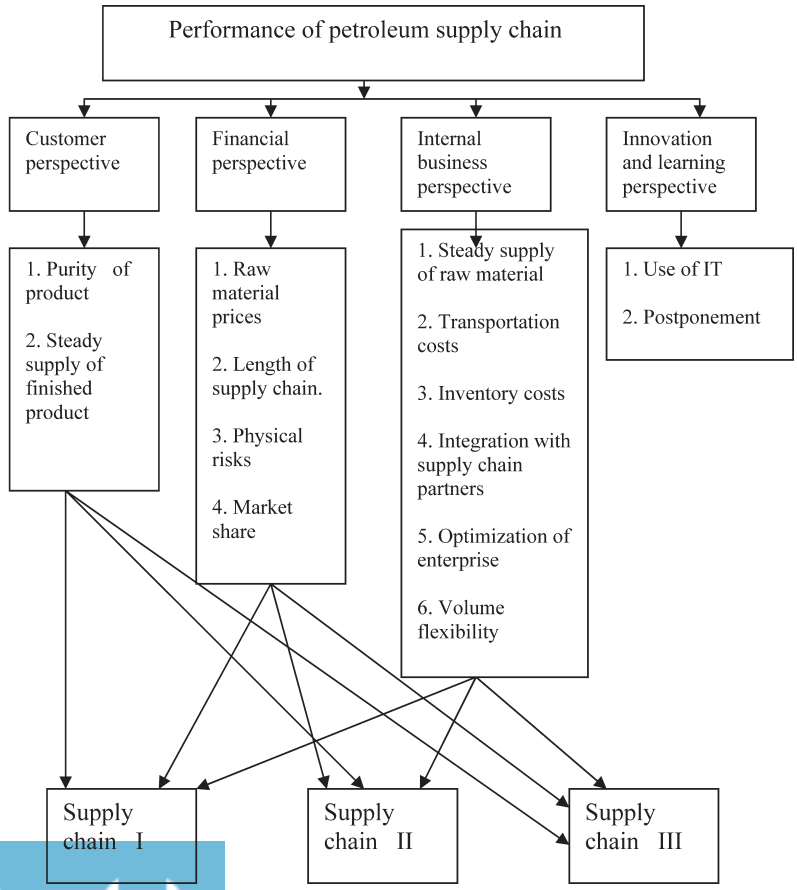

Figure 1.
Formulation of AHP framework applied to BSC to determine supply chain performance

business is dynamic, it is unlikely that these criteria would be affected. Criteria like: steady supply of raw material, raw material prices and optimization of enterprise actually deal with the dynamic nature of the petroleum supply chain. For example, the crude prices keep changing which means that stability of raw material prices is a strategic objective of the supply chain. This has been used as a criterion in the suggested model and would not change even in a dynamic situation.

(4) The AHP model is stable and flexible: stable in that small changes have a small effect and flexible in that additions to a well-structured hierarchy do not disrupt the performance (Chan, 2003).

(5) Inspite of the fact that the model has just two levels, it adequately covers the parameters on which the petroleum supply chain is supposed to perform. In fact, by limiting the number of levels to only two, the model has become easy to use and can find practical utility. From the practitioners point of view, this model is more suitable than one which would incorporate more levels in the hierarchy. In case, any new criterion is identified, it can be mapped to one of the four perspectives of the BSC and the model can be likewise modified. The weights for the criteria at second level will then change accordingly.

Questionnaire

The criteria for determining petroleum supply chain performance have been derived from the strategic objectives that petroleum companies must have. These strategic objectives have been mapped to the perspectives of the BSC in earlier research (Varma *et al.*, 2006a, b). In order to validate the importance of the criteria chosen, industry experts (SMEs) were asked to rate the importance of identified criteria on a Likert scale of 4. The scale of 4 was purposely used to avoid tendency of respondents to choose the middle value. The experts were also given the choice of suggesting any additional criteria, which they thought would be important in the evaluation of the petroleum supply chain. Further, the questionnaire included pairwise comparisons between the criteria at two different hierarchy levels of the AHP. The pairwise comparisons were done on a scale of 1-5. Saaty and Kearns (1985) have recommended a nine-point scale for making pairwise comparisons. However, it was felt that it would be very difficult for any respondent to discern between more than five grades of relative importance. For example, the number 1 on the scale represents "both criteria being equally important", whereas 2 represents "one criteria being slightly more important than the other". It would be virtually impossible for a respondent to find a value of relative importance in between these two values. Hence, it was felt that a five-point scale would be adequate to reflect the opinion of industry experts realistically. These pairwise comparisons were later used to determine the weights of the criteria.

Sample

The questionnaire was designed to collect opinion of SMEs in the petroleum supply chain. Owing to the extremely specific target segment of respondents, it became difficult to collect opinion of a huge number of SMEs. Responses of a total of 24 SMEs were collected. The SMEs were limited to petroleum companies within India. Even within the Indian petroleum industry only those people were eligible to fill in the questionnaire who had sufficient understanding of the petroleum supply chain. Most

respondents carried a designation of Manager and above and had an experience of at least 15 years or more in the industry.

Data and its analysis

The criteria chosen were assessed for importance on a Likert scale of 4. The mean scores and also the values of median, mode and SD for the criteria are given in Table I. All the criteria except for two criteria received an average score of at least 3 out of 4. The lowest average score achieved by a criterion was 2.52 out of 4, which is substantial enough to keep the criteria under consideration. Values of median and mode are either 3 or 4, which validate the importance of the chosen criteria.

In order to arrive at a single figure for pairwise comparisons from the responses obtained from various SMEs, the geometric mean of the responses by SMEs was taken as suggested by Saaty and Kearns (1985). Only those responses were chosen which were consistent, i.e. had a consistency ratio (CR) of not more than 0.1. The consistency of responses was checked by using Expert Choice software. The weights of four perspectives of BSC at the first level of hierarchy and the weights of the criteria under each perspective at the second level were determined using AHP. The relative weights of the four perspectives found by this method are shown in Table II. It is evident that the customer perspective is the most important perspective in the petroleum supply chain. Customer satisfaction being an important objective of SCM, this is as expected.

Perspective of BSC	Criteria	Mean score on 1-4 scale	Median value of score	Mode	SD of score
Customer	Purity of product	3.75	4	4	0.607
	Steady supply of finished product	3.79	4	4	0.414
Financial	Raw material prices	3.71	4	4	0.624
	Length of supply chain	3.13	3	3	0.797
	Physical risks	2.71	3	3	0.550
	Market share	3.00	3	3	0.722
Internal business process	Steady supply of raw material	3.52	4	4	0.510
	Transportation costs	3.35	3	4	0.714
	Inventory costs	3.13	3	3	0.457
	Integration with supply chain partners	3.04	3	3	0.824
	Optimization of enterprise	3.38	3	3	0.646
	Volume flexibility	3.04	3	3	0.55
Innovation and learning	Use of IT	3.48	3	3	0.510
	Postponement	2.52	3	3	0.730

Table I.
Scores measuring relevance of criteria in petroleum supply chain performance

Perspective	Relative weight
Customer	0.3939
Financial	0.2326
Internal business process	0.1881
Innovation and learning	0.1851

Table II.
Relative weights of four perspectives (first level of hierarchy)

Financial perspective is the second most important perspective and this is also as per expectation.

At the second level of the hierarchy, the weights of criteria are given in Table III.

Within the customer perspective, purity of product was found to be more important than steady supply of finished product. This is of particular relevance to India as adulteration of petroleum products at the retail outlets is a common problem. In India, adulteration of petrol and diesel is a big ticket scam that involves an annual recurring loss of at least Rs. 10,000 crore to the exchequer (Ramchandran, 2005). Under the financial perspective, the most important criterion was market share followed by raw material prices. Under the internal business perspective steady supply of raw material was found to be the most important criterion while optimization of enterprise was second. This is not surprising as petroleum keeps the wheels of economy moving for any country. Use of information technology (IT) came out to be a very important criterion within the innovation and learning perspective. This is quite expected as IT is the key to any effective SCM.

Implementing the model in real life

In order to implement the suggested AHP model in real life the following steps need to be carried out:

(1) *Step 1*: determine the values of each of the criteria at the second level of the hierarchy for the supply chains being compared. The Figure 1 shows three such supply chains being compared. There are fourteen criteria at this level, which are also shown in the figure. The units to be used for measuring the criteria are given in the Table IV as also the possible sources for obtaining this information.

(2) *Step 2*: the units of measurement for the various criteria are not uniform as the criteria are of diverse nature. Convert the values obtained in Step 1 to a Likert scale of 1 to 9 and prepare the pairwise comparison matrices for the alternative supply chains for each of the criteria.

(3) *Step 3*: determine the consistency ratio for each of the above matrices. A consistency ratio of 0, 1 or less is acceptable. Expert Choice software can be used for checking consistency ratio.

Perspective	Criteria	Relative weight
Customer perspective	Purity of product	0.5690
	Steady supply of finished product	0.4309
Financial perspective	Raw material prices	0.3158
	Length of supply chain	0.1707
	Physical risks	0.1684
	Market share	0.3448
Internal business perspective	Steady supply of raw material	0.2580
	Transportation costs	0.1309
	Inventory costs	0.1434
	Integration with supply chain partners	0.1376
	Optimization of enterprise	0.1902
	Volume flexibility	0.1486
Innovation and learning perspective	Use of IT	0.7591
	Postponement	0.2408

Table III.
Relative weights of criteria under each perspective (second level of hierarchy)

BSC perspective	Criteria	Proposed units for measuring criteria (A)	Possible source of information for (A)
Customer	Purity of product	Percentage times found pure	Inspection reports from retail outlets
	Steady supply of finished product	Percentage of times in stock	Stock reports from retail outlets
Financial	Raw material prices	Dollar value per barrel	Purchase department
	Length of supply chain	No. of days between ordering for crude and delivery of product at retail outlet	Supply chain department
	Physical risks	Insurance value	Finance department
	Market share	Percentage	Industry reports
Internal business process	Steady supply of raw material	Percentage times in stock (service level)	Refinery
	Transportation costs	Dollars per kilo litre	Supply chain department
	Inventory holding costs	Percentage of material cost	Supply chain department
	Integration with supply chain partners	Likert scale	IT department
	Optimization of enterprise	Supply chain cost (Dollar per kilo litre)	Supply chain department
	Volume flexibility	Likert scale	Storage locations
Innovation and learning	Use of IT	Percentage of revenue spent on IT	Annual report/ balance sheet
	Postponement	Likert scale	Storage locations

Table IV.
Implementation of the AHP model: measurement units and sources of information

(4) *Step 4*: multiply the priority vector of each supply chain for every criteria with the respective weight of the criterion which has been given in Table III. Add all the values thus obtained. This gives the performance of the supply chains with respect to the criteria at the second level of the hierarchy.

(5) *Step 5*: multiply the values obtained in Step 4 with the weights of the respective perspectives of the BSC. These are given in Table II. Add the values thus obtained to give a composite number signifying the performance of the supply chains.

(6) *Entropy weighting*: consider a situation wherein the column vector in our decision matrix $X_j = (X_{1j} + X_{2j} + \cdots)$ that shows the contrast between all the alternative supply chains with respect to the *j*th attribute has similar outcomes for all the alternatives. This attribute has little importance as far as comparison of alternatives is concerned. In such a situation, we can resort to entropy weighting method which determines the importance weights of decision attributes by directly relating a criterion's importance weighing relative to the information transmitted by the criterion. Entropy analysis is based on the assumption that there is a direct relationship between uncertainty and the information provided by a distribution of data points, where complete certainty is associated with the absence of information (Hwang and Yoon, 1981).

In the above column vector, the projected outcomes p_j of j attributes are:

$$p_j = X_{1j} / \sum X_{ij}$$

where i varies from 1 to m, m being the number of alternatives.

$$\text{Entropy } E_j = -(1/\ln m) p_{ij} \ln p_{ij}$$

where j varies from 1 to m and E_j lies between 0 and 1.

Degree of diversification of the information provided is a measure of the importance of the attribute. This is given by d_j where

$$d_j = 1 - E_j.$$

Then entropy weighting w_j is given by:

$$w_j = d_j / \sum d_j$$

where j varies from 1 to n where n is the number of alternatives.

Managerial implications

The study has enabled validation of criteria under different perspectives of BSC, which are important in determining the performance of the petroleum industry supply chain. Apart from financial perspectives, non-financial perspectives of supply chain performance like "steady supply of raw material" and "purity of product" have been included. This makes performance evaluation more comprehensive. An AHP framework has also been formulated which uses the BSC for evaluating the petroleum supply chain. The study has also helped in determining the relative weights of four perspectives as also the weights for each criterion under the four perspectives. This can help companies in reviewing their focus for having improved supply chain effectiveness. It has particular relevance to the Indian context where the traditionally state controlled petroleum industry is undergoing liberalization and it is becoming increasingly important for firms in this industry to have more effective SCM. Even outside India, the study presents a method to compare one petroleum supply chain with the other.

The weights of the criteria at the two levels of the hierarchy shall change temporally and spatially. While the current study is based on expert opinion in India, the opinion in other countries could bring in different results. However, the model would remain the same as the criteria are not just local objectives but objectives which are desired globally from the petroleum supply chain. Even in India, expert opinion after a few years could result in different weights for the criteria.

Limitations of the study

One limitation of the study has been the not too large number of SMEs from whom opinion was collected. A study with a larger number of responses could bring in more accurate values of relative weights. Moreover, the study was limited to India and the results could be somewhat different when applied to the petroleum supply chain of other countries though the methodology would remain the same. Though the method presents a way to do a comprehensive evaluation of petroleum supply chains, it is still

not possible to integrate the various criteria under the different perspectives of the BSC. This is a very tricky task as the criteria involved are very dissimilar. Also, the model could be made more accurate and capable of handling dynamic environment by increasing the number of hierarchy levels. However, this would be at the cost of simplicity, which is currently an advantage with the suggested model.

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