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Performance Measurement in a Supply Chain

F. T. S. Chan

Department of Industrial and Manufacturing Systems Engineering, University of Hong Kong, Pokfulam Road, Hong Kong

The supply chain is an important element in logistics development for all industries. It can improve efficiency and effectiveness of not only product transfer, but also information sharing between the complex hierarchy of all the tiers. There is no systematic grouping of the different performance measures in the existing literatures. This paper presents the formulisation of both quantitative and qualitative performance measurements for easy representation and understanding.

Apart from the common criteria such as cost and quality, five other performance measurements are defined: resource utilisation; flexibility; visibility; trust; and innovativeness. In particular, new definitions are developed for visibility, trust, and innovativeness. Details of choices of these performance measurements are listed and suggested solutions are given, with the hope that a full picture of supply chain performance measurements is developed.

In addition, a multi-attribute decision-making technique, an analytic hierarchy process (AHP), is used to make decisions based on the priority of performance measures. This paper outlines the application and particularly the pairwise comparison which helps to identify easily the importance of different performance measurements. An example from the electronic industry is used to demonstrate the AHP technique.

Keywords: Analytic hierarchy process; Multi-attribute decision-making; Performance measurement; Supply chain

1. Introduction

For physical distribution management, trade-off analysis of distribution requirement planning, and the material flows is required within the business for strategic decision making. Logistics has become one of the topics being seriously discussed in the last few years, which coordinates the cost, time, and the holistic view of the market before eventually making the decision. The flow of the development of supply chain management (SCM) is presented in Fig. 1.

Correspondence and offprint requests to: Dr F. T. S. Chan, Department of Industrial and Manufacturing Systems Engineering, University of Hong Kong, Pokfulam Road, Hong Kong. E-mail: ftschan@hkucc.hku.hk

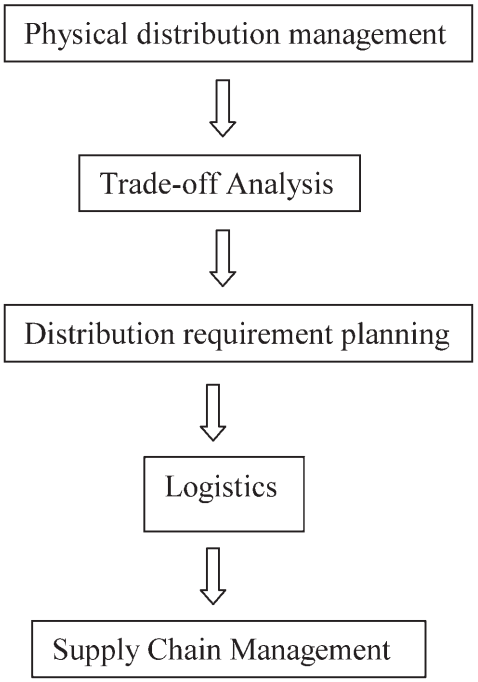

Fig. 1. Flow of development of supply chain management.

The supply chain is even more extensive. It is a continuous process, from raw materials to finished goods, via each traditional distinct function such as forecasting, purchasing, manufacturing, distribution, and sales and marketing. Improvement of this business integration enables management to focus upon managing the core business and delegating the management of the support infrastructure to achieve the benefits of the economies of scale.

The supply chain consists of different levels, e.g. supplier, manufacturing, distributing, and consumer (Fig. 2), and it is a network of companies which influence each other. The complexity and the large network affects one another's performance. How would the supply chain perform? How can the managers choose the most optimum supply chain best suited for its particular industry?

The aim of supply chain management is to gain an advantage in terms of customer service and cost over competitors. There-

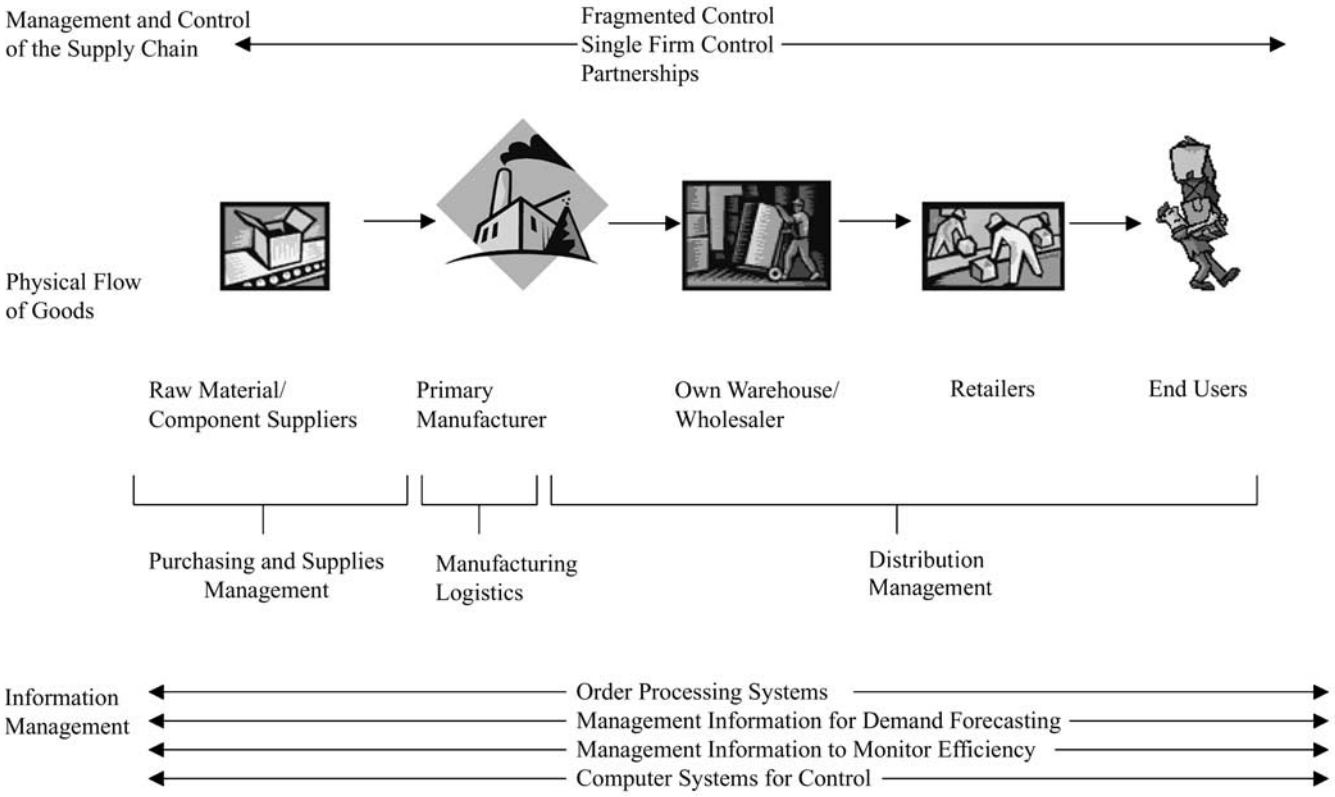

Fig. 2. Supply chain hierarchy.

fore it is desirable to assess the company's performance by benchmarking. The logistics manager must make judgements as to the firm's performance relative to the competition. However, there are different kinds of performance measurement, which have already been discussed in many other papers [1]. However, there is not a complete discussion on each measurement and its suitability for application to each industry. The aim of this work is to give a definition of each performance measurement and how they can be measured, by the time or cost involved.

Customer satisfaction level is an indication of the required standard of service level of a particular company, which is closely related to the whole performance of its supply chain. For different industries, customers look at different measures, such as delivery service, where time is no doubt their major concern; whereas for parts manufacturing, the accuracy of the specification may be the most important consideration. Thus, the weighting of each performance measurement can be different for each industry.

Satisfactory weighting would be complicated with the above constraints and differences. A multi-attribute decision-making technique, called an analytic hierarchy process (AHP) can help to reduce the complication. In the second part of this work, the performance measure identified will be demonstrated by AHP, which is adaptable and changeable for different industries according to their own measures.

How about an electronic industry, which is interpreted as a fast-moving industry? How can its supply chain be measured? By applying AHP, its performance measurements are presented and demonstrated.

Traditionally, performance measurement is defined as the process of quantifying the effectiveness and efficiency of action [2]. In modern business management, performance measurement goes well beyond merely quantification and accounting. It is supposed to contribute much more to business management and performance improvement in the industries. Sink and Tuttle [3] claim that you cannot manage what you cannot measure. From the management perspective, performance measurement provides the necessary information for management feedback for decision makers and process managers. It plays a critical role in monitoring performance, enhancing motivation and communication, and diagnosing problems [4,5]. Furthermore, performance measurement provides an approach to identifying the success and potential of management strategies, and facilitating the understanding of the situation. It assists in directing management attention, revising company goals, and re-engineering business processes [6–8]. Henceforth, accurate performance measurement is helpful in the improvement of SCM.

According to Beamon [1], there is very little literature available on performance measurement systems (PMSs) design and performance measures selection for SCM although various theories and models of average PMSs have been proposed and applied. Beamon [9], in his literature review, categorises the existing performance measures into two groups: qualitative and quantitative, involving customer satisfaction and customer responsiveness, flexibility, supplier performance, costs and

those used in supply chain modelling. Beamon [1] identifies three types of measure: resources; output; and flexibility. Gunasekaran et al. [10] develops a framework for measuring the strategic, tactical, and operational level of performance in a supply chain, which deals mainly with supplier, delivery, customer service, and inventory and logistics costs.

Although workers attempt to build new measures and metrics for SCM, most of the current PMSs for the supply chain have too many defects to meet the SCM requirements. Besides the criticism about the non-connection with strategy and a biased focus on financial metrics, there are some in-depth problems of PMSs in the supply chain context:

1. The lack of a balanced approach to integrating financial and non-financial measures.
2. The lack of system thinking, in which a supply chain must be viewed as a whole entity and the measurement system should span the entire supply chain.
3. The loss of the supply chain context.

As a result these kinds of PMS encourage local optimisation [6,10,11].

2. Framework for Performance Measurement

Performance measurement describes the feedback or information on activities with respect to meeting customer expectations and strategic objectives. It reflects the need for improvement in areas with unsatisfactory performance. Thus, efficiency and quality can be enhanced.

In this section, a new framework for performance measurement is described. It is based on quantitative [12] and qualitative [9] measurements. Some performances are simply quantitative and can be observed easily. This means that they are easily understood as they are usually represented numerically, such as cost represented by money. It is no doubt understood that a lower cost would be preferred in most cases. Other common criteria are cost and resource utilisation, which are the first and are believed to be the most important measures for most people. Qualitative criteria, such as trust and visibility, which are more conceptual, also have an influence on the performance. There is no recognised definition of qualitative criteria and when it can be appropriately applied to the supply chain. Thus, these qualitative concepts are quantified in this work to give an overview of all the attributes of the performance. A brief outline of all the performance measurements is presented in Table 1. A total of seven attributes are identified as important measures for supply chain performance. Two of them are direct quantitative measures (i.e. cost, and resource utilisation), and the other five are qualitative (i.e. quality, flexibility, visibility, trust, and innovativeness).

Quantitative measurements, such as cost and resource utilisation are direct concepts which can be immediately related to how they are judged. Cost should be kept as low as possible, and resources should be kept to an optimum amount for effective use.

Some other factors are recognised and understood to be important for performance; however, it is difficult to quantify them. Many quality assurance systems have been launched to approve products or services as meeting the above standard. The measurements should be quantified as time and accuracy. Details of these measurements will be discussed in the following section.

In the environment of supply chains, the involvement of different companies has also relied on their trust and visibility. These two concepts have not been discussed in detail in previous work. They are also qualitative, but can be measured. Two other concepts are also the current issue in any business, they are the flexibility and innovativeness. They are still new issues and can be investigated for the development of a good supply chain.

3. Quantitative Measures

3.1 Cost

The profit of an enterprise is directly affected by the cost of its operations. Thus, many people understand its importance and influence to the whole performance. Indeed, it is the most significant direct kind of measurement.

Total cost is a sum of all its complex attributes. For different industries, the contribution of each attribute may be different. For a delivery service company, it should deliver its goods within the shortest time. Some may think that cost should be mostly a function of distribution and inventory cost, but a heavy contribution from inventory cost may in fact indicate a poor performance as the goods are always kept for a long time. A manager should investigate carefully each subcost contribution to the performance.

Apart from the domestic supply chain, there is an international supply chain that may entail great geographical distance and time differences. The complication in a global supply chain may consist of multiple national markets which increase the costs, especially the incentive costs and subsidies or the sensitivity to long-term costs.

3.1.1 Measurement

Distribution Cost. This includes the transportation and handling costs, safety stock cost, and duty.

Manufacturing Cost. This includes labour, maintenance and re-work costs. Also, there are purchased materials, equipment charges and the supplier's margin.

Inventory Cost. This includes the work-in-process and finished goods inventories.

Warehouse cost. This is sometimes mistakenly taken to be the same as the inventory cost, but there is a difference as warehouse cost is associated with the allocation from one tier to another and usually involves the finished goods or products.

Incentive Cost and Subsidy. These are taxes and subsidies.

Intangible Cost. This includes quality costs, product adaptation or performance costs and coordination.

Table 1. A brief outline for all the performance measurements.

	Subcriteria level 1	Subcriteria level 2	Performance measurements
A. Quantitative			
Cost		Distribution cost	The transportation and handling cost, safety stock cost and duty.
		Manufacturing cost	Labour, maintenance and re-work costs. Also, there are purchased materials, equipment charges and supplier's margin.
		Inventory cost	The work-in-process and finished goods inventories.
		Warehouse cost	Associated with allocation from one tier to another.
		Incentive cost and subsidies	Taxes and subsidies.
		Intangible cost	Quality costs, product adaptation or performance costs and coordination.
		Overhead cost	Total current landed costs.
		Sensitivity to long-term cost	Productivity and wage changes, exchange rate changes, product design and core competence.
Resource Utilisation		Labour, machine, capacity, energy	Investigate the percentage of excess or lack of that particular resource within a period.
B. Qualitative			
Quality		Customer dissatisfaction	The number of customer complaints registered.
	Time	Customer response time	The amount of time between an order and its corresponding delivery.
		Lead time	The time required once the product began its manufacture until the time it is completely processed
		On-time delivery	The percentage of orders delivered on or before the due date.
		Fill rate	The proportion of orders that can be filled immediately.
		Stockout probability	The instantaneous probability that a requested item is out of stock while number of backorders is the number of items backordered due to stockout.
		Accuracy	Percentage of accurate goods delivered to clients.
Flexibility	Input	Labour	The number of tasks a worker can perform.
		Machine	The efficiency by using a more flexible machine to the traditional switching over machine. Both time and cost saved can be used to express its efficiency.
	Process	Material handling	The number of existing paths between processing centres and the variety of material which can be transported along those paths without incurring high transition penalties or large changes in performance outcomes.
		Routeing	The number of products which have alternative routes and the extent of variation among the routes used without incurring other high costs in performance outcome.
		Operation	The number of products which have alternative sequencing plans without incurring high costs or large changes in performance outcome.
	Output	Volume	The extent of change and the degree of fluctuation in aggregate output level which the system can accommodate without incurring high costs or large changes in performance outcome OR The demand which can be profitably sustained.
		Mix	The number and variety of products which can be produced without incurring high costs or large changes in performance outcomes. OR The time required to produce a new product mix.
		Delivery	The percentage of slack time by which the delivery time can be reduced.
	Improvement	Modification	The number and variety of product modifications which are accomplished without incurring high transition penalties or large changes in performance outcomes.
		New product	Time or cost required to add new products to the existing production operation OR The number and heterogeneity or products which can be produced without involving high transition penalties or large changes in performance outcomes.
		Expansion	The number and variety of expansions which can be accommodated without involving high cost or large changes in performance outcomes.
Visibility		Time	Time required from when the designer changes his idea to when the product starts being processed in the new way.
		Accuracy	The percentage waste of wrong products made after the new design is launched.
Trust		Consistency	The percentage of late or wrong delivery to the next tier which led to an inconsistent supply. For late delivery, it is the percentage of time delayed whereas for wrong delivery, it is the percentage of returned goods.
Innovativeness		New launch of product	Compare the number of products launched by a particular company within a period. OR The percentage sales of a new product to the whole sales within a period for a company.
		New use of technology	The percentage decrease in time necessary for producing the same product.

Overhead Cost. This is the total current landed costs.

Sensitivity to Long-term Cost. Long-term costs include productivity and wage changes, currency exchange rate changes, product design, and core competence. This cost is especially important for a global and worldwide supply chain.

3.2 Resource Utilisation

The performance of a supply chain cannot be focussed only on its output. A manufacturing process includes the input, the process, and the output. Thus, the input to the supply chain demands a further investigation.

The inputs to a manufacturer include raw materials, the equipment or machines, human resources, energy resources, warehouse space, etc. The best performance is obtained by using all these resources in a well-organised and optimum way.

It is easily understood that lack of raw materials for a manufacturing process is not allowed. It may lead to a long delay in finishing time, and most severely, loss of the contract or customer, and even to the loss of the company's reputation in the long term owing to the poor service performance.

Many people think that the best use of raw materials is to have no surplus at the end of the manufacturing process. However, this is not completely true. Safety stock is necessary, as there may be a sudden increase in orders or other interruptions can occur (which should be kept as low as possible) during the manufacture.

Both lack of and excess of resources is a waste of time and money. It is important for the manager to determine the optimum resources necessary for every order. Most companies are now recruiting professionals in the relevant areas to ensure optimum use of the resources.

3.2.1 Measurement

Labour, machine, capacity, energy resource utilisation. To measure the resource utilisation, a company can directly investigate the percentage of surplus or deficit of that particular resource within a period.

Resource utilisation also shows the efficiency of that company. Optimum use of resources can save time and money, and in return, minimise the size of the company, and improve its performance.

4. Qualitative Measures

4.1. Quality

There is much published work [1] on quality as a performance measure in supply chains. Different authors categorise it in different ways. Most of them included lead time and fill rate as their priority; but will all the measurements be the same for different industries or various supply chains? In this section, such terms will be included but other considerations will also be highlighted in order to have a full picture of which qualities should be interpreted.

General speaking, quality is the standard of a product which is related to the customer satisfaction level. Any late deliveries can be regarded as bad for the customers. Thus, quality is related not only to a product but also to the services provided. Therefore, those outcomes resulting in customer satisfaction are all important.

High customer satisfaction is very important, as it is a key indicator of success. Only when the source of customers is unlimited, can a company gain profit and expand its market share and become a leading company within the industry. To provide customers with the type and quality of products and services that they require, time and cost are usually lowered.

4.1.1 Measurement

Customer Dissatisfaction. A direct measurement of the quality is the customer satisfaction level. It can be measured by the number of customer complaints registered. However, the complaints or a questionnaire delivered to customer would only reflect part of the problem. Problems are not usually grouped into categories, and are usually left unsolved or are solved in an unsystematic way. Also, not all the unsatisfied customers would use his or her valuable time to launch a complaint. They would just turn away and place the order with another supplier without giving notice of the poor service delivered. Therefore, it may not totally reflect the real situation of quality perception of a customer.

Time is a very important element anywhere in the world. "Time is money" is a correct and important edict in manufacture. If a product can be produced much faster than by other competitors, customers would certainly retain their relationship with the supplying company.

Customer Response Time. It is the amount of time between an order and its corresponding delivery [13]; however, this term is sometimes misunderstood. It is also termed the order cycle time which includes the reaction time, manufacturing time, and transportation time.

Sometimes, this customer response time is very short, if the product is available from the warehouse. This will be discussed in more detail later in this paper. However, this time element is typical for all types of industry. It is an overall calculation of the time involved, and gives the most direct impression to a customer about how a company performs. In fact, customer response time depends very much on the distribution network design of the company.

Lead Time. It is the time required once the product begins its manufacture until the time it is completely processed. Lead time is made up of queuing time, processing time, batching time, handling time, and transportation time [14]. It is affected by many external and environmental factors, such as capacity loading and scheduling, and it has a big impact on control, and hence on the costs of manufacturing systems.

On-Time Delivery. This measures the product delivery performance. It can be represented by the percentage of orders delivered on or before the due date.

The whole manufacturing process would be delayed significantly for any long lead times. For a delivery industry, such as DHL or UPS, customers rely on their on-time delivery for the important documents or goods transfer. For better performance, a company must reduce all the measurable times for faster placement of orders to reach the end consumers.

Fill Rate. As mentioned above, whether the customer response time can be reduced or not will depend on the product availability. It is instead the fill rate, which can be expressed as the proportion of orders that can be filled immediately. When the customer (provided that the products ordered have already been in manufacture) places an order, some available stock can be used to fill the placed order immediately. It can reduce the customer response time, and hence the customer will be satisfied by this fast response.

Stockout Probability. However, it may not always be such a normal situation as described above. New orders may be based on the original but with a different specification. Then, its production time would depend on the availability of existing raw materials or equipment. The stockout probability of the supplier or backorders needs to be further investigated. Stockout probability is the instantaneous probability that a requested item is out of stock while the number of backorders is the number of item backordered because of stockout.

Accuracy The accuracy of the products delivered is also a measure of quality. There may be inaccurate delivery or more importantly, incorrect specification of products made. It can be measured by the percentage of accurate goods delivered to clients.

Inaccurate delivery greatly reduces the confidence of customers towards the company. It is a serious mistake that must be avoided. Therefore, cross-checks must be included in every production and service to minimise the risk of any mistakes.

4.2 Flexibility

There are many definitions on flexibility. Generally, it is about the ability or the adaptability of the company to respond to diversity or change. A flexible system is important for responding to special service requirements and for achieving a variety of operating attributes. A flexible system is required to support the new introduction of a product and is focused on this change of innovative services to target customers.

The development of a flexible logistics systems is the main method for handling variability [15–17]. Variability cannot be ignored, owing to the ever-changing environment. It does not only apply to product design changes in dimensions or the volume of an order, but to sudden phenomenon, such as breakdown of machines, late arrivals of raw materials, or even new competitors which have a large effect on the market.

Sometimes flexibility is divided into two categories: range and response flexibilities. Range flexibility refers to the extent of the operations to be changed whereas response flexibility is the time or cost or both of the operations which can be changed. However, it is not complete, and cannot cover all types of flexibility. Mix flexibility cannot fit into either of the types as it is measuring the variety of products, which can be produced without incurring high transition penalties or large changes in performance outcomes. In some cases, some measurements overlap both types. Modification flexibility, can be measured by the time required for a new modification to take place (which is the response flexibility) and also the new range that can be reached by a particular change in design, i.e. range flexibility [18].

Instead, flexibility can be categorised simply by input, processes, output, and its improvement within the chain. It is easier to look at each category more carefully and measure its performance in a more comprehensive way.

4.2.1 Measurement

Input: Labour Flexibility. Labour flexibility is relatively less important now, especially as division of labour is emphasised in training labour. It is believed that by specialisation of the skills of workers, efficiency can be raised. Therefore, each individual has their own role. A worker skilful in designing will not be asked to make the product himself or herself. Much routine work is already replaced by industrial automation, only work particularly requiring human intelligence will be done by humans and this kind of work cannot be easily replaced.

However, we must still consider the number of different tasks a worker can perform. To improve labour flexibility, cross-training and appropriate reward structures can reduce transition penalties and lead to the motivation of employees who will be more consistent in working methods.

Input: Machine Flexibility. This is especially important in the shop scheduling and dual resources constraint situation [19]. For a machine which can produce a number or variety of parts, it is more efficient as it reduces set-up time when switching machines or operations. Cost can also be reduced in set-up or the scrap produced due to the changeover.

Therefore, the number and variety of operations that a machine can perform without incurring high penalties or large changes in performance outcomes is important. It can be measured by the efficiency of replacing the traditional switching-over machine by a more flexible machine (e.g. flexible manufacturing system). Both time and cost saved can be used to express its efficiency.

Process: Material Handling Flexibility. Materials should be allocated to different processing centres quickly, accurately, and in the correct amount. Large factories have a large number of working centres, and different volumes of the same materials may be used in different places. Therefore, a flexible material handling system should be installed.

The number of existing paths between processing centres, and the variety of materials, which can be transported along those paths without incurring high transition penalties or large changes in performance outcomes can be considered [20].

Process: Routeing Flexibility. If the routeing of the process is fixed, sudden breakdown or overloading of machines may

affect the efficiency of production. In this connection, it is necessary to have alternative routes to handle uncertainties.

More routeing alternatives makes the system more complex [21,22]; consequently, time and costs will be increased and more controls are required to ensure uniformity and quality.

The general measurement is the number of products which have alternative routes and the extent of variation among the routes used without incurring other high costs in performance outcome [20].

Process: Operation Flexibility. Operation flexibility is the actual changing of operating sequences [23]. This flexibility is different from routeing flexibility, which changes the sequence of machines performing the processes.

It is important for reducing the bottleneck of a particular machine, but attention must be paid as it may change the physical configuration of the part and create addition complexity. Like routeing flexibility, time and cost may be increased owing to the effort spent on monitoring and control the quality and uniformity.

Measurement is similar to routeing flexibility. It measures the number of products which have alternative sequencing plans without incurring high costs or large changes in performance outcome.

Output: Volume Flexibility. Volume of demand may change and organisations have to respond quickly and efficiently to either increases or decreases in aggregate demand levels.

Volume flexibility can be measured in terms of production costs, quality levels or system profitability. An organisation, which can change production volume for its entire product line, is certainly more flexible than one that can change only the volume of production of a simple part.

Then the extent of change and the degree of fluctuation in aggregate output level which the system can accommodate without incurring high costs or large changes in performance outcome can be measured as the volume flexibility.

According to Sethi and Sethi [24], they only measure the demand which can be met profitably.

Output: Mix Flexibility. In an organisation, the level of mix flexibility must be assessed within the current production system configuration without considering major set-ups or facility modifications. It facilitates a broad product line that improves a firm's competitive position. It is sometimes used interchangeably with process and job flexibility [25].

It measures the number and variety of products, which can be produced without incurring high costs or large changes in performance outcomes. Sometimes, it is measured in terms of the time required to produce a new product mix.

Output: Delivery Flexibility. On-time delivery is important. Early delivery can certainly improve the satisfaction level of customers. The ability to move planned delivery dates forward to accommodate rush orders or special orders is described as delivery flexibility.

It is expressed as the percentage of slack time by which the delivery time that is reduced.

Improvement: Modification Flexibility. A customer may request some modifications to the existing products such as a new specification without changing original functions of the product. Modifications must be made for the improved product design.

It is important to satisfy the customer request for high service level and thus modification flexibility is important. It is defined as the number and variety of product modifications which can be accomplished without incurring high transition penalties or large changes in performance outcomes.

Improvement: New Product Flexibility. The introduction of a new product provides an insight to an organisation on product development. Indeed, the variety of new products is the innovation level of the company. New product flexibility is defined as the ease with which new products can be introduced to the system. Time or costs are involved in creating a new product and quality must be controlled for new product.

It is measured either by time or cost required when adding new products to the existing production operation. Alternatively, the number and heterogeneity of products which can be produced without involving high transition penalties or large changes in performance outcomes.

Improvement: Expansion Flexibility. Other flexibilities can be limited on currently available resources in a production system whereas additional machines or labour can be recruited for expansion flexibility. It is important to expand the firm with the state-of-the-art technology to sustain its competitive advantage.

It considers the number and variety of expansions which can be accommodated without high cost involved or large changes in performance outcomes [20].

4.3 Visibility

A supply chain consists of suppliers, manufacturers, distributors, and customers, which may consist of more than one tier at each level. Therefore, once a customer wants to change some specifications or the design of the product, it takes a long time to transmit the message to the end of the supply chain. This not only wastes time, but the accuracy of the message can be distorted. Thus, it is important to improve the quality of information transfer by having a more visible information sharing system.

It is now common to have an electronic data interchange (EDI) system within a supply chain. Thus, direct transfer of any amendment from one end to another is feasible. This shows that new information technology is very important in the development of supply chains.

4.3.1 Measurement

Visibility for a supply chain is important for accurate and fast delivery of information. It is clear that measurement of visibility is the time and accuracy of information transfer.

Time. It is the direct measurement of time required for transferring the new information throughout the supply chain.

Of course, it is not merely the time required for the information to be transferred, but the time required from the moment the designer changes the design to the time the product starts being processed in the new way.

It is important to include the overall time, as though the time required for information transfer on a computer is fast, yet from the top management level to the actual workers the process takes a considerable amount of time. The manager in the factory may have notice of the change of specification of the design so the original manufacture is abandoned. However, the complicated hierarchy-working pyramid may result in an unexpectedly long time to transmit this information to the lowest level. This shows the efficiency is low and shows the need for improvement.

Accuracy. The measurement is by directly matching the new design or specification with new products made. To quantify this measurement, it can be simply interpreted by the percentage waste of incorrect products made after the new design had been launched.

4.4 Trust

Trust is the reliability and consistency between different levels of the supply chain and enhances the long-term relationship between them. Nevertheless, it is not common to investigate the supply chain for trust. As already mentioned, a supply chain is a vertical transmission of information and product making, which links up a number of companies for the successful manufacture of a product. It is important to keep a good relationship between each level or tier as they are dependent on each other. The supplier has to give qualified raw materials to the manufacturer, who in turn processes them to become standardised goods and passes them through distributors to the end users. They have to provide consistent and reliable services for the entire process.

When an action is consistent and predictable over an extended period, it is considered to be reliable. The relationship between two parties should be based on this integrity or honesty.

Trust is a conceptual idea. In order to enhance the reliability of two parties and their long-term relationship [26], an important approach is sharing. This includes risk sharing and information sharing, i.e. through compromise they will inform each other of any urgent issues or problems, so that they can solve the problem as quickly as possible and minimise any risk. Team building and industrial alliances are commonly adopted strategies nowadays by the practitioners concerned. In this connection, the importance of consistency within the supply chain is discussed below.

4.4.1 Measurement

Consistency. Consistent supply from one tier to another is a requirement within many companies [27]. A manufacturer relies on the suppliers' raw material for making and sending a product to the end users, and the end users rely on accurate and on-time delivery of products from the distributors, so it affects the whole chain once a part is delayed. The effect is severe. Therefore, there are usually commitments or contract between the parties to ensure consistent supply.

From another point of view, variability must be decreased. Variability is mainly caused by information distortion [28]. This problem is easy to solve, by making data more direct and available to all streams in the company.

The measure of consistency is the percentage of late or wrong delivery to the next tier which led to an inconsistent supply. For late delivery, it is the percentage of time delayed whereas for wrong delivery, it is the percentage of returned goods [27]. Consistency is a combined measurement of time and accuracy of a product. Inconsistent supply is a delay of products or services which may or may not have a great effect on the final output, but it decreases the image and effectiveness of the whole supply chain.

Trust can be said to be very dependent on information sharing within the supply chain. In this connection, for a company to increase its own trust, agreement must be obtained from all tiers in the supply chain, to enhance their relationship and trust by fast and accurate data transfer. It is not only good for the present situation, but it also enhances the accuracy of forecasting future, which is no doubt important in any industry.

4.5 Innovativeness

In the ever-changing environment, innovativeness is important, thus attempts to add this element in a supply chain is a problem. The competition within industries is strong and it is important to have a particular competitive advantage which can be recognised easily by the customers. Both for a stagnant market, which does not have any growth in market, or a high-technology market, such as the computer or automobile industry, innovativeness is the only way for a company to specialise.

Even in a supply chain, with many levels of manufacturers or distributors within, once an innovative product or service is created, it can help the whole chain to be more specific and even explore a new area.

One example is IBM, which was the largest computer market manufacturer in the 20th century, but there was no great exploration in products or services; but Microsoft used new management methods and developed innovative products in software, which started its current leading role in the market.

4.5.1 Measurement

How can innovativeness, which is such a vague concept, be measured in a supply chain? There are two aspects which are worth of further investigation as stated below.

New Launch of Products. New products are continuously launched into market to stimulate the sales of a particular company or even of the whole market. For a company with innovative products launched periodically, whether or not the product receives a good response from the market, there is a high degree of promotion for the company. It helps the company to be more publicly noticed and advertised. In this connection, innovativeness is probably important.

Thus, we can compare the number of products launched by a particular company within a period, conveniently, we can

compare annually. This can be used to compare two known supply chains or companies.

Alternatively, for a particular supply chain, the acceptance of the innovative product in the market, that is the percentage of sales of the new product to the whole sales within a period of time for a company can be measured.

New Use of Technology. Apart from new products being designed, improving the efficiency can enhance the competitive edge of a company. It includes the use of new technology and even a new method in management.

It may not be easy to relate efficiency to innovativeness. It is instead just one step further. Innovativeness is not applied to physical products only, but also to new management methods or strategies, which in turn help to improve efficiency. However, new technology is difficult to measure directly. Thus, the percentage increase in efficiency can be measured directly, that is the percentage decrease in time necessary for producing the same product.

5. The Analytic Hierarchy Process

To obtain the best and most optimum supply chain for different industries is very difficult [29,30]. The importance of each performance measure is different in various industries. Thus, weightings have to be assigned to each performance measure according to its contribution to the performance of a given supply chain.

With reference to the previous sections, both quantitative and qualitative measurements can be represented as input data for the application of the analytic hierarchy process (AHP). The AHP is a commonly used tool for solving multi-criteria decision-making problems, developed by Saaty [31–33].

The AHP provides a framework to cope with multiple criteria situations involving tangible and intangible, quantitative and qualitative aspects [34,35]. It consists of three steps:

1. Decomposing the complex problem into a hierarchy of different levels of elements.
2. Using a measurement methodology to establish priorities among the elements.
3. Synthesising the priorities of elements to establish the final decision.

To understand the three steps better, they are further discussed as follow. First, a complex problem is broken down into subproblems in hierarchical levels, which is a set of criteria or attributes relative to each subproblem. The top level is the goal, and consists of only one element – the broad, overall objective. Subsequent levels may each have several elements. The elements are to be compared with one another against a criterion in the next higher level, but must be of the same magnitude.

With reference to this case: i.e. the performance measurement of a supply chain, the main goal is simply to choose the best or most optimum supply chain. At the sequent levels, all the performance measures defined are listed. These are all the criteria necessary to achieve the goal.

All available choices are listed and quantified, they are then converted to weights that are used to prioritise a portfolio of ideas. The weights of each element in each hierarchical level are aggregated to the next level.

Pairwise comparison (different alternatives or attributes) can be used to determine the priorities of each pair of criteria, indicating the strength with which one element dominates another with respect to a higher-level element. It provides a clearer priority for each of the criteria, using a nine-point scaling system. It helps to quantify intangible and non-economic factors included in the hierarchies, which make an explicit and informed trade-off among many attributes or criteria possible in selecting the best goal.

The AHP helps to rank and make decision in a rational and systematic way. Weighting can be changed according to different companies or industries, thus it is a flexible kind of data analysis.

Expert Choice [36], based on the AHP is the software commonly used and is applied in this study. It is user friendly and provides an easy-to-understand visual representation of the overall rankings. What-if or graphical sensitivity analysis helps to determine how a change in the importance of an objective may influence the choice of alternatives.

The AHP provides versatility and power in structuring and analysing a complex multi-attribute decision-making problem, by giving a means of quantifying judgmental consistency. The AHP allows flexibility to aid the management decision-making process and reduces assessment bias by pairwise comparison.

6. An Application Example of Performance Measurement in the Electronic Industry

Different industries rely on different measurements for good performance of a supply chain, as mentioned in the previous section; but how can each industry apply AHP to measure their performance? Here is an example for an important industrial sector electronic industry, which is a fast moving and competitive industry.

Every electronic company relies on mutual trust between partner organisations for the improving performance of the inter-firm transactions. Take an example of a semiconductor manufacturing firm, in which Kim et al. [37] found that this industry relies on suppliers of integrated circuit and transistors, which require different levels of technological capability. With different production capability, they may have different judgements of measurement of price, quality, lead time, flexibility, etc. Each manager will judge performance measures in a different way. In this section, the semiconductor industry is employed to demonstrate the perspective view towards its supply chain.

In the electronic industry, each electronic component is cheap, thus its manufacturing cost must be kept as low as possible, and especially in today's highly competitive environment, manufacturers have to control tightly both cost and time, as business can switch to other firms easily. Long-term relationships between consumers and manufacturers do not exist. The company's aim is to supply enough and accurate products whenever orders are given, with new specification or

requirements each time. In this connection, achievements of fill rate in quality, on-time delivery, and manufacturing cost is assigned the highest priority in the following example. Inventory and warehouse costs are very low as electronic components should be kept only in sufficient quantity, as any excess would not be useful in the fast-moving industry. Moreover, innovativeness would be comparatively insignificant in this industry as it has already existed for a long time and no great improvement is expected.

By using pairwise comparison of each tier based on the above assumptions, priority of the performance measurement is ranked, accordingly i.e. for quality, cost, resource utilisation, flexibility, visibility, trust, and innovativeness. As mentioned above, time and accuracy are very important, even leading to a higher preference than cost. The public generally accepts the first three higher ranked performance measures (i.e. quality, cost, and resource utilisation), while visibility and innovativeness are new concepts. The lack of understanding of visibility and support of information transfer results in this low ranking of visibility. Innovativeness is difficult in the semiconductor industry, as it is already so well developed, this is indicated by the lowest value (0.028) in Fig. 3. Table 2 presents all the abbreviation used in the AHP analysis, and Table 3 shows the definition for most of the performance measurements in the electronic industry.

There is more than one method for the pairwise comparison of the relative importance of each performance. One method simply uses verbal comparison, other easier ways are by questionnaire or graphics, as shown in Figs 4 and 5. They can be used to assist the relevant companies in making the suggestions concerning their own judgement of importance.

With reference to Fig. 3, the numerical value inside each bracket is the relative importance of each performance, with quality having 0.315, flexibility having 0.091, etc. All of them added up to a sum of 1. Under each second layer of performance, further breakdowns are shown, with quality breaking down into complaints, customer responsiveness, lead time, and so on. Each inverted triangle shows a further breakdown and each one of them has its relative importance.

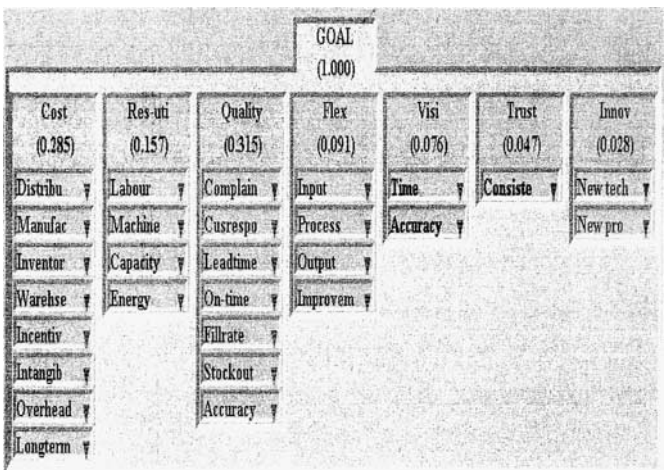

Fig. 3. Performance measurement for electronic industry – AHP display.

Table 2. Abbreviations used in AHP analysis.

Abbreviation	Definition
Cost	Cost measure
Distribu	Distribution cost
Manufact	Manufacturing cost
Inventor	Inventory cost
Warehse	Warehouse cost
Incentiv	Incentive costs and subsidies
Intangib	Intangible cost
Overhead	Overhead cost
Longterm	Sensitivity to long-term cost
Veryhigh	Very high cost
High	High cost
Acc.low	Acceptably low cost
Low	Low cost
Very low	Very low cost
Res-uti	Resource utilisation
Machine	Machine utilisation
Capacity	Capacity utilisation
Energy	Energy utilisation
Labour	Labour utilisation
90%–100%	90%–100% utilised
70%–90%	70%–90%utilised
50%–70%	50%–70% utilised
30%–50%	30%–50% utilised
<30%	<30% utilised
Quality	Quality satisfaction
Complain	Gereral complaints measured by number of complaints directly
Too many	Too many complaints: >50 complaints annually
Many	Many complaints: 30–50 complaints annually
Abithigh	Reasonably high number: 13–30 complaints annually
Reasonab	Reasonable number: 6–12 complaints annually
Quitelow	Quite low number: <6 complaints annually
Cusrespo	Customer response time
Leadtime	Lead time
On-time	On-time delivery of goods or information
Too long	Too long: >1 week
Long	Long: 4–7 days
Rea.long	Reasonably long: 1–4 days
Acc.long	Acceptably long: 12–24 h
Rea.shor	Reasonably short time: 3–12 h
Short	Short time : <3 h
Fillrate	Fill rate
High-fil	High fill rate: >80%
Re.hifil	Reasonably high fill rate: 60%–80%
Re.l-fil	Reasonably low fill rate : 40%–60%
Low-fil	Low fill rate: <40%
Stockout	Stockout probability
Unacc.hi	Unacceptably high stockout probability: >80%
Toohigh	Too high stockout probability: 60%–80%
Rea.high	Reasonably high stockout probability: 40%–60%
Acc.high	Acceptably high stockout probability: 20%–40%
Rightlow	Right stockout probablity: <20%
Accuracy	Accuracy of goods delivery or information sharing
Veryhi-a	Very high accuracy: >90%
Sat.high	Satisfactorily high accuracy: 70%–90%
Low-a	Low accuracy: 40%–70% accurate
Unex.low	Unexpected low accuracy: <0%
Flex	Flexibility in different aspects
Input	Input flexibility
Process	Process flexibility
Output	Output flexibility
Improvem	Improvement flexibility

Table 2. Continued.

Abbreviation	Definition
Machine	Machine flexibility
Labour	Labour flexibility
Mat hand	Material handling flexibility
Routing	Routeing flexibility
Operatio	Operation flexibility
Volume	Volume flexibility
Mix	Mix flexibility
Delivery	Delivery flexibility
Expansio	Expansion flexibility
Modifica	Modification flexibility
New Prod	New product flexibility
Veryhi-g	Very high flexibility
High-f	High flexibility
Re.low-f	Reasonably low flexibility
Low-f	Low flexibility
Ve.low-f	Very low flexibility
Visi	Visibility of supply chain – ability to look thoroughly
Time	Time needed for information sharing
Too long	Too long: >1 week
Long	Long: 4–7 days
Rea.long	Reasonably long: 1–4 days
Acc.long	Acceptably long: 12–24 h
Rea.short	Reasonably short time: 3–12 h
Short	Short time: <3 h
Accuracy	Accuracy of goods delivery or information sharing
Veryhi-a	Very high accuracy: >90% accurate
Sat.high	Satisfactorily high accuracy: 70%–90%
Low-a	Low accuracy: 40%–70%
Unex.low	Unexpectedly low accuracy: <40%
Trust	Mutual trust between suppliers and customers
Consiste	Consistency of supply or demand of goods and information
Very	Very good consistency: 90%–100% consistent
Good	Good consistency: 70%–90% consistent
Rea.good	Reasonably good consistency: 40%–70% consistent
Inconsi	Inconsistent: 30%–40% consistent
No	No consistency: <30% consistent
Innov	Innovativeness
New tech	New use of technology
T80%–100%	80%–100% new technology
T60–80	60%–80% new technology
T40%–60%	40%–60% new technology
T20%–40%	20%–40% new technology
T <20%	<20% new technology
New pro	New launch of product
80%–100%	80%–100% new product
60%–80%	60%–80% new product
40%–60%	40%–60% new product
20%–40%	20%–40% new product
<20%	<20% new product

7. Application of AHP to Other Industries

The previous section described an application of the AHP to the electronic industry. All performance measurements being defined are inserted into the software. However, it may not be the same for other industries, which may need to consider other performance measurements that apply to them.

The outline of the previous section is just a reference guide to the manager. It is flexible, and it is up to the managers to consider the relative importance of the measures according to their industries. Remember that the measurements are not in the second tier, which are the seven categories defined as: cost, resource utilisation, quality, flexibility, visibility, trust, and innovativeness. Not only the understanding of these categories, but the detail of each measurement method should be considered, that is when considering the importance of flexibility, measures such as breakdown of input, process, output, and improvement should be considered, and also details of the inputs of each of them. Thus, different industries can apply the same approach to finding out their optimum measures of the outcome of their own supply chains.

Take the delivery service industry as an example. By considering all the lower-level performance measurement tiers, they may take accuracy, on-time delivery, and lead time as the most important criteria, which are employed to enhance customer satisfaction level. This leads to a high ranking for quality. It would be similar to the electronic industry case as previously mentioned. However, the second ranking may not be cost, but flexibility. The routeing and labour flexibilities are very important. Once a customer gives an order to collect a package, a collector has to draw a flexible route to collect the package within the shortest time. Thus, the performance measures of a delivery service industry will be prioritised differently.

Considering another example, say, the Hong Kong textile industry. There is a downturn of the industry owing to the manufacturing operations having been shifted to the Mainland for its comparative advantages of lower labour and material costs. Cost would certainly be the main concern of this industry. If a garment firm has its design and administrative office in Hong Kong and manufacturing facilities based in South China, every change in specification and design has to be delivered to the manufacturing plant as soon as possible to ensure no loss of productivity. Thus, visibility would not be ranked as low as in the electronics industry. Indeed, visibility would be ranked second, just below cost. Other preferences of the performance measure would also be changed.

Only three industries are briefly mentioned above. However, other industries can be ranked accordingly. The variation can change frequently without difficulty. Instead, the preference should be revised and changed periodically to ensure up-to-date ranking of performance.

8. Application of AHP to Choose the Optimum Supply Chain

The ranking of performance measure had been mentioned above. But the above priority is important to help managers to choose the best supply chain for their own industries. This decision-making process can also be further assisted by using the AHP.

At the very last tier, managers are free to enter their own requirements. Refer to Table 2, for customer dissatisfaction, which is a subcriterion of quality, definitions are given: too many, many, abithigh, reasonab, and quitelow which stand for

Table 3. Definitions for most of the performance measurements of the electronics industry.

	Subcriteria level 1	Subcriteria level 2	Definition for all performance measurements
A. Quantitative			
Cost		Distribution cost	Veryhigh
		Manufacturing cost	High
		Inventory cost	Acc.low
		Warehouse cost	Low
		Incentive cost and subsidies	Very low
		Intangible cost	
		Overhead cost	
		Sensitivity to long term cost	
Resource utilisation		Resource utilisation	90%–100%
			70%–90%
			50%–70%
			30%–50%
			<30%
B. Qualitative			
Quality		Customer dissatisfaction	Too many
			Many
			Abithigh
			Reasonab
			Quitelow
	Time	Customer response time	Too long
		Lead time	Long
		On-time delivery	Rea.long
			Acc.long
			Rea.shor
			Short
		Fill rate	High-fil
			Re.hifil
			Re.l-fil
			Low-fil
		Stockout probability	Unacc.hi
			Toohigh
			Rea.high
			Acc.high
			Rightlow
		Accuracy	Veryhi-a
			Sat.high
			Low-a
			Unex.low
Flexibility	Input	Labor	Veryhi-f
		Machine	High-f
	Process	Material handing	Re.low-f
		Routeing	Low-f
		Operation	Ve.low-f
	Output	Volume	
		Mix	
		Delivery	
	Improvement	Modification	
		New product	
		Expansion	
Visibility		Time	Too long
			Long
			Rea.long
			Acc.long
			Rea.shor
			Short
		Accuracy	Veryhi-a sat.high
			Low-a
			Unex.low

Table 3. Continued.

Subcriteria level 1	Subcriteria level 2	Definition for all performance measurements
Trust	Consistency	Very Good Rea.good Inconsi No
Innovativeness	New launch of product	80%–100% 60%–80% 40%–60% 20%–40% <20%
	New use of technology	T80–100% T60–80% T40–60% T20–40% T<20%

1=EQUAL 3=MODERATE 5=STRONG 7=VERY STRONG 9= EXTREME

1	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Res-uti
2	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quality
3	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Flex
4	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visi
5	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust
6	Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov
7	Res-uti	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quality
8	Res-uti	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Flex
9	Res-uti	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visi
10	Res-uti	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust
11	Res-uti	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov
12	Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Flex
13	Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visi
14	Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust
15	Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov
16	Flex	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visi
17	Flex	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust
18	Flex	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov
19	Visi	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust
20	Visi	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov
21	Trust	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Innov

Fig. 4. Pairwise comparison method – questionnaire.

five categories. Table 4 is a reference for defining the requirements.

Own abbreviation, title and detail can be typed in according to the managers and their own preference. Importance or data can be prioritised based on their own decision. The sum should add up to 1, which is equal to its upper level. Another illustration would be lead time. At the lowest tier, it is categorised into six elements as shown in Table 5.

After entering all the lowest tiers, managers are free to judge the supply chains suggested to them. When they have more than one supply chain on hand, they can start by inserting their judgements of the supply chains. The highest score the supply chain gained would be the best or most optimum supply chain.

AHP software is a decision-supporting tool, which assists managers in different industries. In choosing the best way to measure the performance of their supply chain, or for making decisions accordingly. Data may vary and there should be no hesitation in adding a small part to or deleting it from the above model to suit it to the case in hand.

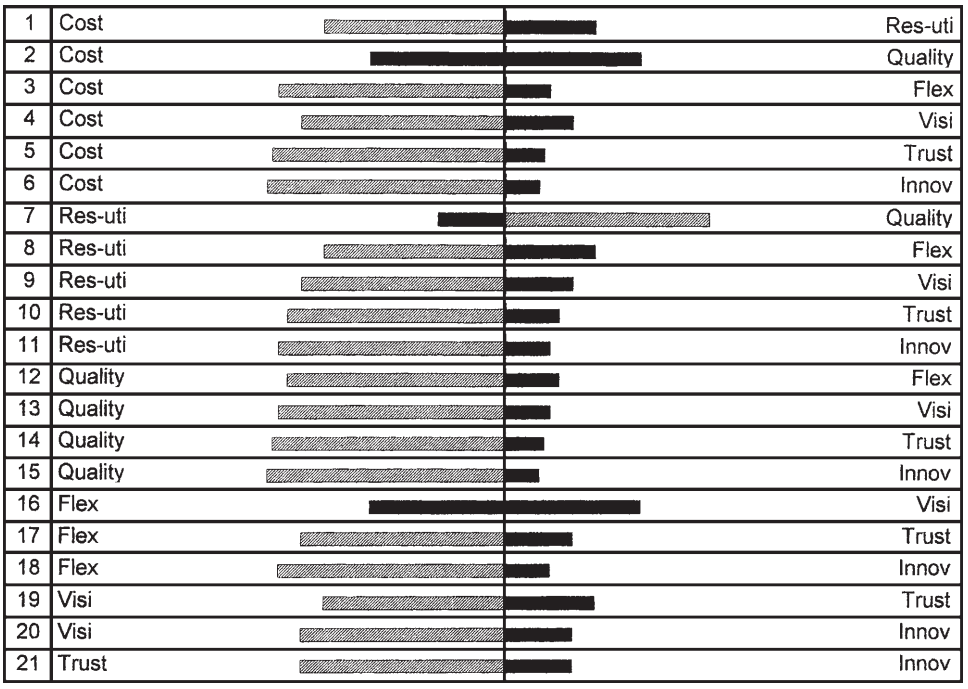

Fig. 5. Pairwise comparison method – graphic.

Table 4. Definition for AHP-quality-customer dissatisfaction.

Abbreviation	Title	Detail	Data
Too many	Too many complaints	>50 complaints annually	0
Many	Many complaints	30–50 complaints annually	0.05
Abithigh	Reasonable high number	13–29 complaints annually	0.15
Reasonab	Reasonable number	6–12 complaints	0.3
Quite low	Quite low number	<6 complaints	0.5 Sum=1

Table 5. Definition for AHP-quality-lead time.

Abbreviation	Title	Detail	Data
Too long	Too long time	>1 week	0
Long	Long time	4–7 days	0.042
Rea.long	Reasonably long time	1–3 days	0.083
Acc.long	Acceptably long time	12–24 h	0.167
Rea.shor	Reasonably short time	3–11 h	0.292
Short	Short time	<3 h	0.416 Sum=1

9. Conclusion

The supply chain management is a concern for all industries nowadays. A supply chain has to have particular advantages to customers. The result of adopting a particular supply chain should give an incentive to managers to review the situation of the firm. A good supply chain relies on its performance. Different supply chains are different for various industries, however, as they only vary in their ranking of relative importance, the way to measure them can be standardised.

Misunderstanding and misconceptions by measuring supply chain by cost only, should be abandoned. Though cost is directly related to profit and is an easy measurement to make, it is only part of the review of the outcome. Customers should be the main concern of a company whereas cost is not really related to the customers. Customers, for example, may not receive any benefits from cost reduction, as the supplying company seems often not to lower the price even though the cost is slightly reduced.

Recently, quality would be the emphasis for most manufacturers; however, it has not been extended to the whole supply chain. Quantifying these measures has no common consensus. Similarly, other performance measures have to be standardised.

In this paper, seven categories of performance measurement have been identified. Quantitatively, cost and resource utilisation are the main concern. They are easily understood by their numerical representation.

Qualitatively, quality, flexibility, visibility, trust, and innovativeness were identified. For qualitative measurements, they are usually conceptual ideas, and people usually judged these performances by their own understanding. This leads to a major problem of inconsistency because of lack of standardisation, hence leading to confusion and biased judgement. Thus, all these five categories are quantified into measurable elements. One important reminder is that there may be more than one way of measuring a performance, e.g. on a time or cost basis. However, a company should adopt only one kind of measurement, which is most related to the particular characteristic of the company.

Furthermore, this method is important to help the managers to choose from their alternative supply chains. A multi-attribute decision-making technique, AHP, aids it. It helps to prioritise the performance by simply inserting data or using pairwise comparison functions. A reference to the electronic industry is used to show the use of AHP to rank performance measurements.

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