Supply chain performance evaluation: A comprehensive evaluation system

Article · January 2011

DOI: 10.1504/IJBPSCM.2011.041376 · Source: DBLP

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Abstract: Supply chain is a network of suppliers, manufacturers, distributors, and retailers that act together to control, manage, and improve the overall supply chain performance. The most important and critical part of decision making is identifying the different sides of supply chain's performance. Evaluating the performance of the whole supply chain is a complex task, due to the complexity inherent in the structure and operations of the supply chain.

This study presents a suggestion for a comprehensive system to evaluate the performance of the supply chain in eight dimensions (i.e., financial, customer, internal operations, learning and growth, people, environmental, and political perspectives). The proposed performance evaluation system (PES) suggests a procedural framework to explain the application methodology of that PES. Moreover, the study offers a simulation modelling methodology for modelling the complex system of supply chain. It also provides a real world case study to clarify the applicability of the proposed PES.

Keywords: supply chain; performance; performance evaluation system; PES; key performance indicators; KPIs; simulation.

Reference to this paper should be made as follows: Abd El-Aal, M.A.M., El-Sharief, M.A., Ezz El-Deen, A. and Nassr, A-B. (2011) 'Supply chain performance evaluation: a comprehensive evaluation system', *Int. J. Business Performance and Supply Chain Modelling*, Vol. 3, No. 2, pp.141–166.

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1 Introduction

Today's changing market conditions drive companies to effectively evaluate their overall supply chain performance and identify improvement areas for gaining competitive advantages. In the last few decades, organisations have improved their internal processes by using initiatives such as JIT, Kanban, and TQM. At the same time new methods and initiatives in the area of supply chain management (SCM) have forced organisations to improve not only their internal processes but also the supply chain to which they belong.

While companies have transformed their supply chain to integrated supply chain, they have in need of a tool which will show the performance of the supply chain, the final outcome of the efforts of all integrated members, new improvement areas through the supply chain, and whether the supply chain is improved or not. This needed tool is a supply chain performance evaluation system (PES).

"Most consultants' recipes for affecting business change and behaviour in an organisation use ingredients for measuring ongoing performance. Many feel that continuous improvement in an organisation relies on "measuring, measuring, and measuring again", "anything measured improves", "you get what you measure, and you cannot manage a system unless you measure it" (Franceschini et al., 2007). "What you measure is what you get", "anything measured gets done", and "you can not manage what you do not measure" (Gaudenzi, 2009). These are the motivations of the current study.

In this study, a PES is proposed. This system consists of three main parts, a structural framework, a procedural framework, and some managerial tools such as performance indicators, and modelling and performance analysis tools. Furthermore, the necessary steps to be followed during the implementation of the proposed PES are identified.

This study focuses on the analysis of dynamic behaviour along the supply chain. It is sometimes possible to model complex supply chains analytically. The complexity of these models limits their usefulness. This motivates the use of simulation. Simulation provides a practical basis for representing complex interdependencies between organisations, and helps realistically analyse performance.

Also, this study suggests a simulation methodology as the modelling tool for applying the proposed PES. The performance evaluation of a real case study is also discussed using the proposed system and the suggested simulation methodology. This study clarifies the significant importance of performance evaluating process and the effectiveness and applicability of the proposed PES.

Despite the recent emphasis, performance indicators in the past primarily focus on production indicators that were aimed at attaining increased short term operational efficiency in terms of financial indicators. This type of evaluation ignores critical performance indicators, such as customer and employee satisfaction.

Based on the above stated difficulties, this study identifies the problem that it seems to be a lack of an integrated PES in the supply chain that could improve their processes and practices to better meet the expectations of their customers for higher quality, lower production cost, and improved service.

Managers can use the result of this study to apply integrated performance evaluation tools to obtain the best financial and non-financial information for effective decision making as well as to suit their managerial needs. Stockholders, potential investors, and business partners will be assisted in their understanding of performance evaluation and the way in which to determine the progress of the companies. The concerned government bodies will be assisted in determining how well the companies operate, how efficiently domestic resources are utilised, and how tax and other similar issues should be handled. Finally, it would be helpful for academic studies on performance evaluation of manufacturing industries in developing countries.

2 Literature review

Folan et al. (2007), state that understanding and determining exactly what is meant by the word ‘performance’ is a critical issue for business environment. As cited in Lebas (1995), performance is defined as: “deploying and managing well the components of the causal model(s) that lead to the timely attainment of stated objectives within constraints specific to the firm and to the situation”. Performance is concerned with what happened in the past or what is happening in the present instance and therefore it is observable and measurable (Hon, 2005). ‘Performance’ may include inputs; outputs; intermediate outcomes; end outcomes; net impacts; unintended outcomes. Performance may relate to economy, efficiency, effectiveness, cost-effectiveness, or equity (Folan et al., 2007).

According to Jie et al. (2007), supply chain performance is defined in two dimensions; effectiveness, which is ‘doing the right thing’ and efficiency, which is ‘doing things right’.

Artley and Stroh (2001) emphasise that the well-known sayings such as "what gets measured gets done" and "you get what you measure" suggest that implementing an appropriate PES will ensure that actions are aligned to strategies and objectives.

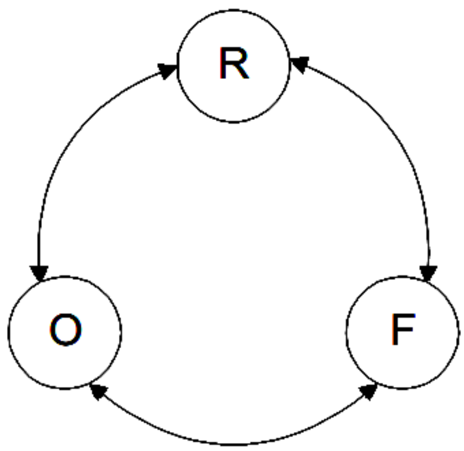
PES is a formal, information-based routines and procedures which can be used by managers to maintain or alter patterns in organisational activities.

According to Bhagwat and Sharma (2007), performance measurement or evaluation describes the feedback on operations which are geared towards customer satisfaction and strategic decisions and objectives. Artley and Stroh (2001), define performance measurement or evaluation as the ongoing monitoring and reporting of programme accomplishments, particularly progress towards pre-established goals. It is typically conducted by programme or agency management.

A supply chain PES consists of a set of parameters that can fully describe the logistics and manufacturing performance of both the whole supply system, as perceived by end customers, and of each actor in the chain, as perceived by downstream players. PES aims to identify, control, and improve organisation's performance. Recent years show great interest from academician and practitioners in PES. Beamon (1999), De Toni and Tonchia (2001), Gunasekaran et al. (2001, 2004) and Chan (2003) have tried to design evaluation systems to evaluate supply chain performance, but these designs appear to have several limitations such as: no reference to strategy, focus on cost to the detriment of non-cost indicators, lack of a balanced approach, insufficient focus on customers and competitors, and loss of supply chain context.

Beamon (1999) develop a new framework for performance evaluation. Within this framework, a supply chain PES that consists of a single performance indicator is generally inadequate, since it is not inclusive and ignores the interactions among important supply chain characteristics. Key strategic elements in the organisation include the evaluation of resources, output and flexibility. Therefore, as shown in Figure 1, a supply chain evaluation system should put emphasis on three separate types of performance indicators: resource (R), output (O) and flexibility (F) measures. Each of the three types of indicators has important characteristics and interacts with others.

Figure 1 The supply chain measurement system



Source: Beamon (1999)

Van der Vorst et al. (2000) distinguish several performance indicators for food supply chains on three levels: supply chain, organisation and process. At supply chain level, five indicators are distinguished: product availability, quality, responsiveness, delivery reliability and total supply chain costs. At organisation level, again five indicators are distinguished: inventory level, throughput time, responsiveness, delivery reliability and total organisational costs. Finally at process level, four indicators are distinguished: responsiveness, throughput time and process yield and process costs.

Gunasekaran et al. (2001) offer a framework for evaluating the performance of supply chain. The offered framework is built upon a literature review of universal practices in performance evaluation of supply chain. The framework classifies the performance indicators in three categories, i.e., strategic, tactical, and operational levels of management. This framework facilitates the decision-making process, as it provides each management level with its appropriate performance indicators.

Brewer and Speh (2000) propose a model based on the BSC's four perspectives: internal, customer, financial, innovation and learning. A set of goals and consistent indicators are suggested for each perspective.

Kleijnen and Smits (2003) summarise how economic theory differs from business practices in the treatment of multiple metrics. Economic theory tends to use scoring methods such as Kiviat graphs[1], empirical utility measurement, uncertain attribute values, mathematical programming (including goal programming), fuzzy set theory, etc. In practice, managers use multiple performance indicators; a single indicator does not suffice.

Chan (2003) analyses seven performance evaluation areas (or attributes): cost, resource utilisation, quality, flexibility, visibility, trust, and innovativeness. For each of them, a set of indicators that can be included in supply chain PESs is proposed.

Gunasekaran et al. (2004) offer a supply chain performance evaluating framework based on the theoretical framework discussed by Gunasekaran et al. (2001), and on an empirical analysis report. This framework may be sought to be a modification of the framework presented in Gunasekaran et al. (2001). The modified framework classifies the performance indicators from both the management level (strategic, tactical and operational) and the major supply chain activities/processes (plan, source, make/assemble, and deliver). These classifications clarify the appropriate level of management authority and responsibility for performance.

Bhagwat and Sharma (2007) develop a performance evaluation framework for evaluating SCM. They follow the construction of the BSC for building their own framework. They also review different SCM performance indicators and distribute them into the BSC's four perspectives.

Olugu and Wong (2009) emphasise the importance of PESs for evaluating supply chain performance. They review previous studies using fuzzy logic application in supply chain performance evaluation. They also point out the strengths and limitations of these studies. They provide a number of suggestions on applying fuzzy logic operations in evaluating the performance of supply chains.

Most of the existing literatures have some limitations in the connection between the proposed approaches and the supply chain strategies; also there is a lake of a balanced approach to integrate the financial and non-financial performance indicators (Chan et al., 2003; Chan and Qi, 2003). Therefore, the current study tries to overcome these limitations.

To implement SCM technique, the critical performance indicators of supply chains must be clearly identified. The modelling approaches for representing supply chains can be classified into five broad classes:

1. network design
2. mixed-integer programming optimisation
3. stochastic programming
4. heuristic methods
5. simulation (Dong, 2001).

Among these five methods, simulation provides a unique capability to capture complex interdependencies among various stages of the supply chain. The use of simulation to model and analyse the dynamic behaviour of supply chain systems is carried-out in this study (Papageorgiou, 2009).

Papageorgiou (2009) says:

> "Supply chain models can either be mathematical programming or simulation-based and their application depends on the task in hand. Mathematical programming models are used to optimise high-level decisions involving unknown configurations, taking an aggregate view of the dynamics and detail of operation (e.g., supply chain network design, medium term production and distribution planning). On the other hand, simulation models can be used to study the detailed dynamic operation of a fixed configuration under operational uncertainty, and can be used to evaluate expected performance measures for the fixed configuration to a high level of accuracy."

3 Proposed PES

This section presents the proposed view for constructing a general system for evaluating supply chain performance based on modelling and simulation. The proposed PES is divided into three main parts:

1. structural framework
2. procedural framework
3. performance indicators.

3.1 General PES

The development of a PES may conceptually be separated into phases of design, implementation, and use (Bourne et al., 2000). The design phase is about identifying key objectives and designing indicators. In the implementation phase, systems and procedures are put in place to collect and process the data that enable the evaluation to be made regularly. In the use phase, managers review the evaluation results to assess if operations are efficient and effective, and the strategy is successfully implemented. A successful

PES includes two frameworks; i.e., structural and procedural framework. Thus, the proposed general PES consists of a structural framework based on the structure of the balanced scorecard (BSC) framework, with the addition of some new perspectives. A developed procedural framework is also used as a step-by-step procedural for implementing the proposed PES. A list of performance indicators for each one of the proposed performance perspectives is also used. The list provides a performance management tool, which enables decision-makers to have the variability of evaluating the supply chain performance.

3.1.1 Proposed structural performance evaluation framework

The main reason of using BSC framework structure as the bases for this study is its ability of translating the supply chain strategy into a course of action (Lawson et al., 2008). BSC framework structure provides a foundation for evaluation perspectives, such as financial, customer, etc. Original structure of the BSC consisted of four perspectives (i.e., financial, customer, internal operations, and learning and growth) (Kaplan and Norton, 1992, 1996, 2001). Therefore, the BSC tells you the knowledge, skills and systems that your employees will need (learning and growth perspective) to innovate and build the right strategic capabilities and efficiencies (internal processes perspective) that deliver specific value to the market (customer perspective) which will eventually lead to higher shareholder value (financial perspective). The structural framework of the BSC attempts to introduce the concept of producing a 'balanced' set of indicators (i.e., non-financial indicators 'balanced' against financial indicators). The proposed structural framework presented in this study is illustrated in Figure 2. It uses the same framework presented in Kaplan and Norton (1992) with the addition of other perspectives, such as people, environmental, governmental, and social (Waggoner et al., 1999; Hon, 2005; Chenhall and Langfield-Smith, 2007; Perotto et al., 2008).

Figure 2 Performance perspectives of the proposed PES

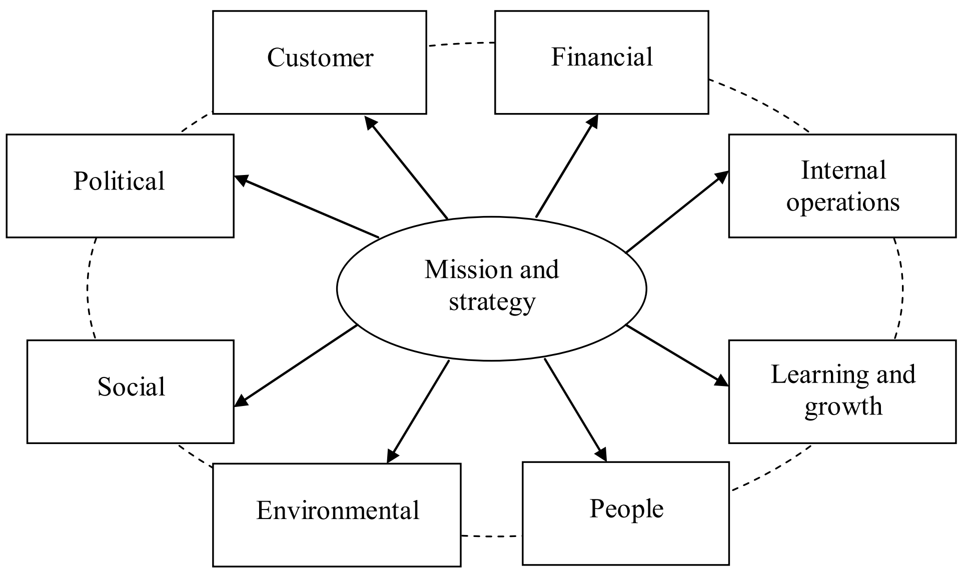


Table 1 Performance perspectives' concern in business environment

Performance perspectives	*Perspective's concern*
Financial	How the firm should appear to its shareholders?
Customer	How the firm should appear to its customers?
Internal operations	What business processes must the firm excel at?
Learning and growth	How will the firm sustains its ability to change and improve?
People	How the firm should appear to its employee?
Environmental	How does the firm interact with its environment?
Social	How does the firm interact with the society?
Political	What is the firm's position from the view of legitimisation[2]?

Table 1 identifies the key concern for each of the proposed performance perspectives. A comprehensive description for the proposed perspectives is provided as follows:

1 Financial perspective: measures the ultimate results that the business provides to its shareholders. This perspective typically contains the traditional financial performance indicators, which are usually related to profitability. This includes indicators such as profitability, revenue growth, return on investment (ROI), economic value added (EVA), cost of quality, and shareholder value.

2 Customer perspective: customers are the source of business profits; hence, this perspective focuses on customer needs and satisfaction as well as market share. This includes service levels, satisfaction ratings, customer complaints, customer loyalty, sales growth, and growth in customer satisfaction.

3 Internal operations perspective: the objective of this perspective is to satisfy shareholders and customers by excelling at some business operations that have the greatest impact. It focuses attention on the performance of the key internal processes that drive the business. This includes such indicators as quality levels, productivity, cycle time, inventory, efficiency, non-value adding activities, and cost.

4 Learning and growth (innovation) perspective: the objective of this perspective is to create long-term growth and improvement through systems and organisational procedures. In the above three perspectives, there is often a gap between the actual and target capabilities. Through learning and growth, organisations can decrease this gap. It directs attention to the basis of a future success. Key indicators might include value of new lines of business, market innovation, technology level, expenditures on new technologies, knowledge sharing, and number of best practice case studies.

5 People perspective: reflects the health of the organisation. Although people cannot be treated as machines, they present the strength of the organisation. Therefore, the best people should be got to work in the best possible way. This perspective includes several indicators such as employee satisfaction, employee safety and health, extent of training, training effectiveness, professional development, and training costs.

6 Environmental perspective: determining the results of environmental aspects of an organisation's management. Also it determines the influence of the industry on the environmental aspects including natural systems such as land, air and water as well as on people and living organisms. This includes the management efforts to influence

an organisation's environmental performance; and the environmental performance of an organisation's operations. It also provides information about the conditions of the environment. The performance should be monitored through measurements, and managed by indicators. Indicators include: energy use, water use, packaging wastes for recycling, emission NOX/unit product, and NOX concentration in air.

7 Social perspective: refers to the impact of an organisation's behaviour on society including the broader community, employees, customers, and suppliers. It also studies human relations, objectives, constraints and behaviour in the supply chain surroundings. The social perspective tries to quantify the nature of interpersonal ties. It plays an important role in the introduction of performance measurement and evaluation systems (Mårtensson, 2009). This perspective enables the PES to describe and explore social environment, and represent and analyse information on communication. Indicators of social perspective might include; % percentage of female employee, lost time incidents, internationalisation, social stability, and trust (Masquefa, 2008).

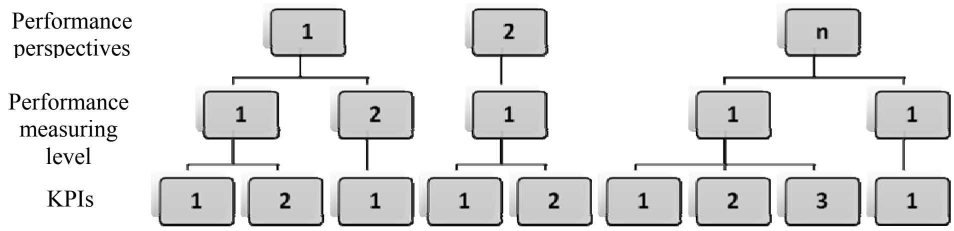
8 Political perspective: every organisation, regardless of its culture, faces potential political constraints, conflicts, and power struggles, and thus can feel the need to justify past actions and decisions. The government plays an important role in determining corporate objectives and strategy, resulting in conflicts of interest between the government, with its own political and social targets, and private investors with their intentions of maximising returns. Therefore, further pressure effects may come from the government's continued activism via direct interventions, the construction of law, and the believe in political ideology such as wealth redistribution (in China) or capitalism (in USA) (Fleming et al., 2009). Political pressures are affecting companies' operations. Political risk is a strong indictor for the business environment. Political changes or activities are broadly referred as the governmental policies or actions that affect the selected or overall enterprises (Chong, 2009). PES structure requires awareness and active management of the political processes within an organisation (Waggoner et al., 1999). Top management teams of firms tend to use PES for legitimisation to a great extent. The political perspective indicators may include political stability, government efficiency and incorruption, government control on market, and government financial support.

Supply chain mission (i.e., the task at hand that the organisation is assigned) and strategy are the starting point and source for strategic objectives in the business environment. The proposed framework helps in translating the mission of the supply chain into a set of performance indicators that provides a link between evaluation and strategic goals. This framework enables managers to evaluate supply chain performance from different dimensions. The proposed framework provides the decision-makers with the capability of controlling the whole boundaries of the system or supply chain.

3.1.2 Proposed procedural performance evaluation framework

PES is also concerned with a procedural element, which helps to determine exactly how the process of PES should be carried out. The procedural performance evaluation framework is effectively detailing the components of a system. A hierarchical view of PES is illustrated in Figure 3.

Figure 3 A hierarchical view of the proposed PES



To use the BCS framework for evaluating supply chain performance, the following procedural performance evaluation framework steps should be followed (this could be done through periodically workshops and meetings between head managers and consultants of participating organisations in the supply chain):

1 Mission statement: clearly defines the supply chain's mission statement (profitability, market share, quality, cost, flexibility, dependability, and innovation).

2 Strategic objectives: identify the supply chain's strategic objectives and goals using the mission statement as a guide.

3 Performance dimensions: performance perspectives or dimensions of great interest should be identified. This is done with the help of the decision-makers in the supply chain. The process of performance dimensions identification relies on the mission and strategic objectives of the supply chain.

4 Performance dimension weight: a weight (e.g., % percentage or score from 10) for each perspective should be decided. This step is known as a 'normalisation process' (Kleijnen and Smits, 2003; Krakovics et al., 2008) and it is typical analytic hierarchy process (AHP) approach (Chan et al., 2001; Chan and Qi, 2003; Lee et al., 2008). The decision-makers should decide and identify these weights based on the chosen normalisation process. A pair-wise comparison among perspectives might be carried-out. For each pair of perspectives a score between one (equals important) and nine (absolutely more important) will be assigned for each comparison depend on the judgment of the decision-maker (see Table 2). The result is a pair-wise comparison matrix. The relative weight for each perspective can be generated by normalising of the pair-wise comparison matrix. For example, if four perspectives, i.e., P1, P2, P3, and P4 were decided to be the performance perspectives; then a pair-wise comparison is made. The comparison is made upon two stages:

   - comparison questionnaire of managers or consultants
   - comparison matrix for determining the weight of each perspective.

   If the result of pair-wise comparison questionnaire is estimated as shown in Table 3, then the pair-wise comparison matrix will be as illustrated in Table 4. The relative effects of the factors on performance can be generated by normalising the dominant (real, positive) eigenvector associated with the maximum dominant eigenvalue (Lee et al., 2008).

5 Performance indicators: the performance indicators for each decided perspective are then to be chosen (no performance indicators are explicitly pre-defined, the set of the chosen performance indicators relies upon the system design methodology to formulate them during the system building process). Choosing the correct qualitative and/or quantitative indicators making the dimensions of performance operatively measurable. These indicators are known as key performance indicators (KPIs).

6 Performance indicators weights: weights for every performance indicators in each performance perspective should be estimated by the procedure mentioned in Step 4.

7 Cause and effect relationships: cause and effect linkages (strategy map) between different performance indicators should be made. Perspective objectives are related to one another through cause and effect relationships. The cause and effect linkages are similar to 'if-then' statements. For example, if employees' skills were improved or increased through continuous training (Objective 1), then the product quality will be enhanced (Objective 2) and customers will be more satisfied with high quality products (Objective 3) and corporate profitability will increase (Objective 4). These cause and effect linkages should be explicit. The linkages should be able to be easily changed and edited as appropriate.

8 Prioritising performance indicators: a prioritisation process of performance indicators should be done. This step relies on the strategy map which is constructed in Step 7. The prioritisation process aims to quantify the relative effects of several indicators on performance. ABC classification (or Pareto analysis) can be used to reduce the number of performance indicators. This analysis can be used to group these indicators into Classes A, B, and C based on their effects on performance as shown in Table 5.

9 Periodic revision: business environment is dynamic, and as a result, factors that influence supply chain performance vary dramatically. Periodically revision is provided for the selected performance perspectives and the overall evaluating system to identify the weakness points and the possible improvements that could be provided to the proposed evaluating system. Some factors may change day-to-day, others month-to-month or year-to-year. Therefore, in addition to ABC classification of performance indicators, it is important to establish the rate of change in the factors which cause a change in the performance indicators itself. The general principle being: factors having the greatest impact and that change most rapidly should be revised or monitored most frequently, while those of less importance or more stables can be monitored less often. Based on the principles of ABC classification and rate of change, a classification of performance indicators should be developed as indicated in Table 6. This classification can be used as a general guideline in classifying the performance indicators into three categories, i.e., critical, moderate, and minor. As indicated in Table 7, the moderate and category is classified into Moderate I, Moderate II, and minor category is classified further into Minor I, Minor II. This classification may be used to determine the frequency of performance evaluation where critical measures are monitored more frequently, moderately measures are monitored less frequently, and minor indicators may be monitored seldom.

Table 2 Values of pair-wise comparison

Impact/importance	*Value*
Extremely strong (EXS)	9
Intermediate (IR1)	8
Very strong (VS)	7
Intermediate (IR2)	6
Strong (S)	5
Intermediate (IR3)	4
Moderately strong (MS)	3
Intermediate (IR4)	2
Equally strong (EQS)	1

Table 3 Pair-wise comparison questionnaire

Perspective	P_2	P_3	P_4
P_1	MS	VS	EXS
P_2	-	S	VS
P_3	-	-	EQS

Table 4 Pair-wise comparison matrix

Perspective	P_1	P_2	P_3	P_4	*Weight*
P_1	1	3	7	9	0.589
P_2	1/3	1	5	7	0.292
P_3	1/7	1/5	1	1	0.064
P_4	1/9	1/7	1	1	0.055

Table 5 Classification of performance indicators into three groups

Classification	*Impact on performance*
A	75%–100%
B	5%–75%
C	0%–5%

Table 6 The classification and monitoring frequency determination of performance indicators

		Rate of change		
		Fast	*Medium*	*Slow*
Impact on performance	A	Critical	Moderate I	Moderate II
	B	Moderate I	Moderate II	Minor I
	C	Moderate II	Minor I	Minor II

Table 7 The periodically revision table for performance indicators

Classification of performance indicators	*Revision*
Critical	Day to day
Moderate I	Daily to weekly
Moderate II	Weekly to monthly
Minor I	Monthly to quarterly
Minor II	Quarterly to yearly

4 Case study

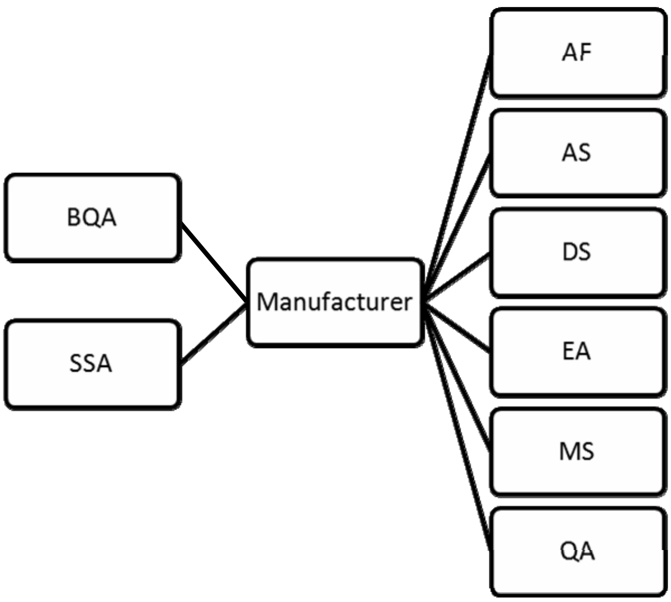
This case study is a real world application for the proposed PES which was discussed in the previous chapter. The current case study illustrates the applicability of the PES and the potentiality of this PES.

4.1 Case study description

This case study analyses the performance of a plastic fabrication supply chain. The supply chain consists of three echelons (i.e., supplier, manufacturer, and customer echelon), as illustrated in Figure 4.

The supplier echelon includes two participants; i.e., BQA, and SSA, which provide the supply chain with the required raw materials. The manufacturer echelon contains only one factory for producing plastic bags; while the third (customer) echelon includes six customers (AF, AS, DS, EA, MS, and QS) which generate orders for the manufacturer.

Figure 4 The case study supply chain



In this study, a plastic bags factory was visited and studied its production, sales, purchasing and other processes carefully. This factory manufactures plastic bags in different sizes. The factory uses the polyethylene as its raw material. It produces mainly two types of products; i.e., high and low density (LD) of polyethylene. The two types expands to four types of bags; i.e., high density (HD), printed high density (HDP), LD, and printed low density (LDP) bags. The factory has six main customers, which are named: AF, AS, DS, EA, MS, and QS. These customers make orders of the aforementioned four products. Table 8 presents the customers' orders of different products.

Table 8 Types of products for each customer

Main customers	*Product*			
	HD	*HDP*	*LD*	*LDP*
AF	✓	✓	✓	✓
AS	✓	✓		
DS		✓		
EA			✓	✓
MS	✓	✓		
QS	✓		✓	

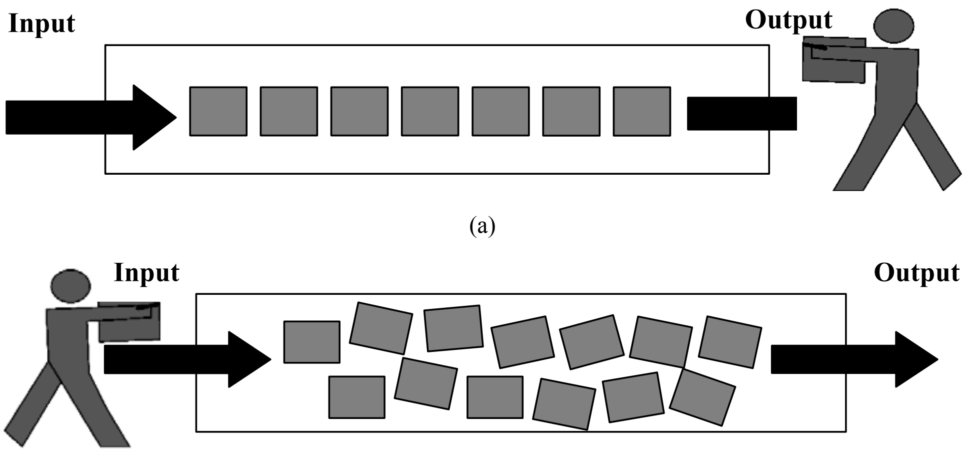
The raw material replenishment is accomplished from two big suppliers (named; SSA, and BQA) which have infinitely capacity, i.e., any order of raw materials, at any time with any quantity, will be accomplished.

Since stocks cause problems, (such as product damage, space seizing, etc.) and high costs, The factory apply a pull production system upon the principle of only produce on real customer demand, with the contrast of the push system, which produce on an estimated customer demand. Using the pull principle, production and logistics are only triggered in the supply chain when current customer demand is present. Figure 5 represents a comparison between pull and push systems.

The factory consists of three manufacturing departments. The first department produces plastic film rolls, with variability in film thickness and width. This department consists of three machines; each of them has its own production capacity. Two of them (named Old and Venus machines) produce HD film products only, while the third one (named New machine) produces LD film products. The second department is the printing department for printed plastic bags. A single printing machine carries out the printing task. While the third department contains four machines (named Cutting machine 1, 2, 3 and 4) for welding and cutting the plastic film rolls into bags with the desired lengths.

The analysis is carried out from the focal company perspective, i.e., the supply chain leader that coordinates the material and information flows across the supply chain. The focal company for the current supply chain is the factory. The factory management team wants to evaluate the performance of the factory; which affects the supply chain performance. The management team wants also to identify the possible suggestions which may contribute in performance improvements. The study of the current case will be carried out by using the pre-discussed PES linked with a simulation study methodology as discussed in the following section.

Figure 5 Representation of pull and push systems (a) pull system (b) push system



(a)

(b)

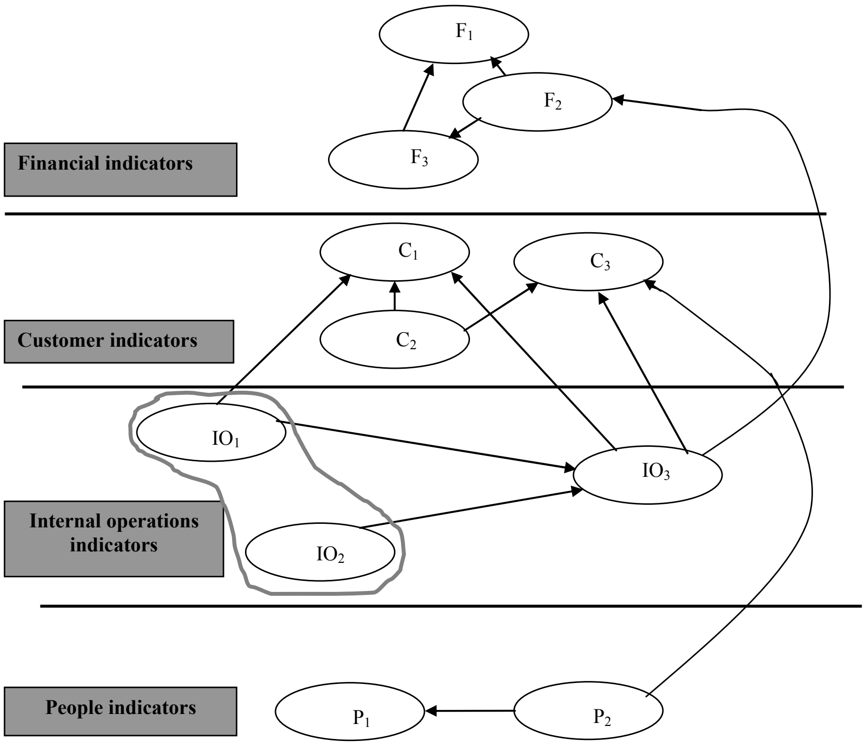
4.2 Performance dimensions and indicators used

This subsection describes the performance dimensions and indicators used for evaluating the performance of the case study; it also presents the relationships between these indicators. The focal company concentrates on the financial (F), customer (C), internal operations (IO), and people (P), perspectives as its dimensions for performance evaluation. For each one of the three performance perspectives a number of performance indicators are chosen (KPIs), as follows:

- financial perspective
  1. net income by business, (F_1)
  2. value of work in progress ($), ($F_2$)
  3. EVA per machine ($), ($F_3$).
- customer perspective
  1. fill rate, which is the fully satisfied demand (number or percentage), (C_1)
  2. order frequency (number of orders coming in per day), (C_2)
  3. average time from customer enquiry to delivery time, (C_3).
- internal operations perspective
  1. percentage of major machines utilisation, (IO_1)
  2. production time, (IO_2)
  3. queue production time, (IO_3).
- people perspective.
  1. accidents per month worked, (P_1)
  2. number of employees, (P_2).

Cause and effect relationships: The cause and effect diagram or strategy map for the performance indicators in different performance perspectives is illustrated in Figure 6. This figure shows that the performance indicators IO_1 and IO_2 have a significant effect on most of the remaining performance indicators, and hence they have a significant effect on the overall company performance. Therefore, these two performance indicators (IO_1 and IO_2) must be given the highest priority in improvement (value enhancement).

Figure 6 The cause and effect diagram of the performance indicators



5 Simulation study methodology

The simulation methodology presented here is based upon Altiok and Melamed (2007) and Wainer (2009). The simulation study is performed as follows: the building of the model and the validation of the model. The methodology that was applied is a ten-step model, consisting of ten separate activities. All activities must be performed before the simulation study is complete. The use of such a methodology ensures a valid simulation result and helps in the development of the model.

5.1 Simulation study methodology description

The suggested simulation study methodology presented in Figure 7 should be undertaken for the purpose of discrete-event simulation modelling. Starting with Step 1 for formulating the problem; then the objectives of the study should be determined and the specific issues to be considered identified (as discussed in the previous section). Second, data should be collected (if it exists) based on the objectives of the study. Step 3 is the validation of the data. Subsequently, Step 4 is the construction of a computer model based on a conceptual model. Step 5 consists of carrying out the pilot run and step 6 of conducting the verification and validation. Steps 7 through 10 are the design of experiments, simulation runs for providing performance data on the systems of interest, output analysis considering statistical techniques for analysing the output of the simulation runs, and the implementation of the best alternative.

The main defining feature of this methodology is the collection of tangible data to produce tangible results based on a sequential process. Therefore, discrete-event simulation is a typical quantitative research method.

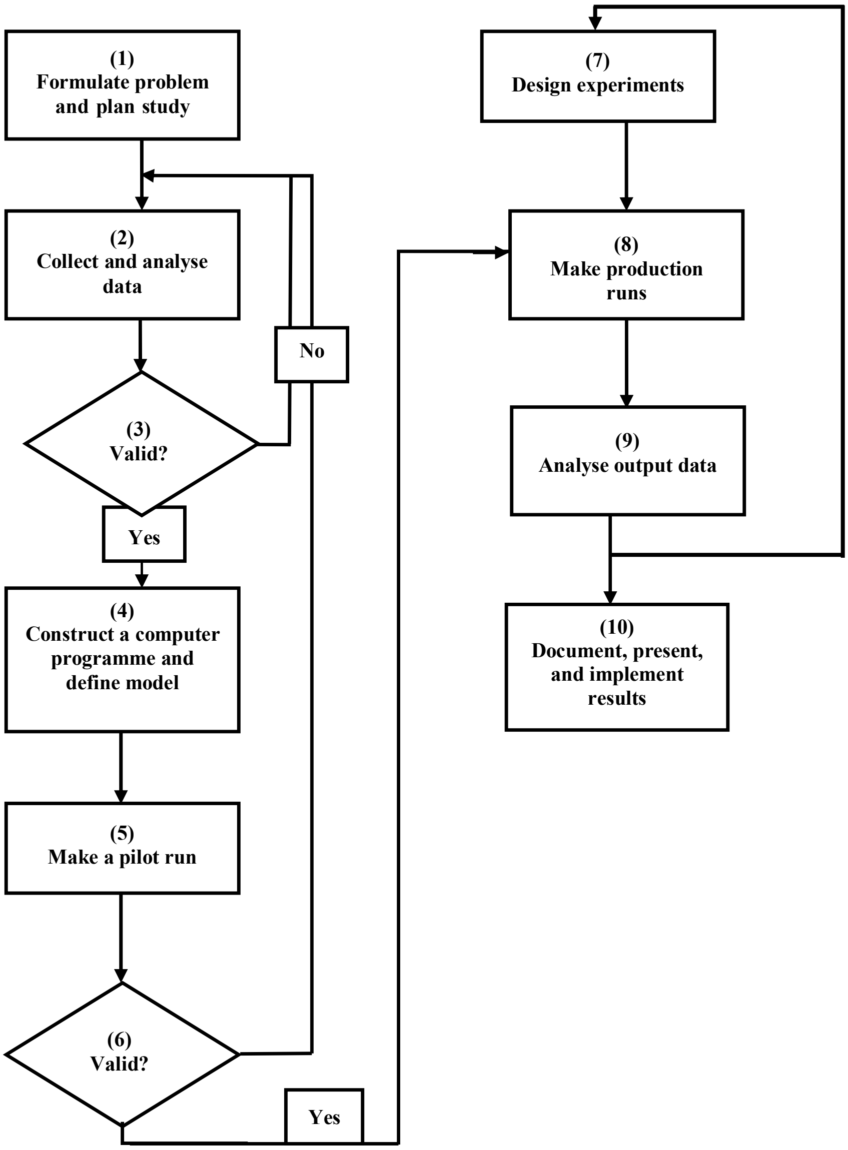
Of vital importance are the validation and verification activities (Wainer, 2009). If these activities fail to correct all model errors, the result of the simulation study can be questionable (Altiok and Melamed, 2007). It is therefore of the utmost importance to use proven methods for these activities. There exists three main categories of simulation model errors namely Type I, II and III errors, these errors must be prevented (Wainer, 2009). A Type I error is to state that a valid simulation model is invalid and reject the model's output. Type II errors are the opposite, when an invalid model is considered valid. Finally, a type III error is to solve the wrong problem. Most validation methods aim at minimising the risk of Types I and II errors.

Generally, simulation is an invaluable tool in the modelling of supply chain environment. Having gained more useable knowledge about the system, and its behaviour to certain change of parameters, different improvements approaches can be approved and their impact on the system's performance can be documented. In the main, "a successful simulation project is one that delivers useful information at the appropriate time to support a meaningful decision" (Wainer, 2009).

A computer simulation model of the focal company is constructed with high accuracy and minimal simplification assumptions. The higher is the accuracy of the construction process of the model, the more is the validity of the constructed model. Also, the minimal are the simplification assumptions, the more is the validity of the model, which means the more is the reality of the model. The detail level, abstraction level, or fidelity of the model is a critical process, and must be selected to an appropriate level. This process is influenced by several factors such as; data availability, purpose of the effort, expertise of the modeller, simulation software capabilities, and time availability. Discrete-event simulation modelling is a popular method for predicting the performance of complex systems (like supply chains). ARENA; is a general-purpose simulation software package, which is selected to be the modelling tool. This package allows complete flexibility in determining the scope and abstraction level for different aspects of the model. The focal company with its main three production departments, with two main suppliers, and six main customers, is modelled using ARENA 11.0 package.

Verification is the process of ensuring that the model operates in the right way. Verification can be considered as 'Building the model correctly'. Whereas validation is the process of insuring that the model represents reality. In other words, validation is the process of 'Building the correct model'. The simulation model is said to be verified if it includes all of the components specified under the system definition phase, and also be able to run without any errors or warnings. Verification was performed using ARENA's debugging tools and system animation. The use of animation is perhaps the most effective tool for performing basic verification, as it able to visualise what the model is doing, this makes it easier to detect errors in the model. The simulation model validation process consists of both face validity and statistical validity. Face validity is the continuous process of ensuring that the model, at least on the surface, represents reality. Face validity is achieved through a cyclic model review and improvement process with the assistance of domain experts. Face validity is a necessary but not individually sufficient condition for establishing complete model validity. Statistical validity involves comparison of the simulation model with the actual system. In statistical validity, some output measures of performance (such as fill rate for some customers, WIP time and WIP numbers of different products) is collected and compared between the built model and the actual system.

Figure 7 Simulation study methodology



6 Results and discussion

In this section the output results of the performance indicators in each performance perspective are presented and analysed. These results are obtained from the simulation model. The evaluated values of the performance indicators are determined for the existing case (no improvements for the system are applied up to this point).

6.1 Output results of financial perspective

Table 9 presents the evaluated values of different performance indicators in the financial perspective. The comparison of the values shows relatively low values of F_3 (in \$/day) for the New machine, Cutting machine 1, and Cutting machine 2. This is due to their low utilisation (see Table 11).

Table 9 Evaluated values of financial performance

Financial performance	*Evaluated values*
F_1	46,387.3 \$/6 months
F_2	2,742.91 \$/week
F_3 for:	
Old machine	70.38 \$/day
Venus machine	62.22 \$/day
New machine	9.22 \$/day
Printing machine	30.27 \$/day
Cutting machine 1	0.52 \$/day
Cutting machine 2	13.93 \$/day
Cutting machine 3	26.07 \$/day
Cutting machine 4	45.11 \$/day

6.2 Output results of customer perspective

Table 10 shows the evaluated values of different performance indicators in the customer perspective. For the orders frequency, the HDP product type has a very high value/day; also the HD product type has high value/day. For the fill rate indicator, the HD products get a very low fill rate percentage; this is due to the limited capacity of HD product machines (see Table 11). For the same reason, the HDP product faces low fill rate, but its value is higher than the HD product fill rate, because the focal company give HDP product higher priority in production. Although it has the highest priority in production, the average time to delivery of orders for the HDP product type is very high. This is due to its high order frequency. Also the HD product has a high time to delivery, because of its high order frequency, and its low production priority.

Table 10 Evaluated values of customer performance

Product type	*Evaluated values*		
	C_1 (Percentage)	*C_2 (kg/day)*	*C_3 (days)*
HD	72.5%	5,496.73	120.9
HDP	84.6%	17,165.7	135.08
LD	100%	761.7	9.44
LDP	100%	301.31	9.15

6.3 Output results of internal operations perspective

Table 11 shows the evaluated values of different performance indicators in the internal operations perspective. The utilisation percentages of the new machine is low, this is due to the low order frequency of the LD and the LDP products. Also all Cutting machines 1, 2, 3 and 4 have low utilisation percentages. This is a result of the limited capacity of the HD production machines, which have low production capacity than the cutting machines.

Table 11 shows that the production cycle time of the HDP product is high. The queue time of the HD and the HDP products have very high values this is due to the limited capacity of HD production machines.

Table 11 Evaluated values of internal operations performance

Internal operations performance	*Evaluated values*	*Internal operations performance*	*Evaluated values*
IO_1 for:	*Percentage*	*IO_2 for:*	*Days*
Old machine	100%	HD	22.41
Venus machine	100%	HDP	37.12
New machine	13%	LD	5.28
Printing machine	29.13%	LDP	2.92
Cutting machine 1	16%	*IO_3 for:*	*Days*
Cutting machine 2	38.23%	HD	98.5
Cutting machine 3	64.36%	HDP	97.96
Cutting machine 4	64.71%	LD	4.16
		LDP	6.23

6.4 Output results of people perspective

Table 12 shows the evaluated values of different performance indicators in the people perspective. Two accidents per month were observed, this value is very high. The management team should raise the employees' safety culture and healthcare, by organising healthcare cycles, distributing notebooks, and/or hinging attention photos. The focal company employees work hardly for above 16 hours a day. The number of employees has a great effect on the accident number. If the employees' number is increased the employees get an appropriate time for refreshment.

Table 12 Evaluated values of people performance

People performance	*Evaluated values*
P_1	Two accidents per month
P_2	employees

6.5 Suggested system improvements to enhance the performance

The focal company has low performance from financial perspective, customer perspective, internal operations perspective, and people perspective. This section provides some recommendations for improving the focal company performance. These recommendations are based on the output of the simulation model, and on the cause and effect diagram of the performance indicators (Figure 7). The recommendations are:

1 For improving the financial, the customer, and the internal operations performance, the focal company may execute one or more of the following recommendations:
   - introduce or purchase a machine for producing HD product type
   - making design improvements for the existing New machine (which produces only the LD product type) to enable it for producing HD product type
   - eliminate the Cutting machine 1 (as it has low percentage utilisation) from the production cycle, and transfer its jobs to the Cutting machine 2
   - get new contracts for the LD product type.

2 For improving the people perspective performance, the focal company might increase the employees' number. Also, the focal company must increase the employees' safety culture and healthcare, by organising healthcare cycles, distributing notebooks, and/or hinging attention photos.

6.6 Output results after applying the suggested system's improvements

For enhancing the financial, customer, and internal operations perspectives' performance, the focal company chooses to make some improvements in the design of the New machine to produce HD product type as well as LD product type. This choice is better than the purchasing of a HD product type machine form the cost view. For enhancing the people perspective performance, the focal company is planning for increasing its employees' safety culture. The output results from the simulation model after making the system improvements are illustrated in Tables 13, 14 and 15. From these tables the enhancement in the values of performance indicators, performance perspectives, and overall performance can be determined. These enhancements are illustrated in Table 16. The enhancement values are estimated upon their weights, which was obtained as discussed in Steps 4 and 6 of the procedural framework.

Table 16 shows positive performance enhancement value in most of the performance indicators which are used for evaluating the focal company performance. The performance indicator C_2 has no change in its value because it presents the order frequency per day which does not influenced by the system's improvement (it is an external factor). The performance indicator IO_3, has a negative value of performance enhancement as it presents the time spent in production queues. This matter was expected because the production queues are facing increased products due to the using of the New machine in producing HD product type. All of the performance perspectives have positive performance enhancement values, and so do the overall system performance.

Table 13 Evaluated values of financial performance for the improved system model

Financial performance	*Evaluated values*
F_1	65,665.27 \$/6 months
F_2	3,631.27 \$/week
F_3 for:	
Old machine	70.12 \$/day
Venus machine	63.44 \$/day
New machine	70.88 \$/day
Printing machine	33.51 \$/day
Cutting machine 1	0.88 \$/day
Cutting machine 2	13.84 \$/day
Cutting machine 3	47.91 \$/day
Cutting machine 4	64.22 \$/day

Table 14 Evaluated values of customer performance for the improved system model

Product type	*Evaluated values*		
	C_1 (Percentage)	*C_2 (kg/day)*	*C_3 (Days)*
HD	84.27%	5605.19	98.8
HDP	86.95%	17108.04	97.2
LD	100%	677.92	28.6
LDP	100%	263.17	26.49

Table 15 Evaluated values of internal operations performance for the improved system model

Internal operations performance	*Evaluated values*	*Internal operations performance*	*Evaluated values*
IO_1 for:	*Percentage*	*IO_2 for:*	*Days*
Old machine	100%	HD	28.58
Venus machine	100%	HDP	29.27
New machine	100%	LD	5.47
Printing machine	30.29%	LDP	6.46
Cutting machine 1	19.77%	*IO_3 for:*	*Days*
Cutting machine 2	33.09%	HD	70.22
Cutting machine 3	94.28%	HDP	67.75
Cutting machine 4	97.54%	LD	23.13
		LDP	20.13

Table 16 Average values of performance enhancement

Performance indicator	*Enhancement value*	*Performance perspective*	*Enhancement value*	*Overall performance enhancement value*
F_1	41.56%	Financial	39.54%	
F_2	32.40%			
F_3	41.57%			
C_1	3.95%	Customer	4.55%	
C_2	-			27.63%
C_3	8.55%			
IO_1	35.15%	Internal Operations	17.78%	
IO_2	12.39%			
IO_3	–3.03%			

7 Conclusions and suggestions for future work

Performance evaluation has played an important role in setting objectives, evaluating performance and determining future courses of actions. However, until recently, most of the PESs have been focused on financial aspects evaluation. There is still lack of a comprehensive performance evaluating system which involves critical non-financial aspects.

The main focuses of the present study, are two fold:

- designing a comprehensive performance evaluating system for evaluating supply chain performance
- using simulation modelling tools to implement the proposed performance evaluating system.

7.1 Comprehensive performance evaluating system

A comprehensive PES is built. It consists of three main parts, i.e., structural framework, procedural framework, and some managerial tools.

The structural framework presents eight performance perspectives, i.e., financial, customer, internal operations, learning and growth, people, environmental, social, and political perspectives. These perspectives include all dimensions of the performance of any supply chain. The variety of performance perspectives enables the managers or decision makers to get a multi-dimensional view of measuring the supply chain performance.

The procedural framework presents a step-wise for implementing the proposed PES. A nine-step procedure is proposed as the implementation methodology of the PES. The first three steps of the procedure are, the definition and determination of the mission, strategic objectives, and performance dimensions of the supply chain. Step four gets a weight for each performance dimension. Steps five and six identify the KPIs for each performance perspective and get a weight for each performance indicator, respectively. Step seven illustrates the cause and effect relationships between the selected performance indicators, while step eight provides a prioritisation process of the performance indicators through an ABC classification. Step nine suggests periodic revision (i.e., daily, weekly, monthly, or yearly) based on the ABC classification of step eight and the change of business environment.

The managerial tools are essential for the PES implementation. These tools include performance indicators list for each performance perspective, statistical analysis tools, and modelling tools.

7.2 Using simulation to implement the proposed PES

Simulation is an advantageous tool for modelling complex systems as supply chain. The current study presents the potentiality of implementing the proposed PES using a simulation methodology.

The real case study reflects the ability and the possibility of implementing the proposed PES in the real world. Also, it draws the guidelines for applying the PES and the suggested simulation methodology. This application clarifies the importance and the necessity of implementing PES for evaluating the performance of the supply chain. Also, it clarifies the benefits of using the simulation in quantifying the performance and in quantifying the possible system's improvements. This is done with little effort, small period of time, and without additional expenses in executing the system's improvements in the real world.

Although this work focuses on designing a PES, the culture of performance evaluation should be announced, companies should have great levels of transparency with each other, and also personnel resources should get training cycles on applying PES and using simulation for PES implementation.

7.3 Suggestions for future work

- a study of the influence of levels of transparency on the overall supply chain performance
- the influence of levels of information sharing on the overall supply chain performance
- the cause and effect relationships between performance indicators should have some detailed study.

References

Altiok, T. and Melamed, B. (2007) *Simulation Modeling and Analysis with Arena*, Academic Press, Elsevier Inc., California, USA.

Artley, W. and Stroh, S. (2001) *The Performance-Based Management Handbook: A Six-Volume Compilation of Techniques and Tools for Implementing the Government Performance and Results Act of 1993, Volume 2 Establishing an Integrated Performance Measurement System*, Prepared by the Training Resources and Data Exchange Performance-Based Management Special Interest Group.

Beamon, B.M. (1999) 'Measuring supply chain performance', *International Journal of Operations and Production Management*, Vol. 19, No. 3, pp.275–292.

Bhagwat, R. and Sharma, M.K. (2007) 'Performance measurement of supply chain management: a balanced scorecard approach', *Computers & Industrial Engineering*, Vol. 53, pp.43–62.

Bourne, M., Mills, J., Wilcox, M., Neely, A. and Platts, K. (2000) 'Designing, implementing and updating performance measurement systems', *International Journal of Operations and Product Management*, Vol. 20, pp.754–771.

Brewer, P. and Speh, T. (2000) 'Using the balanced scorecard to measure supply chain performance', *Journal of Business Logistics*, Vol. 21, No. 1, pp.75–93.

Chan, F.T.S. (2003) 'Performance measurement in a supply chain', *International Journal of Advanced Manufacturing Technology*, Vol. 21, pp.534–548.

Chan, F.T.S. and Qi, H.J. (2003)'An innovative performance measurement method for supply chain management', *Supply Chain Management: An International Journal*, Vol. 8, No. 3, pp.209–223.

Chan, F.T.S., Ip, R.W.L. and Lau, H. (2001) 'Integration of expert system with analytic hierarchy process for the design of material handling equipment selection system', *Journal of Materials Processing Technology*, Vol. 116, pp.137–145.

Chan, F.T.S., Qi, H.J., Chan, H.K., Lau, H.C.W. and Ip, R.W.L. (2003) 'A conceptual model of performance measurement for supply chains', *Management Decision*, Vol. 41, No. 7, pp.635–642.

Chenhall, R.H. and Langfield-Smith, K. (2007) 'Multiple perspectives of performance measures', *European Management Journal*, Vol. 25, No. 4, pp.266–282.

Chong, H.G. (2009) 'Measuring performance of Chinese joint ventures', *Advances in Accounting, incorporating Advances in International Accounting*, Vol. 25, pp.81–88.

De Toni, A. and Tonchia, S. (2001) 'Performance measurement systems: models, characteristics and measures', *International Journal of Operations & Production Management*, Vol. 21, Nos. 1/2, pp.46–70.

Dong, M. (2001) 'Process modeling, performance analysis and configuration simulation in integrated supply chain network design', Doctoral dissertation, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Fleming, D.M., Chow, C.W. and Chen, G. (2009) 'Strategy, performance-measurement systems, and performance: a study of Chinese firms', *The International Journal of Accounting*, Vol. 44, pp.256–278.

Folan, P., Browne, J. and Jagdev, H. (2007) 'Performance: its meaning and content for today's business research', *Computers in Industry*, Vol. 58, pp.605–620.

Franceschini, F., Galetto, M. and Maisano, D. (2007) *Management by Measurement: Designing Key Indicators and Performance Measurement Systems*, Springer-Verlag Berlin Heidelberg.

Gaudenzi, B. (2009) 'Assessing risks in projects and processes', in Zsidisin, G.A. and Ritchie, B. (Eds.): *Supply Chain Risk: A Handbook of Assessment, Management, and Performance*, Springer Science+Business Media, LLC, New York, USA.

Gunasekaran, A., Patel, C. and McGaughey, R.E. (2004) 'A framework for supply chain performance measurement', *International Journal of Production Economics*, Vol. 87, pp.333–347.

Gunasekaran, A., Patel, C. and Tirtiroglu, E. (2001) 'Performance measures and metrics in a supply chain environment', *International Journal of Operations & Production Management*, Vol. 21, Nos. 1/2, pp.71–87.

Hon, K.K.B. (2005) 'Performance and evaluation of manufacturing systems', *CIRP Annals – Manufacturing Technology*, Vol. 54, No. 2, pp.139–154.

Jie, F., Parton, K. and Cox, R. (2007) 'Supply chain practice, supply chain performance indicators and competitive advantage of Australian beef enterprises: a conceptual framework', *Australian Agricultural and Resource Economics Society (AARES 51st Annual Conference)*, Feb 13–16, Rydges Lakeland Resort, Queenstown, New Zealand.

Kaplan, R.S. and Norton, D.P. (1992) 'The balanced scorecard: measures that drive performance', *Harvard Business Review*, Vol. 70, No. 1, pp.71–79.

Kaplan, R.S. and Norton, D.P. (1996) *The Balanced Scorecard: Translating Strategy into Action*, Harvard Business School Press.

Kaplan, R.S. and Norton, D.P. (2001) 'Transforming the balanced scorecard from performance measurement to strategic management: Part I', *American Accounting Association, Accounting Horizons*, Vol. 15, No. 1, pp.87–104.

Kleijnen, J.PC. and Smits, M.T. (2003) 'Performance metrics in supply chain management', *Journal of the Operational Research Society*, Vol. 54, No. 5, pp.507–514.

Krakovics, F., Leal, J.E., Mendes, P., Jr. and Santos, R.L. (2008) 'Defining and calibrating performance indicators of a 4PL in the chemical industry in Brazil', *International Journal of Production Economics*, Vol. 115, pp.502–514.

Lawson, R., Hatch, T. and Desroches, D. (2008) *Scorecard Best Practices: Design, Implementation, and Evaluation*, John Wiley & Sons, Inc.

Lebas, M.J. (1995) 'Performance measurement and performance management', *International Journal of Production Economics*, Vol. 41, pp.23–35.

Lee, A.H.I., Chen, W-C. and Chang, C-J. (2008) 'A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan', *Expert Systems with Applications*, Vol. 34, pp.96–107.

Mårtensson, M. (2009) 'Recounting counting and accounting from political arithmetic to measuring intangibles and back', *Critical Perspectives on Accounting*, Vol. 20, pp.835–846.

Masquefa, B. (2008) 'Top management adoption of a locally driven performance measurement and evaluation system: a social network perspective', *Management Accounting Research*, Vol. 19, pp.182–207.

Olugu, E.U. and Wong, K.Y. (2009) 'Supply chain performance evaluation: trends and challenges', *American Journal of Engineering and Applied Sciences*, Vol. 2, No. 1, pp.202–211.

Papageorgiou, L.G. (2009) 'Supply chain optimisation for the process industries: advances and opportunities', *Computers and Chemical Engineering*, Vol. 33, pp.1931–1938.

Perotto, E., Canziani, R., Marchesi, R. and Butelli, P. (2008) 'Environmental performance, indicators and measurement uncertainty in EMS context: a case study', *Journal of Cleaner Production*, Vol. 16, pp.517–530.

Van der Vorst, J.G.A.J., Beulens, A.J.M. and van Beek, P. (2000) 'Modelling and simulating multi-echelon food systems', *European Journal of Operational Research*, Vol. 22, pp.354–366.

Waggoner, D.B., Neely, A.D. and Kennerley, M.P. (1999) 'The forces that shape organisational performance measurement systems: An interdisciplinary review', *International Journal of Production Economics*, Vols. 60–61, pp.53–60.

Wainer, G.A. (2009) *Discrete-Event Modeling and Simulation: A Practitioner's Approach*, Taylor & Francis Group, LLC.

Notes

1 The Kiviat graph alternates good and bad attributes (for example, fill rate, stock, confirmed fill rate, response delay), so an attractive product results in a star-like graph oriented upwards.

2 Legitimisation is defined as intentional acts of influence to enhance or protect the self-interest of individuals or groups.