Master’s thesis

Business Information Systems (MBA)

2014

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PERFORMANCE MEASUREMENT FRAMEWORK FOR ENGINEERING SUPPLY CHAIN

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MASTER´S THESIS | ABSTRACT
TURKU UNIVERSITY OF APPLIED SCIENCES

Business Information Systems (MBA)

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One of the primary concern on the supply chain management (SCM) is the performance measurement because it is evident that there cannot be managed where there cannot be measured in supply chain performance. Supply chain performance measurement (SCPM) has taken a great role for set-up the concrete strategy and a driving force for improvement in organizational productivity. Accordingly, it is vital to establish the right performance measures and measurement system to set up strategic objectives, to evaluate the organizational performance, and to manage the future of business goal and activities effectively.

The main objective of this case study research is to define the most effective performance metrics and to develop the corresponding framework with its criteria to improve the efficiency of engineering supply chain performance. Moreover, the performance measurement framework has been targeted to support the managerial decision-making systematically and dynamically by providing a management dashboard including feedbacks and KPIs.

The research questions are generated to identify the problems, and the objectives of research works are defined as following three tasks. First, what measures can represent the performance effectively? Second, how can the performance are measured systematically? Third, how can the measured performance be analyzed and utilized to provide with a managerial decision-making tool?

As the result of the research, performance module concept based on BSC (Balanced Score Card) with implementation of AHP (Analytic Hierarchy Process) methodology has been developed to meet the research objectives. The framework of BSC+AHP has been proposed, and it can contribute on the performance measurement and its effective measures and metrics for engineering supply chain, where the multi-dimensional performance measures are transformed into the representing BSC+AHP modules for a dedicated performance evaluation.

This SCPM (Supply chain performance measurement) framework proposes the measures and metrics for the engineering supply chain performance. However, this measurement framework also could be utilized in different industrial areas of business by customizing the BSC+AHP modules and its metrics in accordance with the business characteristics.

KEYWORDS:

Supply chain performance measurement; Performance measures and metrics; Analytic Hierarchy Process (AHP); BSC+AHP Performance measurement framework;

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LIST OF ABBREVIATIONS (OR) SYMBOLS

SC	Supply Chain (SC) is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services that are delivered to the ultimate consumer. (Christopher 1992)
SCM	Supply Chain Management (SCM) is the integration of business processes from end user through original suppliers that provide products, services and information that add value for customers. (International center for competitive excellences 1994)
AHP	Analytic Hierarchy Process (AHP) is a multi-criteria decision making approach in which factors are arranged in a hierarchic structure. (Thomas L. Saaty 1990)
BSC	Balanced Scorecard (BSC). The Balanced Scorecard translates an organization's mission and strategy into a comprehensive set of performance measures that provides the framework for a strategic measurement and management system (Kaplan and Norton 1996)
KPI	Key performance indicator (KPI) is a type of performance measurement. An organization may use KPIs to evaluate its success, or to evaluate the success of a particular activity in which it is engaged. (en.wikipedia.org)
SCOR	The Supply Chain Operations Reference-model (SCOR) is a process reference model that has been developed and endorsed by the Supply Chain Council as the cross-industry standard diagnostic tool for supply chain management. (Supply Chain Council)
CAD	Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design (Narayan, K. Lalit (2008)

1 INTRODUCTION

STX Finland Oy is one of the well-known international shipbuilding companies, which has built the most sophisticated and biggest cruise ship of “Oasis of the Seas” in 2010. And the company is a leading ship designer and shipbuilder of the most innovative cruise ships and specialized vessels worldwide with the shipbuilding history of 300 years. The employees in STX Finland Oy are varying from 2500 to 5000 in accordance with the project workloads. Moreover, the total number of working personnel in shipyard reached up to 8000 workers including subcontractors at the peak time. The business characteristics of company are collaborating with the great amount of supply chain networks globally. In other words, supply chain management has the great importance for the case company of STX Finland.

The specialty of Finnish Shipbuilding industry has created many great products during the long history, and it proves the innovativeness and creativeness in design, sophisticated production management, and the qualified skillful personnel. However, the recent global economy recession and the competing market situations are requesting more competitiveness in productivity together with the higher performance of supply chains to maintain the sustainable business.

Due to the business characteristics and the nature of production processes of the cruise shipbuilding, the functions and the roles of supply chain networks are significant, and, therefore, their performances are substantial on the productivity, delivery, profitability and competitiveness of the case company.

This case study research has been initiated as a part of the shipyard’s cost saving initiatives through the improvement of supply chain performance measurement and management. The research objective is identified as the performance measurement and management criteria of the engineering supply chain. Moreover, the final target of this research aimed at the development of a measurement framework as the managerial decision-making tool for the case Company.

1.1 Background of Research

The case company measures the performance of the engineering supply chain with the progress of CAD modellings in percentage, delivery accuracy in number of drawings, and customer satisfaction level by 10 grades on a monthly basis. However, it is understood that these measures do not provide with the holistic view of supply chain performance. Moreover, the progress monitoring cannot ensure the delivery reliability as well as the quality of the engineering products.

The performance of the engineering supply chains that are participated in the project, are measured and managed by the design coordinators who are working for the organization. It is also noted that there do not exist the common priority and the common criteria of decision making among performance measures. So, various decision priority and criteria on performance measures are implemented by the individual design coordinators as per their expertise and experiences. For example, delivery performance is considered as the most important measures for a certain managers, while the quality of engineering process is considered as a dominant measure for other design coordinators.

In shipbuilding production processes, the measures and its criteria of engineering supply chain performance have multi-dimensional characteristics, and the decision-making is very complicated due to the performance measures are interrelated and affected each other.

The common perception on the priority and criteria of performance measures, and the enhancement of sharing the information have been the continuous challenging topic for the engineering supply chains for the case company.

In this case study, the research approaches to the implementation of multi-dimensional criteria of the performance measures into the Analytic Hierarchy Process (AHP) methodology together with the BSC module concept in order to transform the characteristics and to represent the performance of the supply chain.

1.2 Goal and Specific Objectives of Research

The goal of this case study research is to improve the performance management of engineering supply chain for the case company. The specific research objectives are set up to identify the performance measures and metrics, and then developing a performance measurement framework. The framework is utilized to evaluate the performance of the supply chains, and to provide with the managerial decision-making tool for the case Company. Also, it has been considered to implement the framework for all levels including the responsible managers or design coordinators in operating level as well as the top managers in higher management level.

The relevant literatures are reviewed to investigate the performance metrics and measures that are suitable to represent the performance characteristics of engineering supply chains. And then, the metrics are categorized into the key criteria and sub-criteria for evaluation of performances with the influencing priorities.

To realize these objectives, suitable identification and establishment of performance criteria, measures, metrics together with the measurement methodology, and the frameworks for performance evaluation, are needed to be developed.

1.3 Research Tasks

This case study research is aiming at understanding complex phenomena of the engineering supply chain performance and its measurement. In order for understanding the engineering performance measurement, it is essential to study the engineering processes in their genuine context.

It is not often clear on interrelationship between the phenomena and context in engineering supply chain performance and that makes the research tasks more complicated in development of performance framework.

For carrying out this research work, the case study approach is utilized for implementation of the research processes and methodologies.

According to Ghauri and Gronhaug (2004), a case study is suitable if the research topic is focusing on the current phenomena in a real-life context and the questions of “How” or “Why” are to be answered to the topics.

Following research question has been raised as the main issue and it has been the driving force for further improvement on the performance measurement of the case Company;

How to measure the progress of engineering supply chain performance?

In order to answer to the research question, the following three (3) research tasks are settled up:

Task1*. What measures and metrics can represent the progressive performance of the engineering supply chain effectively?*
Task2*. How can the selected performance metrics be measured from the engineering supply chain effectively?*
Task3*. How can the measured performance metrics be analyzed and utilized to provide as managerial decision-making tool?*

In order to carry out these research tasks, the literature reviews on the supply chain performance measurement metrics and frameworks provides with the benchmarking on suitable models to develop a performance measures and measurement framework for the case company. The study also focuses on how the performance of engineering supply chain needs to be measured and how the performance of engineering supply chain can be evaluated and managed.

In addition to above, the final goal is planned to provide with the managerial decision-making KPIs and its dashboard to increase the efficiency of the supply chain performance measurement and management.

The key terms of this study are defined as follows.

Key criteria of SC Performance Measurement	Key terms of Research Objectives
. Identification of the right performance measures and metrics. . Implementation methodology of effective measures and metrics for supply chain performance evaluation.	. Characteristics of multi-dimensional criteria of performance metrics. . Analytic Hierarchy Process (AHP) with Saaty's nine scale ratings.
. Framework of Engineering Supply Chain Performance Measurement	. Balanced Scorecard Approach . Development of BSC Modules; "BSC-SCPM-XX"

1.4 Thesis structure and research methods

This research is a single case study. According to Klenke (2008), single case studies are preferred approach if the research topics belong to unique or extreme cases such as specific dedicated business organizations. In this research, the case company represents one of the leading international shipbuilding companies, which builds cruise ship and specialized vessels.

The business environment of the shipbuilding companies are heavily related to the performance of the supply chain networks and the supply chain management and performance measurement is commonly requested for the shipbuilding industry.

This thesis is based on quantitative research method as well as qualitative research approach since it involves multi-dimensional characteristics of supply chain performance measurement metrics, and the performance measures are interrelated each other. The Balanced scorecard concept and Analytic Hierarchy Process (AHP) with Saaty's nine scale ratings of pair-wise comparison method are utilized as a locomotive tool to accommodate these complexities.

. Theoretical backgrounds	. Supply chain performance measurement, measures and its frameworks
. Research paradigm	. Empirical analysis with implementation of the latest research development
. Research strategy and research approaches	. Qualitative and Quantitative research . Data from ERP systems (Kronodoc, JIRA), experiences, observations, documents, discussions/interviews
. Research methods	. Case study approach . Balanced Scorecard concept (BSC) . Analytic Hierarchy Process (AHP)

This case study research focuses on the framework for performance measurement of the engineering supply chain in the case company.

Also, the research presents the establishment of the metrics and its modules for SC performance measurement by the employing of the Analytic Hierarchy Process (AHP) methodology, together with Balanced Scorecard (BSC) concept in order to provide the case company with the managerial decision-making criteria.

2 LITERATURE REVIEW

In order to benchmarking the relevant models to fit this research objectives, the current literature reviews have been investigated on supply chain performance measurement, the measures and metrics and the framework approaches, and highlighted as follows.

It has been emphasized the necessities and importance of performance measurement by claiming that, "*You cannot manage what you cannot measure*" (Sink & Tuttle, 1989). In real-life business management viewpoint, if there are no measurement data and there are no physical features of information, the management environment is in uncertainties, and a decision-making is very difficult for decision makers as well as the process managers.

Also, Wouters (2009) claims that actual performance measurement supports: the deployment of strategy, an enhancement of communication, and the monitoring of processes.

Supply chain performance measurement (SCPM) is the core components for improvement of supply chain management (SCM). Therefore, SCPM system should be developed in line with the strategy of SCM for fulfilment of customer satisfaction through the most efficient utilization of the organizational resources.

In order to conduct the effective supply chain performance measurement, the establishment of right performance measures and metrics is one of the crucial issues because the performance objectives vary with the purpose of business and its strategies. Furthermore, the performance of supply chain needs to be analyzed and evaluated on the various aspects as a whole entity in continuous changing circumstances.

Accordingly, the performance measures and metrics need to be measurable, non-bias and non-interconnected in association with many other relevant features. For example, it is evident that supply chain performance measures need to be balanced with the financial against the non-financial aspects.

2.1 Supply Chain Performance Measurement (SCPM)

From the business operational perspective, the core purpose of performance measurement system is “a process of quantifying the efficiency and/or effectiveness of action” (Neely et al., 1995).

Moullin (2002) also defines it as “the process of evaluating how the organizations are managed well and how the values are delivered for customers and other stakeholders.”

From the modern business management perspective, the performance measurement provides the necessary information of management feedback for process managers as well as decision makers, and it takes a significant role in monitoring performance, enhancing motivation, improving communication, and diagnosing potential problems. Furthermore, performance measurement can support the deployment of management strategies and facilitating the feedback for the futuristic situation.

In addition, performance measurement supports in directing management attention, revising and updating company goals, and re-engineering business processes accordingly. Therefore, the accurate supply chain performance measurement is essential in the continuous improvement of supply chain management (Chan 2003).

The major purposes of a performance measurement system are presented by Gunasekaran & Kobu (2007) as follows;

- identify customer demands and requirements as well as capability, non-values in process, problems and improvement opportunities
- provide better understanding of processes
- enable monitoring and controlling the achievements
- facilitate the more communication and collaboration
- support feedback for decision-making

It is very hard to elaborate common measures and metrics for measuring total supply chain performance effectively and precisely, and, therefore, the metrics are usually to be established independently for each business unit organization.

The features of multi-dimensional parameters and diversity of business objectives emphasize the importance of performance measurement approaches such as financial, non-financial, qualitative and quantitative. Also, the performance measures and metrics including plan, resource, time, cost, quality, flexibility, reliability, agility with the operational processes and activities are relevant to the approach of performance measurement.

SC performance measurement system is a performance measurement model which is based on mutually agreed goals, measures, measurement methodology that specify procedures, responsibilities and accountability of supply chains, and the criteria of the measurement system together with supply chains. (Holmberg 2000)

A performance measurement is defined as the feedback on operations which are dedicated to customer satisfaction, company strategy and business objectives. Also, it asserts that performance measurement motivates the need for improvement in operational processes that are referred to as the critical paths in performance measurement. (Bhagwat and Sharma, 2007)

The importance of performance measurement systems is summarized by Gunasekaran et al. (2004) as follows;

- Driving organizational activities to achieve higher performance with the monitored outcomes by identifying the improvement area.
- Providing a basis of evaluation and criteria of decision-making for actions at all the levels of strategic, tactical and operational function.
- Facilitating feedbacks on process tracking, diagnosis of problems and identification of potential opportunities for improvement through the internal and/or external communications.

The futuristic research topics on supply chain performance measurement are the actual implementation in business performance management, proactive performance measurement of supply chain, measurement approach in intangible and tangible metrics, dynamic measurement systems, and flexibility of measurement systems across the industries (Neely, 2005).

2.2 Measures and Metrics of Supply Chain Performances

According to Neely et al. (1995), the primary purpose of a performance measurement is to quantify the efficiency and effectiveness of activities of organization, and the performances of activities can be evaluated and analysed by asking following questions;

- What performance measures are used?
- What purpose are they used?
- How much do they cost?
- What benefit do they provide?

It is noted that the performance measures and metrics can provide with more open and transparent communication in the organization, and they lead to a cooperative working environment, and hence, resulting into the improved organizational performance (Gunasekaran and Kobu, 2007). However, designing, implementation, and execution of a set of performance measures are to be ensured continuous updating of the system (Beamon, 1998; Bourne et al., 2000).

In the literature review, there are several highlighted the contemporary performance measurement issues as follows. (Shepherd and Gunter, 2006)

- the influencing measures of the successful implementation of performance measurement systems (Bourne et al., 2000)
- the forces of shaping the evolution of performance measurement systems (Kennerley and Neely, 2003; Waggoner et al., 1999)

- Sustainable performance measurement systems to aligned with dynamic environments and changing strategies (Bourne et al., 2000; Kennerley and Neely, 2003).

There are a few literatures which deal with the practical performance measures and metrics for supply chain performance measurement (Gunasekaran and Kobu, 2007). Moreover, there is little evidence of systematic empirical research on the implementation of performance measurement systems (Bourne et al., 2000; Neely et al., 2000; Nudurupati et al., 2011). However, there are a limited number of empirical researches on the implementation of dynamic performance measurement systems (Bourne et al., 2000). Therefore, implementation and updating of performance measurement systems have not received keen attention for many years (Bourne et al., 2000; Kennerley and Neely, 2003; Nudurupati et al., 2011)

The fundamental characteristics and requirements of proper performance measurement and metrics have been presented and elaborated with the following topics of performance measurement metrics including, (Gunasekaran et al. 2004; Gopal and Thakkar, 2012);

- Identification of the key performance indicators (KPIs).
- Reflection of the balance between financial and non-financial measures.
- Linkage of the strategic, tactical and operational levels of decision-making and control.
- Classification basis of the push, pull, and push-pull supply chains.
- Mathematically valid features of metrics and measures.
- Allowance in setting targets, aggregation & disaggregation, prioritisation, weighting and integration.
- Tailoring of the complex supply chain networks.
- Simple and easy for use in the form of ratios.
- Responding to the rapid changes.
- Handling of collaborations, partnerships, agility and flexibility.
- Defining of business excellences.

- Adopting of a proactive approach, rapid response and continuous improvement.
- Fitting of the functions for all levels.
- Being coherent and transparent

The establishing and implementing a performance measurement system to meet all these requirements is a challenging task, and requiring comprehensive considerations on business processes, technical and organisational and managerial issues. These challenges grow to more complexity by increased demands for measuring partnership, collaboration, agility, and business excellence requirements in the modern business environment (Akyuz and Erkan, 2010).

Hence, the efficiency is a measure on how the company's resources are utilized economically with the condition of a given level of customer satisfaction, it is essential to develop the effective measures for the efficient performance measurement system. However, monitoring and measurement of performance of the supply chains have become increasingly complex task (Cai et al., 2009).

In order to develop a performance measurement and measures, it needs to focus on what and how the measures are implied, and how to analyse the measures appropriately. Moreover, the performance measures differ from contexts to contexts that are resulting into complexity since they are involved with the multi-dimensional characteristics.

Furthermore, the composition of measures of the performance measurement system in supply chain is different in relation to the customer's requirements and objectives of a supply chain. Moreover, it is important to keep developing and improving the performance measures of supply chain with the continuous updating and benchmarking to the current rapid changing business environment.

The selection and implementation of the right measures of supply chain performance is a critical topic for management because it is needed for decision makers to evaluate supply chain performance on various aspects with the multi-dimensional criteria. Moreover, the selection of the right performance also measures enhancing the clear communicating strategy and encouraging its implementation (Agami et al., 2012).

Researchers have developed the supply chain performance measures in the various perceptions and approached as follows (Gopal and Thakkar, 2012);

- Qualitative or quantitative (Beamon, 1999; Chan, 2003);
- Cost and non-cost (Gunasekaran et al., 2001);
- Quality, cost, resource utilization, flexibility, Innovativeness (Chan, 2003);
- Resources, outputs and flexibility (Beamon, 1999);
- Input, output and composite measures (Chan and Qi, 2003);
- Strategic, operational or tactical approach (Gunasekaran et al., 2001);
- Supply chain operations reference (SCOR) model (SCC);
- Key performance measures and metrics (Gunasekaran and Kobu, 2007);
- Scorecards approach (Brewer and Speh, 2000);
- Financial and non-financial approach (Gunasekaran et al., 2004)

According to Gopal (2012), the researchers have focused on specific areas of the perspective analysis on the supply chain performance including;

- collaboration and trust,
- integration,
- product variety,
- partnership,
- organizational structures,
- collaboration,
- information technology,
- system perspective,
- environmental,
- agile,
- risk

From the above highlighted points, it can be concluded that researchers have perceived supply chain performance from various perspectives. The researchers' perspective is a unique view of what supply chain management (SCM) objectives are about. Researchers' perspective can be described in terms of the perceived nature of the supply chain (Otto and Kotzab, 2003).

Shepherd and Günther (2006) present taxonomy of measures of supply chain performance as follows.

- Measures are categorized as supply chain actions: *plan, source, make, deliver and return*.
- Measures also recognized as the perspectives: *cost, time, quality, flexibility or innovativeness* approach*.*
- Measures are divided into two characteristics: *quantitative and qualitative* measures.

Gunasekaran et al. (2004) focus on classification of various supply chain measures based on supply chain activities with respect to levels of an organization (strategic, operational and tactical) to address the authority and responsibility of management at appropriate level.

Thakkar et al. (2009) present the essential features of the performance metrics for identification of SC performance measurement:

- measurement system should have the capability to capture the essence of organizational performance

- measurement system should ensure an appropriate assignment of metrics to the areas where they would be most appropriate

- measurement system should allow the minimum deviations between the organizational goals and measurement goals

- measures and metrics should provide an adequate balance between financial and non-financial perspectives

- measures and metrics should support the decision-makings at the various level of strategic, tactical, and operation.

However, recent literature review points out that many of performance measures and metrics are lacking in strategy alignment, balanced approach and system implementation. Moreover, they have difficulty in identifying the most relevant metrics systematically. Also, they state that current SC performance measurement systems do not provide definite inter-relationship among the various individual performance measures and metrics. (Akyuz and Erkan 2010, Cai et al. 2009)

In today's trends of successful business excellences of supply chain, collaboration, agility and flexibility are among the critical success criteria, but the current supply chain performance management still appears to have a difficulty in measuring the degree of collaboration, agility and flexibility (Akyuz and Erkan, 2010).

In order to achieve the effective performance management, it is vital to select the right performance metrics and measures. Moreover, the evaluation of the performance measurements is the key to the success because the performance measures and metrics in supply chain are involved with the complexity of multi-dimensional characteristics. In this view, Analytical hierarchy process (AHP) is a proven effective methodology for evaluation of performance measures and metrics by prioritizing the attributes and linking to the objectives in supply chain. AHP facilitates with the decision makers best suits for their decision-making in daily business operations. (Bhagwat and Sharma, 2007)

AHP is a common tool for solving multi-criteria decision-making problems. AHP provides a framework for involving tangible and intangible as well as qualitative and quantitative approach. AHP provides versatility and power in structuring and analyzing a complex multi-attribute decision-making problem, by giving means of quantifying judgmental consistency. (Chan et al., 2003a; Korpela et al., 2001)

2.3 Supply Chain Performance Measurement System Approach

Supply Chain Management (SCM) and its performance measurement are an effective business perception and strategy that keep continuous attention from researchers and business entrepreneurs to achieve the business objectives with the customer satisfaction. Performance measurement of supply chain facilitates supply chain to strategically manage and systematically achieve the goal of objectives. Therefore, the performance measurement provides the motivation and driving force for performance improvement in pursuit of supply chain excellence.

The current literature review identifies that an effective SC performance measurement system should be characterized by Akyuz and Erkan (2010):

- Covers necessary aspects and processes of a supply chain
- Allows for evaluation under different operating environment
- Features measurable for evaluation
- Compatible with goals and strategy

Upon historical literature review on the type of SC performance measurement system, the financial performance measurement systems are traditionally referring as measures and methods for measuring supply chain performance. Therefore, the systems are mainly focused on financial features, and hence there were much criticisms on the effectiveness of performance measurement, and there has been presented on the importance of strategic non-financial measures.

The performance metrics are further categorized as financial measures or non-financial measures. Such measures and metrics are interrelated together with the hierarchical mechanism of supply chain performance measurement and mapped with the performance measures into the organizational goals.

Gunasekaran et al. (2004) classified measures as strategic, tactical and operational level measurement. The main perception is that how to assign measures and where they can be best fit at the appropriate management level.

Agami et al. (2012) asserted that nine different types of non-financial SC performance measurement approaches in accordance with their criteria and perception of measurement as described in Table 1.

Table 1 Type of Non-Financial Performance Measurements (Agami et al., 2012)

No.	Type of Measurement system	Criteria of Measurement
1.	Function-based Systems (FBMS)	Performance measures of functions within each process of the supply chain.
2.	Dimension-based Systems(DBMS)	Performance evaluation of pre-determined key dimensions across the supply chain.
3.	Hierarchical-based Systems (HBMS)	Performance measures identified on three levels of management: Strategic, Tactical and Operational.
4.	Interface-based Systems (IBMS)	Performance measures defined between supply chain linkages, i.e. stages.
5.	Perspective-based Systems (PBMS)	Performance measures on six perspectives of the supply chain: Operations Research, System Dynamics, Logistics, Marketing, Organization and Strategy.
6.	Efficiency-based Systems (EBMS)	Performance measures to evaluate the supply chain efficiency.
7.	SC Operations Reference Model (SCOR)	Performance measures along the five main supply chain processes: Plan, Source, Make, Deliver and Return
8.	SC Balanced Scorecard (SCBS)	Performance measures across four supply chain perspectives: Financial, Customer, Internal Business Processes and Innovation and Learning.
9.	Generic Systems (GPMS)	Performance measures are strategy aligned

In addition to above, there are several different theories and systematic approaches for the supply chain performance measurement system including;

- a dynamic modelling that combined with classical control theory.
- a multi-stage and stochastic mixed integer linear model to cover the supply chain dynamics.
- an iterative analytical approach based on eigenvalues for dependence modelling of key performance indicators (KPIs).

- a stepwise regression to analyze the dependency of measures.
- an analytical hierarchy process (AHP) approach for prioritizing weight of metrics.
- a simulation-based experimental approach of ERP-based supply chain performance measurement.

2.3.1 Supply Chain Performance Metrics Framework

Gunasekaran et al. (2004) asserts that the metrics for supply chain performance measurement framework are to be selected to cover all level of the processes. Top management focuses strategic and tactical measures for managerial decisions, but lower management and workers need operational measures for daily activities. And, therefore, a framework should include the metrics of SC performance as follows;

- *Measures for planning*: order entry method, order lead-time, planned process cycle time.
- *Measures for purpose*: strategic level measures, tactical level measures, operational level measures.
- *Measures for production*: master production schedule, capacity utilization, accuracy of forecasting techniques.
- *Measures for delivery performance*: total distribution cost, delivery lead-time.
- *Measures for customer services*: flexibility, customer query time.
- *Measures for logistics*: cost of assets, ROI, information processing cost.

According to Sillanpää (2011), performance metrics of supply chain performance measurement framework have been identified into two categories of financial or non-financial in association with the three management levels of strategic, tactical and operational as shown in Table 2. It provides the more physical perception of the performance measurement framework.

Table 2 Metrics of supply chain performance framework (Sillanpää, 2011)

Strategic Level Performance Metrics	Tactical Level Performance Metrics	Operational Level Performance Metrics
Financial metrics		
Net profit vs. productivity ratio		Cost per operation hour
Rate of return on investment		Total inventory
Variations against budget		
Flexibility of service systems		
Financial and non-financial metrics		
Total cash flow time	Accuracy of forecasting techniques	Supplier rejection rate
Customer query time	Supplier cost saving initiatives	Information carrying cost
Buyer-supplier partnership level	Delivery reliability	
Delivery performance		
Non-financial metrics		
Range of product and services	Product development cycle time	Capacity utilization
Total SC cycle time	Order entry methods	Quality of delivery documentation
Level of customer perceived value of product	Effectiveness of delivery invoice methods	Efficiency of purchase order cycle time
Order lead-time	Purchase order cycle time	Driver reliability for performance
Supplier lead-time against industry norm	Effectiveness of master production schedule	Quality of delivered goods
Level of supplier's defect free deliveries	Planned process cycle time	
Delivery lead-time	Supplier assistance in solving technical problems	
	Supplier ability to respond to quality problems	
	Supplier booking in procedures	
	Responsiveness to urgent deliveries	
	Effectiveness of distribution planning schedule	

2.3.2 Supply Chain Balanced Score Card (BSC) Framework

The basic idea of Balanced Score Card has been claimed by Kaplan and Norton (1992) who realized that the tendency of performance measurement are too much focused on financial performance measures, and raised the issues with following arguments that;

The performance measurement system and performance measures are affecting in various aspects on the operational perception of managers and behaviour of employees in the organization, and therefore, the traditional financial performance measures cannot give the holistic feature of the organizational performance.

Kaplan and Norton (1992) presented that the managers should establish a strategic balanced scorecard system with four perspectives of financial, business process, customer, and growth as shown in Figure 1.

Moreover, they emphasized that the goals and measures of each score cards' perception are to be met with following questions.

- Financial perspective : How should we appear to shareholders?
- Business process perspective : What process must we excel at?
- Learning & growth perspective : How shall we sustain our core strength?
- Customer perspective : How should we appear to our customers?

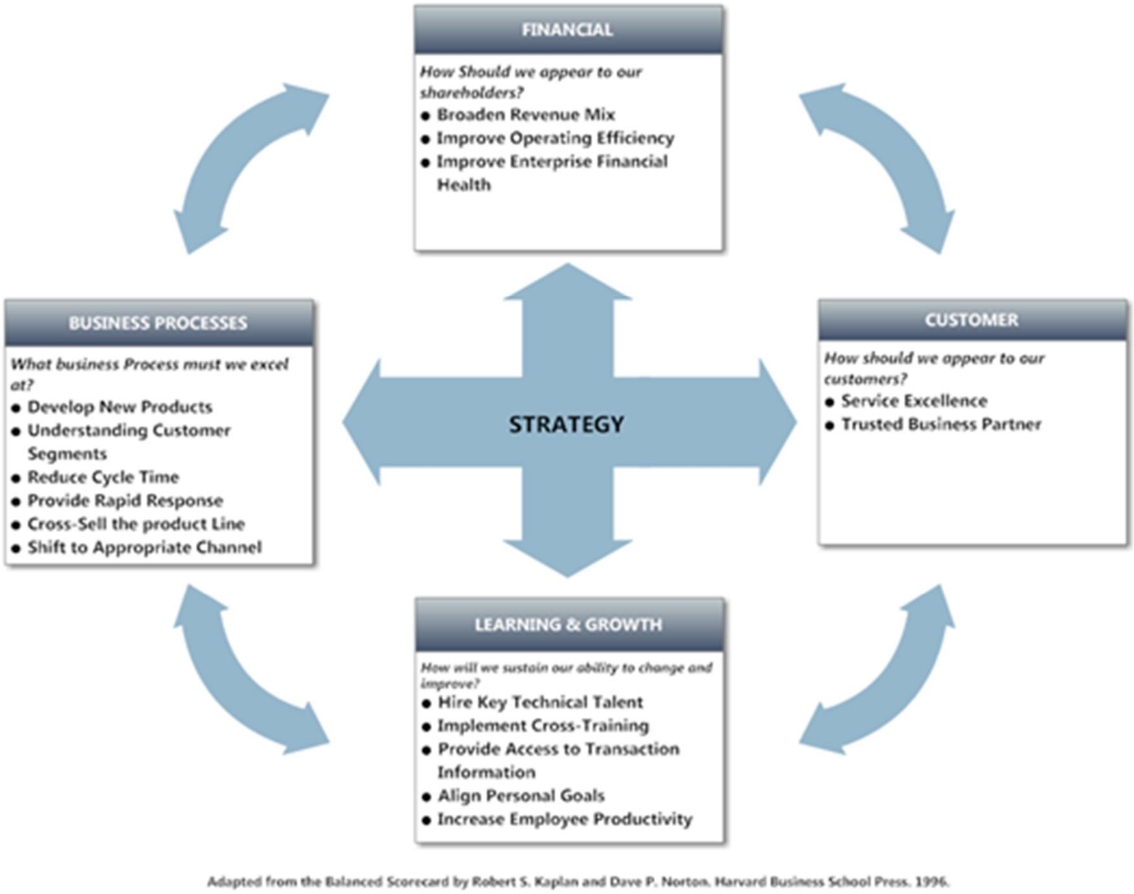

Figure 1 Balanced scorecard model (Kaplan & Norton, 1996)

The perspective of BSC has two main approaches as customer perspective and financial perspective. The mission of customer perspectives is to achieve a vision by delivering value to customers in association with internal business processes that aim to promote efficiency and effectiveness. The mission of the financial perspective is to succeed financially, by delivering value and vision to the stakeholders, by sustaining innovation and enhancing capabilities, through continuous learning and growth strategies for the future (Neely et al., 1995; Kaplan and Norton, 1996; Bhagwat and Sharma, 2007).

Bhagwat and Sharma (2007) introduced BSC framework approaches with the measures in four perspectives. It consists of financial perspective, internal business perspective, customer perspective, and Innovation & learning perspective. The details are shown in Table 3.

Table 3 SC Performance measures for BSC Framework (Bhagwat & Sharma 2007)

Customer Perspective:	**Internal Business Perspective:**
. Customer query time	. Total supply chain cycle time
. Level of customer perceived value	. Total cash flow time
. Range of products and services	. Flexibility of service system on client needs
. Order lead time	. Supplier lead time against industrial norms
. Flexibility of service system on demands	. Level of supplier's defect free deliveries
. Buyer-Supplier partnership level	. Accuracy of forecasting technique
. Delivery lead time	. Product development cycle time
. Delivery performance	. Purchase order cycle time
. Effectiveness of delivery invoice methods	. Planned process cycle time
. Delivery reliability	. Effectiveness of master production schedule
. Responsiveness to urgent deliveries	. Capacity utilization
. Effectiveness of distribution planning	. Total inventory cost
. Information carrying cost	. Supplier rejection rate
. Quality of delivery documentation	. Efficiency of purchase order cycle time
. Reliability for performance	. Frequency of delivery
. Quality of delivered goods	
. Achievement of defect free deliveries	
Financial Perspective:	**Innovation & learning Perspective:**
. Customer query time	. Supplier assistance in solving problems
. Net profit vs. productivity ratio	. Supplier ability to respond to quality problem
. Rate of return on investment	. Supplier cost saving initiative
.Variations against budget	. Supplier's booking in procedures
. Buyer-Supplier partnership level	. Capacity utilization
. Delivery performance	. Order entry methods
. Supplier cost saving initiative	. Accuracy of forecasting technique
. Delivery reliability	. Product development cycle time
. Cost per operation hour	. Flexibility of service system on client needs
. Information carrying cost	. Buyer-Supplier partnership level
. Supplier rejection rate	. Range of products and services
	. Level of customer perceived value of product

2.3.3 Supply Chain Operations reference (SCOR) Model Framework

The SCOR framework has been developed by the Supply Chain Council (www.supply-chain.org). The SCOR is a hierarchical model that describes the management scopes related to the supply chain in five primary management processes of Plan, Source, Make, Deliver, and Return. Each of these processes is decomposed into four levels of detail: Top Level as Process type, Configuration Level as Process categories, Process Element Level as Decompose processes, and Implementation Level as Decompose process element, as shown Figure 2.

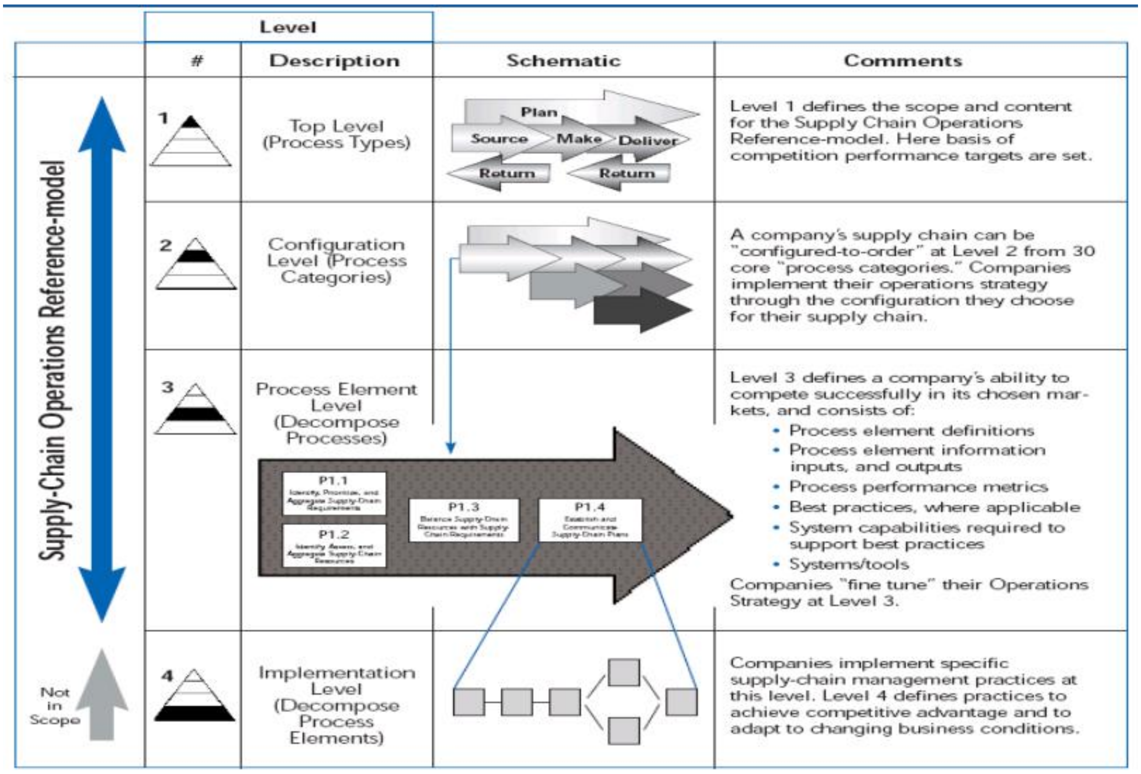

Figure 2 SCOR Model Hierarchy (SCOR Model Version 10.0, SCC)

The SCOR model is consisting of four primary components of Performance, Process, Practices and People, and the SCOR model hierarchy presents the process architecture of business process framework as follows; (Supply-Chain Council, SCOR Rev. 11.0)

- *Performance*: Composed with the standard metrics to describe process performance and define strategic goals. This performance component decomposed into two elements by performance attributes and performance metrics. The performance attributes are a group of metrics to express the strategy which includes reliability, responsibility, agility, costs, and assets. An attribute itself cannot be measured, but it is used to set strategic direction. Performance metrics measures the ability of the supply chain to achieve these strategic attributes.
- *Processes*: Provides a set of pre-defined descriptions for activities most companies perform to execute their supply chain effectively. The five processes of Plan, Source, Make, Deliver and Return are adopted in SCOR process model. Also, each process deploys three level processes to define the span, categories, capabilities, and detailed activities.
- *Practice*s: Consists of best practices organized by original objectives for improving overall supply chain operational performance (SCOR), and Green SCOR for improving the environmental footprint of the supply chain, and Risk Management for mitigating the risks of an undesired event taking place, limiting the impact of such an event and improving the ability to recover from the event.
- *People*: Facilitates a standard for describing skills required to perform the tasks and manage the supply chain processes. Skills are described by the standard definition and association to other people aspects: Aptitudes, Experiences, Trainings and Competency level.

A performance attribute is a grouping of metrics used to express a strategy, and the group is defined by five (5) performance attributes; Reliability, Responsiveness, Agility, Costs, Asset Management Efficiency as (Supply-Chain Council, SCOR Rev. 11.0);

- *Supply Chain Reliability Attribute.* The Reliability attribute for supply chain addresses the ability to perform tasks as expected. Reliability attribute is defined the performance of the supply chain in delivering: the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer. Typical metrics for the reliability attribute include: on-time, the right quantity, the right quality. Level 1 strategic metric (SCOR KPI) is Perfect Order Fulfillment. Reliability is a customer-focused attribute.

- *Supply Chain Responsiveness Attribute.* The responsiveness attribute describes the speed at which tasks are performed by the request of clients. Level 1 strategic metric (SCOR KPI) is Order Fulfillment Cycle Time. Responsiveness is a customer-focused attribute.
- *Supply Chain Agility Attribute.* The agility of SC in responding to marketplace changes to gain or maintain competitive advantage. The agility attribute describes the ability to respond to external influences and the ability to change. External influences include: non-forecasted increases or decreases in demand; suppliers or partners going out of business; natural disasters; acts of terrorism; availability of financial tools; or labor issues. Level 1 strategic metric (SCOR KPI) includes Flexibility and Adaptability. Agility is a customer-focused attribute.
- *Supply Chain Cost Attribute.* The cost attribute describes the cost associated with operating the supply chain. It includes labor costs, material costs, and transportation costs. Level 1 strategic metric (SCOR KPI) includes Cost of Goods Sold and Supply Chain Management Cost. Cost is an internal focused attribute.
- *Supply Chain Asset Management Efficiency Attribute.* The effectiveness of an organization in managing assets is to support demand satisfaction. It includes the management of the both assets: fixed and working capital. The asset management efficiency attribute describes the ability to utilize assets efficiently. Asset management strategies in the supply chain include inventory reduction and in-sourcing versus outsourcing. Level 1 strategic metric (SCOR KPI) include Cash-to-cash Cycle time and Return on fixed assets, Return on working capital. Asset management efficiency is an internal focused attribute.

The SCOR metrics are diagnostic metrics and it measures the ability of the supply chain to achieve these strategic attributes, while the individual metric represents a standard for measurement of the performance of a process.

The SCOR model composed as three levels of predefined hierarchical metrics structure which are referred to as decomposition through Level 1 to Level 3: (Supply Chain Council 2010)

- Level 1 metrics: denote the diagnostics for the strategic feature of the supply chain. These metrics are also known as key performance indicators (KPI).
- Level 2 metrics: provide the diagnostics for the level 1 metrics. The diagnostic output serves to identify the root cause or causes of a performance gap for a level 1 metric.
- Level 3 metrics: serve as diagnostics for level 2 metrics as the same concept.

Theeranuphattana (2008) summarized the benefits for users by implementing the SCOR model as follows:

- utilize and make benchmarking on the standard descriptions of management processes for the supply chain
- define a framework with the predefined standard processes
- afford the structured hierarchical standard metrics to measure process performance
- achieve the management practices that provide best performance
- apply the standard alignment to software features and functionalities.

The SCOR model does not include the quality measures (Theeranuphattana and Tang 2008, Li et al. 2011). Also, the Supply Chain Council explains that the SCOR Model is silent in the areas of human resources, training, and quality assurance (Supply-Chain Council 2010). However, Li et al. (2011) point out that performance attributes of reliability and responsiveness are included in the performance and process framework, and then it can also be considered as quality measures.

Summarizing the strengths of the SCOR model, it can be identified that its core strength is the capability and availability of global implementation and adoption of the comprehensive model structure with the support of IT development. The Supply Chain Council has developed the SCOR model and it continues improvement in association with the various types of corporate members, academic institutions and other non-profit organizations. The SCOR model provides a standardized method to evaluate the processes of the supply chain with an enormous database of benchmarks from the member organizations.

As one of weak points of the SCOR model, the model consists of a huge number of metrics with complicated hierarchical processes. For effective implementation of the SCOR model for the dedicated supply chain, all of these metrics and processes should be scrutinized to find the suitable ones, which capture essence of the performance in the dedicated supply chain. The abundance of metrics also requires a huge amount of input data, which in some cases does not exist in the dedicated supply chains.

Despite above mentioned shortcomings and challenges, the SCOR model is developing the continuous updating and desirable performance measurement framework because SCOR model includes most of the business processes and practices where a supply chain needed.

2.3.4 SCOR – BSC Framework

Thakkar et al (2009) presented an integrated performance measurement framework for supply chain by using a set of qualitative and quantitative measures. It integrates the well-known contributions of the balanced scorecard (BSC) and the structured process of supply chain operation reference (SCOR) model to provide a comprehensive performance measurement framework for SMEs.The overall concept of approach and skeleton of the proposed SCOR-BSC framework is shown in Figure 3.

The integrated SCOR-BSC framework approach has been developed in order to ensure the better effectiveness of performance measurement system on the following grounds (Thakkar et al. 2009):

- Interrelationship and traceability: Balanced scorecard (BSC) approach does not provide a mechanism for maintaining the relevance of defined measures, while Supply chain operation reference (SCOR) model adopts a building block approach and offers complete traceability.

- Process execution: BSC does not provide to link measures of top tactical level, strategic scorecard level, and operational level, where it is potentially making execution of strategy problematic. However, SCOR clearly defines the type of process (planning, execution and enabling) and configures them to suit the SC requirements.

- Customizing implementation: BSC does not provide benchmarking to specify a customizing development process. SCOR model motivates to develop customized software system.

The notable features and contribution of the SCOR-BSC framework in a field of performance measurement are summarized as follows. (Thakkar et al., 2009).

- The framework includes both tangible and intangible performance measures. The tangible measures of cost, time, capacity, productivity and utilization are easy to collect the relevant data directly. The data of intangible measures such as reliability, availability, and flexibility cannot be directly measured. In order to measure these intangible performances, the measures need to be transformed to other measurable performance indicators. For example, delivery flexibility can be measured by assessing in-time delivery rate and error rate.
- Each of the metrics describes one critical dimension of performance of the activity and process.
- An attempt to interlink the various issues for the complexity of supply chains.
- The framework has conceptualized the various decision areas of SCOR model and included various metrics for category of BSC approach.

- The framework defines physical inputs and output for implementation.

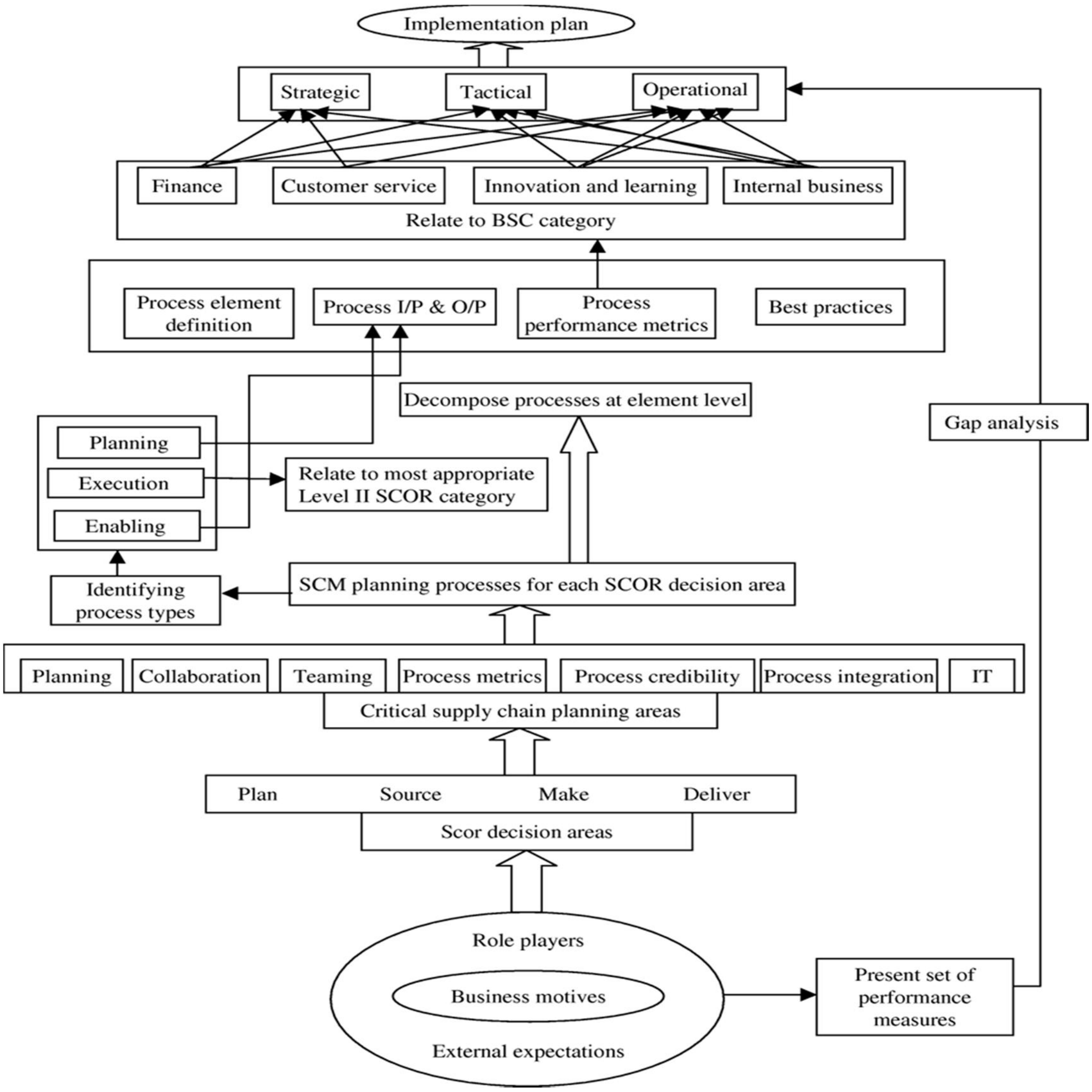

Figure 3 Skeleton of SCOR-BSC Framework for SMEs (Thakkar 2009)

2.3.5 Process-based Performance Measurement Approach

Chan and Qi (2003) propose a new approach with a process-based model to analyze, manage the supply chain, and measure supply chain performance. This approach implements seven steps of process decomposition. Moreover, the concept of performance of activity (POA) is presented to identify and to employ the performance measures and metrics.

For this purpose, process models are to be built from missions and particular functions among the inter- and intra-organizations of supply chain. A process in the supply chain is concerned about series of activities from original suppliers and manufacturers, and the core business processes, which are of essential importance to business objectives and strategies, are to be identified and confined for this performance measurement approach.

The first task for this process-based performance measurement approach is to identify and decompose the involved processes.

The seven steps and processes of analyzing and decomposing the processes to be measured are as shown in Figure 4 (Chan and Qi 2003a):

1) Identifying the involved processes of internal and external organization.
2) Defining and confining the core processes.
3) Deriving the missions, responsibilities and functions of the core processes.
4) Decomposing and identifying the sub-processes.
5) Deriving the responsibilities and functions of sub-processes.
6) Decomposing and identifying the elementary activities of sub-processes.
7) Structuring hierarchy from processes to elementary activity.

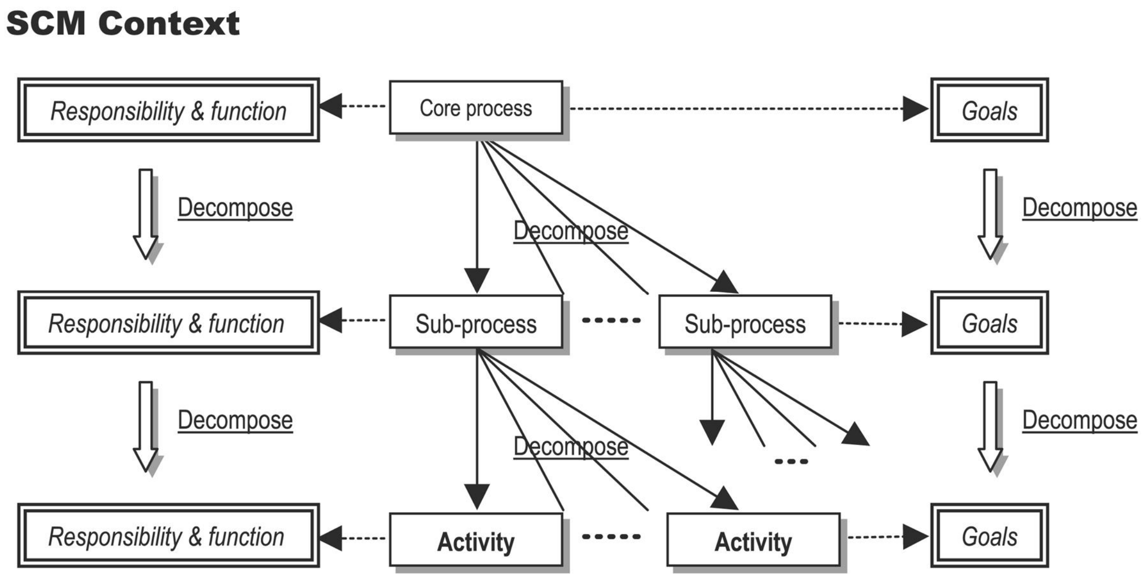

Figure 4 Structure of decomposition in supply chain process model

In association with this model, a new concept of Performance of Activity (POA) is introduced to identify and employ performance measures and metrics. POA includes a board of performance metrics, each of which represents one of the dimensions of activity performance.

According to Chan & Qi (2003a), process-based approaches are provided with the board of performance metrics containing; cost, time, productivity, resource utilization, capacity, capability, and outcome.

- *Cost* is the financial expense for carrying out one event or activity. It is always one of the indispensable aspects in assessing the performance of the business activities and processes.
- *Time* is another indispensable dimension in order to understand the supply chain operation and it is necessary to measure the activity time.
- *Capacity* is the ability of one specific activity to complete a task or perform a required function, and this dimension mainly concerns the maximum amount of tasks that a process or activity can complete under the normal conditions.
- *Capability* is the aggregate ability by which the activity or process functions, which is identified with four soft measures as effectiveness, reliability, availability and flexibility. These soft measures are intangible, and thus cannot be

directly measured, and needs to be transformed to other measurable performance indicators.

- *Productivity* is the rate at which one specific event or activity adds value at the cost of resources, which is based on the ratio of the effective or useful output to the total input such as capital, labor, materials and energy.
- *Utilization* means the utilizing rate of the resources to carry out one specific activity, which reflects the ability of resource management and the effect of strategies and planning.
- *Outcome* is the results or value added of one specific activity or event, which may be a value added to the products and services.

Chan and Qi (2003) asserted that assessing process performance provides an opportunity for examining the effectiveness of process management. Moreover, the process-based measurement facilitates a great deal of supports in enhancing integration and improvement of the cross-organizational processes. The main advantages of adopting process-based performance measurements are highlighted as:

- To provide the opportunity of recognizing the problems in operations and enabling of the corrective actions for the problems.
- To facilitate linking with the operational strategies, identifying success, and testing the effect of strategies.
- To support the monitoring of the progress.
- To assist the direct management attention and resource allocation.
- To enhance communication of process objectives and position among the processes involved in the supply chain, thus improving trust and common understanding.

2.4 Challenges for Supply Chain Performance Measurement

It has been known that many business organizations could not succeed in managing their supply chain performances to the maximum level because they have had failed to develop the right performance measures and metrics. Moreover, they also found the difficulties to integrate and implement the system fully to measure the performance of their supply chains effectively and efficiently. (Gunasekaran et al., 2004).

Akyuz and Erkan (2010) have investigated and presented the major problems in performance measurement as summarized below:

- Inconsistencies in performance measurement as well as in the selection of the right performance measures and metrics.
- Representing a set of financial and non-financial measures in a balanced framework. Approach of biased measures in a framework.
- Too many numbers of metrics make it difficult to identify the critical governing issues.
- Failure to link the strategy objectives and the measurement measures.
- Failure to balanced focus on financial metrics or operational ones.
- Too much inward looking insights.

The criticism about the failure to link with strategy and keeping biased focus on financial metrics, there are three fundamental challenges of performance measurement system in supply chain contexts (Gunasekaran et al. 2001, Sillanpää 2010).

- the lack of a balanced scorecard approach is integrating financial and non-financial measures.
- the lack of a holistic feature to viewed as a whole entity in the measurement system.
- the loss of the supply chain context which encourages local optimization.

Also, Lin and Li (2010) present four challenges for supply chain performance measurement in the literature as follows.

- Majority of measures are focused on intra-organizational performance measures that do not cover SC performance as a whole entity.

- Less consideration in the effectiveness of measured values. The decision makers need to find the real value of measures, to identify weak areas, to take corrective countermeasures, and to keep continuous improvements.
- Less common metrics is developed for evaluating different processes on the same scale. Different characteristics of associated processes cannot be evaluated precisely without using the correct metrics.
- Less integration of human attributes such as cooperation, skill, communication, which have been claimed as the important dimensions of the SC performance measurement model.

According to Akyuz and Erkan (2010), implementation of appropriate performance measurement system to meet all these requirements and to suit the specific organization is a challenging task because it is requiring a precise analysis of the business processes and operations in technical, organizational as well as managerial issues. These challenges are more significant if it is required to measure the qualitative performances such as a partnership, collaboration, agility, and business excellence.

With all these challenging problems highlighted, there seems to be no global common agreement on the right measures of the qualitative performance of supply chain. Moreover, the supply chain performance measurement in qualitative measures is very much fragmented.

As many of current performance measurement systems are missing on strategy alignment, balanced approaches, and systematic implementation. Therefore, they have the difficulties in identifying the most appropriate metrics systematically (Cai et al. 2009).

According to Cai et al. (2009), these performance measurement systems and metrics do not provide a definite cause–effect relationship among hierarchical individual KPIs since many measurement systems are static, and they lag the trend.

It has been suggested from the researchers that the basic concept on qualitative measures, process implementation, and business excellence, as well as the human attributes and organizational issues, are still the key considerations for performance measurement system of future (Wouters, 2009).

It has been realized that one of the most challenging issues in supply chain management is the uncertainty inside the processes and systems. Uncertainty lead to inefficient processes and non-value added activities in planning, managing, processing, monitoring and controlling. Where there is more uncertainty in the process, there exist more inefficiencies and non-value activities in the process (Van der Vorst and Beulens, 2002).

2.5 Conclusion of Literature Review in view of Engineering SCPM

Performance measurement of the holistic processes of the supply chain is important for many reasons. Performance measurement provides information for management and enables the decision makers identifying the success, and assists in directing management attention, updating company goals, and re-engineering business processes.

According Sillanpää (2010), three principal approaches for supply chain performance measurement are presented as follows:

- Managerial approach

  The components of SC managerial approach consist of strategic, tactical and operational level. Therefore, the SC performance can be measured in three different levels. Strategic level performance measures are essential for needs of senior management. Tactical levels performance measures are collecting feedback against targets for mid-management. Operational level performance metrics requires information that is relevant to s management. (Gunasekaran et al*.,* 2004)

  The performance measurement is categorized into SC activities and its managerial approach. The SC performance activities are composed of plan, source, make/assemble, and delivery.

- Time based approaches

  The three approaches of operational, tactical and strategic measurement are of interest for time measurement of SC performance. Time provides the same condition of measurement to every resource, every company, and every production line. Moreover, it is still an accurate and effective measure as the important source of competitive advantage. The performance measurement of time-based approach is commonly used widely in the supply chain performance measurement because time is stable and accurate in measurement. In supply chain performance measurement, all management levels are interested in time measurement such as lead-time, cycle time, cash flow time, query time. (Sillanpää, 2010)

- Quantitative and qualitative measures

  Chan (2003) presents SC performance measurement approach that consists of qualitative and quantitative measures. Quantitative measures are identified with cost and resource utilization while qualitative measures are related to quality, flexibility, visibility, trust and innovativeness.

Agami et al. (2011) suggests the future research directions on the performance measurement system of supply chain for following perspectives:

- Dynamic and systematic framework development on both theoretical and empirical approaches.
- Assessment and development of measures to fit strategic performance
- Development of a new maturity model supported by SCOR model to enable benchmarking of performance measurement systems.
- Development of integration methodology to address the holistic performance against the complex features of an engineering supply chain.
- Further elaboration from performance measurement to its implementation and continuous improvement.

Information technology (IT) system is one of the most important infrastructures in the engineering supply chain management because it can link the entire supply chains together into a single integrated management unit. The use of supporting IT system is vital for effective supply chain performance measurement because the information technology system can support internal operations as well as the collaboration between the supply chains by using advanced high-technology network systems.

However, there also exist challenges on IT system for effective supporting of performance measurement system in supply chain. The commercial CAD systems are commonly utilized in engineering supply chains and the database of CAD system are normally shared among the supply chain networks for easy access and exchange the modelling information. Problems through different CAD systems and IT systems of supply chains can cause difficulties of transaction of information, and further integration efforts are requested to share the concurrent engineering information into the information flow lines. In viewpoint of performance measurement of engineering supply chain, common information systems as working tools is vital for achieving the effectiveness and efficiency of supply chain management.

There are little relevant articles on performance measurement systems related to engineering in the shipbuilding and offshore industry specifically. In general terms, there are some articles on engineering in connection to manufacturing, construction and research and development (R&D) environment (Chen, 2006).

Traditionally, engineering performance has been associated with time and cost for service, and the production of design documents. Performance measurements in engineering and design organization are very traditional, and no global frameworks seem to be developed for this purpose. Also, it has been claimed that the performance measures in engineering supply chain are fragmented, and it is not easy to assess and measure the effect of the design and engineering process as a whole.

For the topic of a performance measurement in engineering supply chain, literatures mostly focus on the processes and how to establish a performance measurement system for the engineering supply chains. One of the most common measures to monitor the engineering performance is the amount of consumed hours per document or per task or per service. However, these measures emerge several identified weaknesses. For example, it is difficult to identify the dedication and separation of the consumed hours among the current running tasks and the corresponding documents to capture the correct data during the several projects are processing in parallel (Georgy, 2005).

Some researchers claim that the importance of performance measurement is overestimated in complex organizations because it is unable to reveal the light problems if they are not supported by feedback, discussion and debate. This debate contributes to the deficiency of research on performance measurement for design and engineering supply chain in the context of complex products and systems.

Recent performance measurement in engineering supply chain is mostly subjective by the underlying processes of accumulated knowledge and experience in the organization. They are not suitable to measure of performance as a basis for improvement because the design and engineering processes are fragmented in itself (Salter, 2003).

Because engineering and design services are largely based on intangible knowledge-based processes that make them difficult to plan, manage measure and improve. Performance measurement in engineering supply chain is dominated by measurements that are easy to measure, and they are not what management considered critical for the design and engineering process (Johnsson, 2008).

As the highlighted challenges of the performance measurement in the design and engineering supply chains, this case study research is focused more on the performance of the production engineering process rather than the area of concept development and feasibility engineering. This research approach minimizes the highlighted deficiencies and opens the possibilities of further development. Moreover, this case study research contributes to the possibilities to overcome certain challenges in engineering supply chain performance measurement, with the proposed measurement framework of BSC+AHP module concept approach.

3 DEVELOPMENT OF PERFORMANCE MEASUREMENT FRAMEWORK FOR ENGINEERING SUPPLY CHAIN

This research case study pursues to improve the effectiveness of performance measurement of the production engineering supply chain for the case Company through systematic approach to supply chain performance measurement and the corresponding managerial decision-making framework.

The methodology of performance measurement and their analysis is evaluated by using multi-dimensional criteria decision-making tool of Analytic Hierarchy Progress (AHP) of which purpose is to identify the relative priority weights for each objective criterion.

The performance measurement criteria and measures and metrics are evaluated on the basis of the design coordinators' experiences, observations and already existing data of the case company, while their relative priority weights are calculated through AHP methodology. The performance measurement contexts and the priority weights are to be discussed with the management for integration of the strategy and agreed with the supply chain networks for compliance when the projects are started. The essential information of the literature review of this thesis has been taken into account while structuring of the criteria and metrics for the Analytical framework.

This analytical performance measurement framework contains the concept of BSC approach in association with the selection of performance measurement metrics and the analysis methodology is compiled on the basis of AHP theory.

The performance metrics of engineering supply chain has a complex and multi-dimensional characteristics. In order to represent these features of the performance measurement metrics, the concept of BSC Modules has been established, and the performance metrics are transformed into the BSC module to integrate the influences of each metrics thru AHP methodology.

Finally, the solution proposal presents a framework of the decision-making criteria with BSC modules for evaluating the performances of the engineering supply chains continuously and dynamically.

3.1 Establishment of key metrics for SC Performance measurement

In this case study, key objective criteria is identified as a performance measurement improvement in a production engineering supply chains. The key objective criteria of performance measurement have been established as the results of the literature review in association with the evaluation of the relevancies to the engineering supply chain.

The case company outsources the most of detail design and engineering works from the engineering supply chain network. Therefore, the performance of the participating engineering supply chains affects the productivity of the case company significantly. Also, the management system of the case company affects the performance of supply chains as well.

3.1.1 Metrics for order planning performance evaluation

- *The service order entry method*

  The service order entry method determines the methods and extents to which customer specifications and requirements are interpreted into information agreed with the supply chains (Gunasekaran et al., 2001). Due to the characteristic of engineering services that the order planning process usually takes place when the service contracts are documented. It is important and mandatory that the service order information should be passed down along the supply chain, accurately, timely and effectively. Hence, the service order entry method is vital as a metric of performance measurement of engineering supply chain.

- *The service order lead-time (Total order cycle time)*

Service order lead-time identifies the periods between the time of receipt of the order and the time of delivery of the finished products to the customer. The savings in the order lead-time lead to improvements in service supply chain response time, and improve the process efficiency. Therefore, order lead-time takes a great importance in supply chain performance management and it is an influencing performance measure and source of the competitive process (Christopher, 1992).

- *The service order path*

  The customer service order path defines a set of activities that need to deploy the information of order to the organizational processes. By identifying order path activities through the organizational process, the time spent in different processes and non-value adding activities can be identified. Then, suitable steps of managerial actions can be taken to eliminate those activities of wastes in the process. A series of activities on planning order and the identification of order steps and their processes can seriously affect the performance of supply chain, and thus, it is vital as a metric of performance measurement.

3.1.2 Metrics for managerial performance evaluation

In order to achieve the qualified services demanded by the customers, the customers' ability to link and to collaborate effectively and efficiently with supply chains has become the issues of the supply chain management.

- Consideration on evaluation of supply chain performance

  The performance of engineering supply chain is identified as the criteria of productivity, quality, agility and customer satisfaction. Also, the performance is measured and evaluated to fit with the strategic, operational and tactical level. Moreover, the performance metrics needs to include the categories of financial, financial/non-financial, and non-financial, as the part of the important performance criteria.

- *Strategic level measures* include productivity, variation against budget, total cash flow time, order lead-time, and delivery performance.
- *Tactical level measures* include accuracy of forecasting technique, supplier cost saving initiative, delivery reliability, order entry method, effectiveness of the master schedule, ability to respond to problems, responsiveness.
- *Operational level measures* include cost per operation unit, supplier rejection rate, capacity utilization, quality of delivery, and delivery reliability.

- Consideration on partnership in supply chain

Recently, a partnership between the buyer and supplier is the growing issue in the supply chain. In this context, supply chain relationship management is a vital part of supply chain performance evaluation. A partnership is a comprehensive approach to enhance the business cooperation as a business relationship level, to improve coordination as a process level, and to increase communication as information systems level, between the customers and its supply chains. The partnership is realized with a direct and long-term relationship with mutual cooperative planning and collaborative problem solving efforts. It is evident that those activities improve the effectiveness and efficiency of supply chain in collaboration, quality, reliability, and innovation simultaneously (Mettler and Rohner, 2009).

According the researchers, the criteria and parameters for evaluation of partnership level in supply chain are summarized as (Thakkar et al., 2009);

- understanding on common business perspective and long-term growth
- confirming on productivity and delivery reliability
- sharing system and information
- sharing of risk and profit initiatives
- cooperation in innovation and growth

- collaboration in problem solving efforts

3.1.3 Metrics for production performance evaluation

A production performance is the series of activities carried out by organizations in supply chain, and their performance has a significant impact on production cost, quality, delivery reliability, and competence of the customer. Also, the production activities are the critical part of the total supply chain performance, and in this context, the production performance is the essential part of the performance and it needs to be measured and improved continuously.

Suitable metrics for the production level are recommended as follows:

- Product range of design and engineering
  The manufacturers of a broad product range are likely to introduce new products more slowly than the plants that have a narrow product range in general. In viewpoint of value added per employee, speed and delivery reliability, and total efficiency of the plants that can manufacture a wide range of products are likely to have a less productivity. These phenomena clearly present that the wide product range affects supply chain performance. (Mapes et al., 1997). In this context, the same logic is evidently effective in engineering supply chain performance. The engineering organization which can produce wide range of engineering services should have sufficient enough resources and facilities; otherwise, the added value per employee will lead to less effective in performance than the strategically focused organization.

- Capacity utilization rates
  According to Slack et al. (1995), resource capacity utilization affects the responsiveness and agility to customer demand through its impact on availability, lead-time and deliverability. In this context, it is evident that the rate of participation resources by capacity of supply chain in planning and determin-

ing of the activities is quite important parameter for the performance of supply chain.

- Effectiveness of scheduling techniques

  A Planning and scheduling of order is defined the set of activities to allocate the engineering resources to perform the tasks over a given time to achieve the specific process objectives. Scheduling can have a significant impact on capacity utilization, process performance and customer satisfaction. It determines how the resources are to contribute effectively in the production processes. The effectiveness of production schedule has an important impact on production process in supply chain performance. A production scheduling depends heavily on customer demands and performance of supply chain. In this context, the system and tools of the scheduling need to be viewed in the viewpoint of supply chain performance (Little et al., 1995).

3.1.4 Metrics for progress performance evaluation

- Order fill rates

  Turner and Bititci (1998) assert that the performance measuring approaches lead to maintaining an internal control system and the reliability of order processes eventually. Because of the importance of the uninterrupted performance without any problems such as delay on delivery, unsatisfactory quality of the product and lack of fulfillment on requirements at the final delivery stage, customers seek the confidence on the qualitative product with on-time delivery to keep their production schedule successfully.

  In the design and engineering service industries, the CAD system is a fundamental infrastructure for the engineering activities, and thus the sharing of its database among the supply chains are essential for collaboration works.

  The readiness percentage of production modelling in association with the CAD system can provide tangible and reliable information on the performance progress of the individual supply chain. In this context, the readiness and progress of modelling represent the order fill rates, and it is the vital part of performance measurement and its evaluation.

- Earning rates (labor to cash cycle)

  For a balanced approach against non-financial measures of order fill rates, financial measures for the corresponding performance are earning performance measures of supply chain. The earning rates are measured by the variation of the budget, earned hours versus spent hours in production as well as the frequency of issuing the invoices to convert the labor hours into cash.

3.1.5 Metrics of delivery performance evaluation

The most important measure of delivery performance is on-time delivery. On-time delivery support to determine how efficiently the delivery has met on agreed time frame, and it is also a measure of customer service level (Stewart, 1995).

In engineering industries, the delivery of engineering product is completed by uploading documents into the customer’s CAD system, and there are not physical logistic processes are involved such as location and vehicle speed.

- On time delivery

  It is a measure the amount of finish goods or services delivered to customers on the right time, right place and right quality. This performance measure helps to determine how efficiently the supply chains are keeping the customer's expectation or predefined time frame.

  The production master schedule defines the delivery date, time and condition with the preplanned agreement during the order stage. The gap between the actual result against the plan can be determined the delivery performance, and the areas of discrepancy can be identified for further development and improvement.

- Delivery flexibility

  In the field of design and engineering industry, there always exist the possibilities of changes, and it leads to the change of processes or deliveries. Moreover, the customers often request the delivery flexibility that can adapt the changes due to the various environments for changing the design information and the corresponding change orders. The various change environments refer to agility of supply chain in capturing a customer's delivery requirement. Flexibility and agility of delivery performance in supply chain evidently influence the productivity of customer, and it is also selection criteria in order process (Novich, 1990).

3.1.6 Metrics for quality service evaluation

The customer's satisfaction is the most effective and successful strategy of the supply chain and it refers to the metrics for quality service evaluation.

It has been emphasized that performance metrics must focus on customer satisfaction in order to assess supply chain performance successfully with following perspectives (van Hoek et al., 2001).

- Flexibility

  Supply chain flexibility is identified as the ability to respond to the changes. Flexibility of supply chain requires the ability to respond the changes without increasing the customer's operational cost and supply chain costs with no delay in response time. The changes include the changes in requirements, demand volume, prices, costs, conditions, or supply disruption. (Simchi-Levi, 2008)

- Responsiveness (Customer query time)

  Responsiveness of supply chain is identified as the ability to respond proactively within the required time scale to customer demand in order to keep the competitive advantage. A rapid and accurate response to the customer's demands is essential for retaining customer's satisfaction (Holweg, 2005).

- Reliability

  Reliability means ability to perform the expected or agreed services dependably and accurately. The metrics of reliability performance includes on-time and the right quality, and it is a customer focused attribute. (Supply-Chain Council)

- Agility

  Agility is an operational strategy that is focusing on the influences of the changes. It embraces organizational structures, communication systems, decision-making processes, and business culture. A key feature of agility is flexibility. The integration of Information System (IS) can facilitate better agility in the supply chain since it supports the improvement of operational performance in responsiveness, flexibility, reliability, and innovation (Christoper, 2000).

3.2 Hierarchical structure of metrics for performance measurement criteria

The relevant issues and its suitable measurement metrics and measures for evaluating the service supply chain are classified and structured for supporting a managerial decision-making and effective operational management.

In this framework of engineering supply chain performance measurement, the metrics are classified into strategic, tactical and operational levels of management as proposed by Gunasekaran et al. (2001).

The set of metrics and measures are summarized as shown on Table 4.

Table 4 Metrics for engineering supply chain performance evaluation

Level	Performance Metrics	Categories	Remarks
Strategic	. Productivity	F	. F: (Financial)
Level	. Variation against Budget	F	. F/NF : (Financial &
	. Total cash flow time	F/NF	Non-Financial)
	. Delivery performance	F/NF	. NF: (Non-Financial)

	. Order lead-time	NF
	. Defect free delivery	NF
	. Delivery lead-time	NF
Tactical Level	. Accuracy of Forecasting technique	F/NF
	. Supplier cost saving initiative	F/NF
	. Delivery reliability	F/NF
	. Order entry method	NF
	. Effectiveness of delivery invoice	NF
	. Effectiveness of master schedule	NF
	. Ability to respond to problems	NF
	. Responsiveness	NF
Operational Level	. Cost per operation unit	F
	. Supplier rejection rate	F/NF
	. Capacity utilization	NF
	. Quality of delivery	NF
	. Delivery reliability	NF

As the measures and metrics have a broader perspective, the different dimensions of aggregative assessment for evaluating the supply chain performance has been carried out based on the dimensions and criteria of performance measures classified by Fitzgerald et al. (1991). The results are summarized as shown on Table 5.

Table 5 Metrics dimension and criteria for supply chain performance evaluation

Dimension	Criteria	Definition	Performance Metrics
Management	Tactical Operation	. Strategic objectives . Key performance indicator . Capacities	. Variance against budget . Unit cost rate efficiency . Resource utilization rate . Labour to invoice cycle
Operation	Order Progress	. Business process . Operational efficiency . Capabilities	. Order progress fill rate . Delivery lead-time . Task resource variation . Sub-contracting rates
Service	Service Quality	. Responsiveness . Reliability	. Rates of change order . Task defect rates

	. Agility	. Schedule fill rates . Agility on demand

With these two approaches of defining the measures and metrics dimension for evaluation of engineering supply chain are based on this case study research, and the hierarchical structure is structured for further process of BSC+AHP performance measurement module creation.

3.3 Constructing AHP structure for performance measurement

The performance evaluations in an engineering service supply chain are complex and complicate tasks. The performance measurements involve multi-dimensional criteria, uncertainty and qualitative attributes that are difficult to measure directly.

According to Buyukozkan et al. (2011), one of the most popular and effective multi-dimensional criteria evaluation method is Analytic Hierarchy Process (AHP) that has been used as a performance decision-making tool for years in a service sector. The AHP is a mathematical pair-wise comparison methodology that facilitates the priority weights for structuring complex multi-dimensional problems. Moreover, it provides with an objective outcome for decision-making tool for solving the problems by a set of solution matrix. It was developed by Saaty in 1980, but it has been still effective and it has been used commonly in this field.

3.3.1 Selection of key performance criteria and sub-criteria

The hierarchy structure of performance criteria and their performance metrics are established as described in section 3.2, and three major performance criteria of Tactical operation, Order progress and Service quality are settled up for performance measurement framework of engineering supply chain in this case study. Those three criteria represent the aggregation of the metrics based on the practical working environment in compliance with the recent development of supply chain performance measures by academia and practitioners. The selected metrics are composed with the opinions and experiences of the design coordinators as well as design managers in the case company.

3.3.2 Prioritization of performance criteria and performance metrics

The priority weight of each selected metrics is computed by using pairwise comparison between two criteria at a particular level with the Saaty's nine rating scale as specified below in Table 6.

Table 6 The Saaty's nine Scale Rating

Intensity	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

3.3.3 Multi-criteria analysis with an AHP approach

Three key performance criteria- Tactical operation, Order process, and Service quality are selected in this case study. Each criterion is then decomposed into four performance metrics. The three key performance criteria (A, B, C) and their twelve sub-criteria (Ax, Bx, Cx: performance metrics) are structured into two-level hierarchy model as shown in Table 7.

Table 7 Key performance criteria and performance metrics

Group	Key Criteria	Performance Metrics	Formulation
A	Tactical Operation	A1. Variation against budget	Yes
		A2. Unit cost rate efficiency	Yes
		A3. Resource utilization rates	Yes
		A4. Labour to invoice cycle	Yes
B	Order Progress	B1. Order progress fill rates	Yes
		B2. Delivery lead-time	Yes
		B3. Task resource variation	Yes
		B4. Sub-contracting rates	Yes
C	Service Quality	C1. Rates of change order	Yes
		C2. Task defect rates	Yes
		C3. Schedule fill rates	Yes
		C4. Agility on demand	Yes

The two groups of performance data analysis and matrix calculation are conducted by mathematical computation that specialized in matrix calculation of business application for multi-criteria decision-making software. In this case study, the open source of AHP software (www.bpmsg.com) has been utilized. The software program provides priorities, decision matrix and consistency ratios for analysis and decision-making solution on multi-criteria metrics.

The AHP software is to be integrated into ERP system or BI system in a later stage when all environments are provided for implementation.

3.3.3.1 Key performance criteria priority weights and ratings

Three key performance criteria of Tactical operation, Order process, and Service quality, have been carried out the pairwise comparison calculation to define the relative priority weights and ratings in the case company. The relative priority of the performance criteria has been based on the predefined priority scales by the discussion with the design coordinators. Figure 5 shows how the comparison between the criteria has made and how the corresponding decision matrix, eigenvalue, consistency test result, and priority weight and ranking, are calculated.

The relative priority of the key performance criteria can be updated or benchmarked with the specific project by the decision of the management before execution of the actual project in due course.

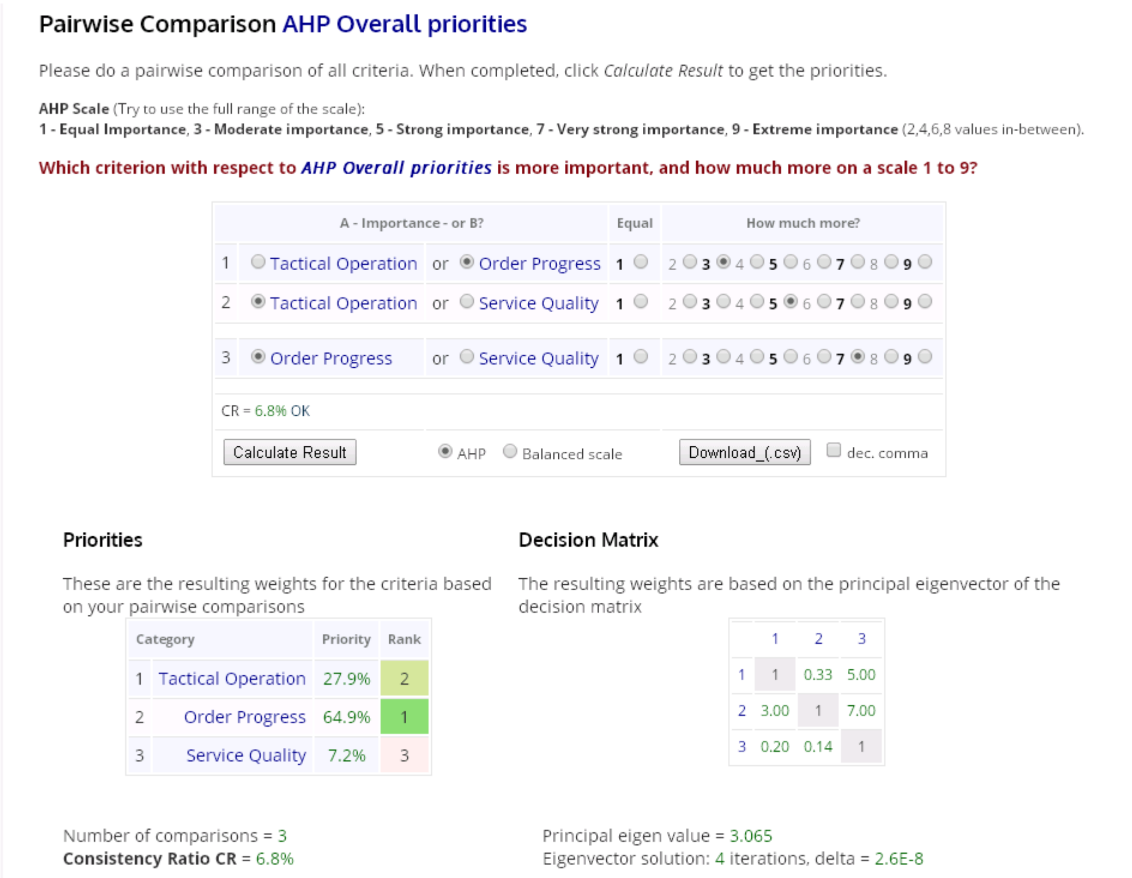

Figure 5 Relative priority weight of three key performance criteria: Overall

As the results, the priority weight and ranking of the key performance criteria are defined as: 1) Order progress of 64.9%, 2) Tactical operation of 27.9%, 3) Service quality 7.2%, as shown in Table 8.

This process result defines the common performance criteria in supply chain performance management to cope with the company strategy of the project, where the managers have to achieve as the goal of the business objectives.

Table 8 Pair-wise comparison for key performance criteria

Criteria	A	B	C	Priority	Rank
A	1	0.33	5	0.2790	2
B	3	1	7	0.6491	1
C	0.25	0.14	1	0.0719	3

3.3.3.2 Tactical Operation matrix priority weights and ratings (sub-criteria)

Among the three key performance criteria, the key performance criteria of Tactical operation consists of four key performance metrics of *Variation against budget, Unit cost rate efficiency, Resource utilization rate, Labour to invoice cycle,* those are inter-related and they are influenced to the key performance criteria. The four key performance metrics have been carried out the pairwise comparison calculation to find out the relative priority weights and ratings as per the methodology of AHP. The relative priority of the performance metrics has been applied based on the predefined priority scales as the same methodology for key performance criteria. Figure 6 shows the outcome of the comparison between metrics and the corresponding decision matrix, eigenvalue, consistency ratio (CR), and priority weight and ranking.

As the same principle, the relative priority of the key performance metrics can be updated or benchmarked with the specific project by the decision of the management before execution of the actual project in actual process.

As the results, the priority weights and rankings of each key performance metrics that embraced in Tactical operation are calculated and defined as: 1. Variation against budget of 44.6%, 2. Unit cost rate efficiency of 36.5%, 3. Resource utilization rate of 13.1%, and 4. Labour to invoice cycle of 5.8%, as shown in Table 9 below.

This process result facilitates the common target of performance management criteria for the managers (design coordinators in the case company) to cope with the company strategy of the project, where the managers have to achieve as the goal of the business objectives.

Figure 6 Relative priority weight of t performance “A”: Tactical Operation

Table 9 Pair-wise comparison for sub-attribute of Tactical Operation

Criteria	A1	A2	A3	A4	Priority	Rank
A1	1	2	3	5	0.4461	1

A2	0.5	1	4	7	0.3646	2
A3	0.33	0.25	1	3	0.1309	3
A4	0.20	0.14	0.33	1	0.0584	4

3.3.3.3 Order Progress matrix priority weights and ratings (sub-criteria)

As the same process, the key performance metrics of corresponding Order progress performance of supply chain: 1) *Order progress fill rates, 2) Delivery lead-time, 3) Task resource variation, 4) Subcontracting rates,* those are inter-related and they are influenced to the key performance criteria. The four key performance metrics have been carried out the pairwise comparison calculation to find out the relative priority weights and ratings as per the methodology of AHP. The relative priority of the performance metrics has been applied based on the predefined priority scales as the same methodology for key performance criteria. Figure 7 shows the outcome of the comparison between metrics and the corresponding decision matrix, eigenvalue, consistency ratio (CR), and priority weight and ranking.

As the results, the priority weights and rankings of each key performance metrics that embraced in Order process are calculated and defined as: *1) Order progress fill rate of 49.0%, 2) Delivery lead-time of 31.6%, 3) Task resource variation of 11.6%, and 4) Sub-contracting rate of 7.8%,* as shown in Table 10 below.

This process result facilitates the common target of performance management criteria for the managers (design coordinators in case company) to cope with the company strategy of the project, where the managers have to achieve as the goal of the business objectives.

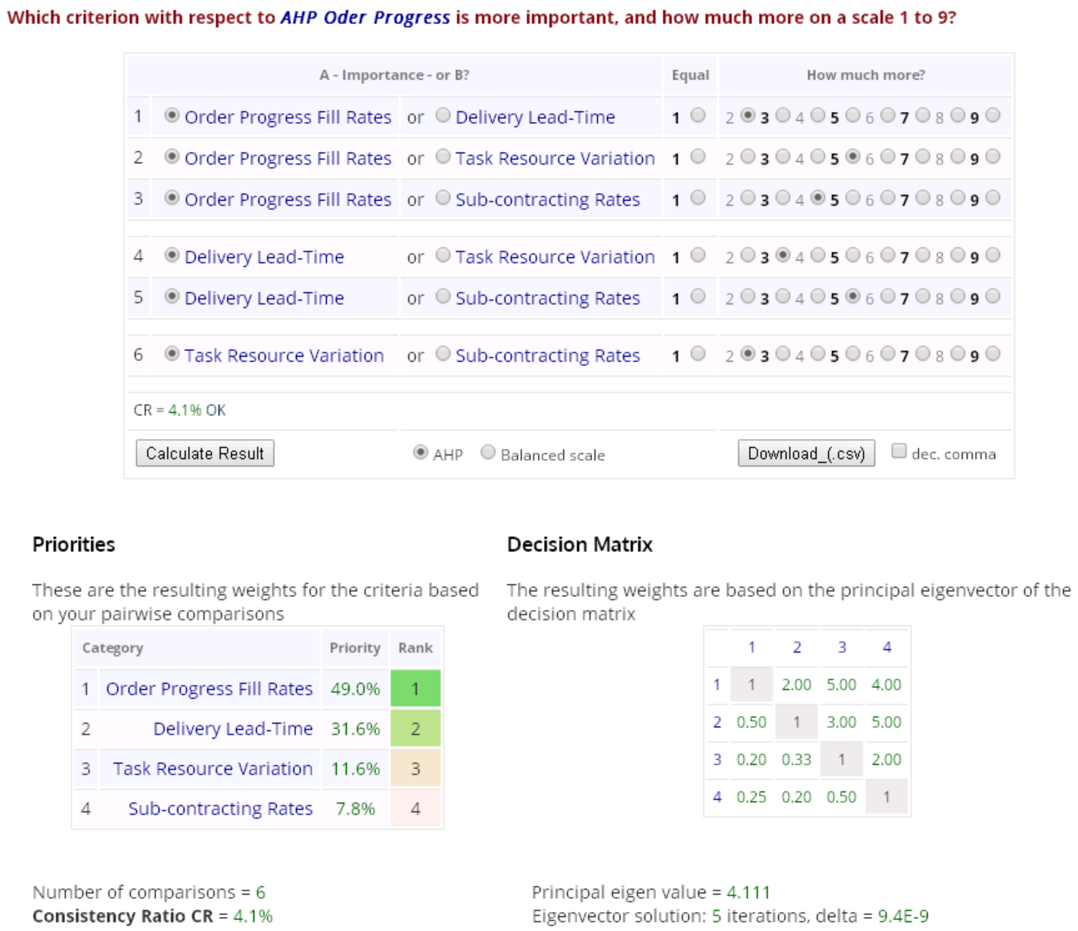

Figure 7 Relative priority weight of t performance “B”: Order Progress

Table 10 Pair-wise comparison for sub-attribute of Order Progress

Criteria	B1	B2	B3	B4	Priority	Rank
B1	1	2	3	5	0.4461	1
B2	0.5	1	4	7	0.3646	2
B3	0.33	0.25	1	3	0.1309	3
B4	0.20	0.14	0.33	1	0.0584	4

3.3.3.4 Service Quality matrix priority weights and ratings (sub-criteria)

As the same process, the key performance metrics of corresponding Service quality performance of supply chain: 1) *Rate of change order, 2) Task defects rates, 3) Schedule fill rates, 4) Agility on demand*, those are inter-related and they are influenced to the key performance criteria. The four key performance metrics have been carried out the pairwise comparison calculation to find out the relative priority weights and ratings as per the methodology of AHP. The relative priority of the performance metrics have been applied based on the predefined priority scales as the same methodology for key performance criteria.

Figure 8 shows how the comparison between the criterions has made and the corresponding decision matrix, calculated eigenvalue, consistency ratio, and priority weight and ranking in this performance metric of supply chain.

As the results, the priority weights and rankings of each key performance metrics that embraced in Service quality are calculated and defined as: *1) Task defect rates of 49.8%, 2) Schedule fill rates of 37.9%, 3) Rate of change order of 7.8%, and 4) Agility on demand of 4.5%,* as shown in Table 11.

This process result facilitates the common target of performance management criteria for the managers (design coordinators in case company) to cope with the company strategy of the project, where the managers have to achieve as the goal of the business objectives.

Figure 8 Relative priority weight of t performance “C”: Service Quality

Table 11 Pair-wise comparison for sub-attribute of Service Quality

Criteria	C1	C2	C3	C4	Priority	Rank
C1	1	2	3	5	0.4461	1
C2	0.5	1	4	7	0.3646	2
C3	0.33	0.25	1	3	0.1309	3
C4	0.20	0.14	0.33	1	0.0584	4

3.3.3.5 Composite priorities of key performance criteria and sub-criteria

Composite relative priority weight of key performance criteria and its sub-criteria (key performance metrics) have been summarized as shown on Table 12.

The priority weight of the key performance metrics (sub-criteria: Ax, Bx, Cx) are directly affected on the priority weight of Key performance criteria (key criteria: A, B, C). Moreover, the establishment of key performance criteria and the definition of the corresponding key performance metrics is a critical issue for successful supply chain performance measurement. In other words, it requires the keen attention of the management and strong commitment of top management.

Table 12 Pair-wise comparison for key criteria and sub-attributes

Criteria	A	B	C	Eigenvalue	CR	Priority
A	0.2790	0.6491	0.0719	3.0649	0.0677	**0.2790**
A1	0.4461					0.1246
A2	0.3646					0.1017
A3	0.1309			4.1690	0.0619	0.0365
A4	0.0584					0.0163
B		0.6491				**0.6491**
B1		0.4899				0.3178
B2		0.3161				0.2052
B3		0.1157		4.1109	0.0406	0.0751
B4		0.0783				0.0508
C			0.0719			**0.0719**
C1			0.0779			0.0056
C2			0.4984			0.0358
C3			0.3791	4.2410	0.0884	0.0273
C4			0..446			0.0032

3.4 Integrated Performance measurement with BSC+AHP approach

The balanced scorecard system is a system of combining financial and non-financial measures of performance in a simple scorecard with the four perspectives of performance metrics as financial perspective, customer perspective, internal business process perspective and innovation perspective. The use of the balanced scorecard improves managerial decision making by aligning performance measures with the business objectives of goals and its strategies.

The balanced scorecard focuses on the business processes and outcomes, and it is considered as a tool to support strategy formulation, implementation, and communication. Moreover, it also supports in monitoring the performance and facilitates information for managerial decision-making. In this context, the balanced scorecard provides organizations with the improvement of an effective performance management and the better implementation of the strategic objectives.

Evidently, the performance measurement is vital for effective planning and control as well as efficient management of the organization. The balanced scorecard is a strategic planning and management system which is aligning the activities and strategies of the organization for their continuous improvement of operational performance.

In this context, this case study research proposes an approach of the balanced scorecard framework by implementation of AHP methodology to evaluate the supply chain performance in their daily business performances. It has been designed that the managers can take the benefits at all decision levels from a systematic framework based on the criteria and measures that have been predefined and agreed in advance.

It is evident that the balanced scorecard system with the analytic hierarchy process (AHP) approach has the following competitive advantages in performance measurement of supply chain including:

- The BSC is a comprehensive system to understand the target of customers, their requirements, the business processes, and the performance gaps.
- The BSC is capable of articulating the strategy implementation with the business excellence that requires the qualitative objectives.
- The AHP provides logic for evaluating intangible and qualitative measures that were difficult to deal with the traditional performance measurement systems.

- The BSC+AHP enhance communication through all level of organization to understand strategy and strategic objectives more clearly to their day-to-day operations and activities.
- The BSC+AHP facilitate physical performance information and feedbacks for a continuous improvement of key performance indicators (KPIs).

3.5 Transformation of SC performance measures into BSC+AHP Modules

The BSC+AHP module structure is formed with the three level of components as: influencing sub-criteria level, key performance metrics level, and objective BSC module level with two transformation processes as shown on Figure 9. The key performance metrics are formulated with the influencing sub-criteria that are measured as input from the supply chain.

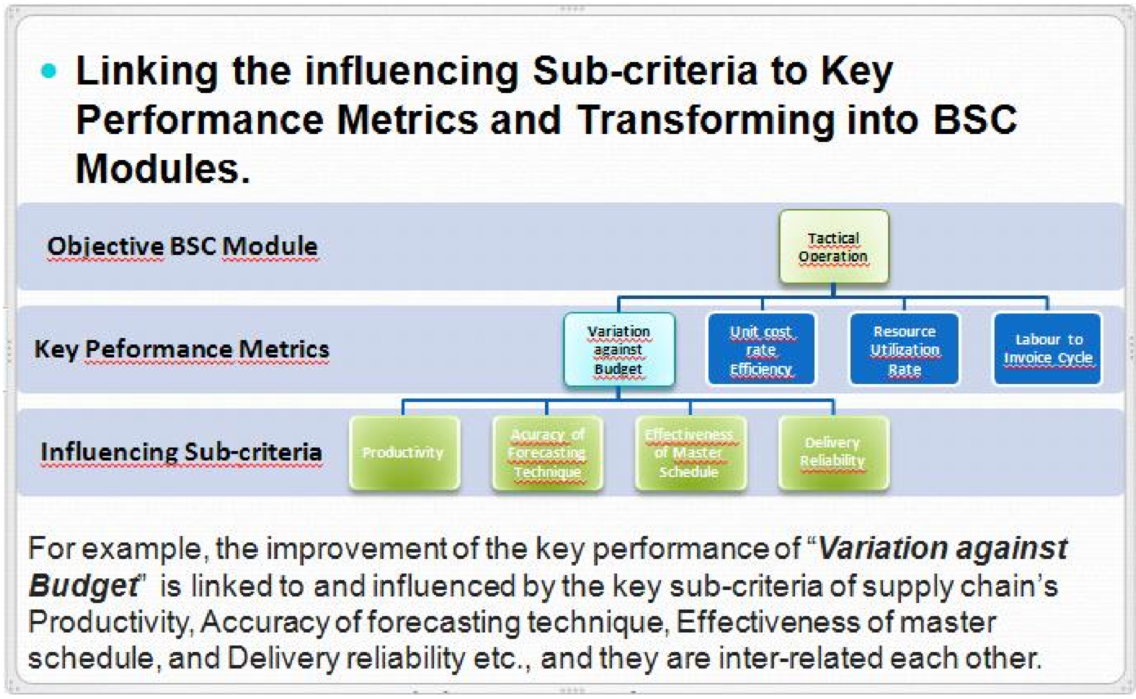

Figure 9 Basic concept of transforming measures into BSC+AHP Modules

The formulations of each objective BSC+AHP modules are defined as follows.

3.5.1 Formulation of Tactical Operation- [BSC-SCPM-TO Module: “A”]

- A1. Variation against Budget(= Spent Hours/Budget Hours)
- A2. Unit Cost Rate Efficiency(= Invoiced €/Spent Hours)
- A3. Resource Utilization Rate(=Spent Hours /No. of Engineers)
- A4. Labour to Invoice Cycle(=Actual Invoice €/Planned Invoice €)

The Tactical operation module is derived from the key performance metrics of strategic objectives and organizational capacities which are linked or interrelated to the relevant influencing sub-criteria.

This module is mainly related to the performance of strategic management of the supply chain with the focusing on the financial performances.

3.5.2 Formulation of Order Process- [BSC-SCPM-OP Module: “B”]

- B1. Order Progress Fill rate (=Actual POC %/Planned POC %)
- B2. Delivery Lead-Time (=Remained Hours/Available Hours)
- B3. Task Resource variation (=Working Engineers/Planned Engineers)
- B4. Subcontracting Rate (=Subcontracting Hours/Total Hours)
  *Subcontracting Hours;(2nd Layer: Kf=0.7, 3rd Layer: Kf=0.5)/Total Hours)

The Order Progress module is derived from the key performance metrics of business process objectives, operational efficiencies, and capabilities that are linked or interrelated to the relevant influencing sub-criteria.

This module represents a performance of the organizational business process in supply chain with the focusing on the productivities and efficiencies of operational performances.

3.5.3 Formulation of Service Quality- [BSC-SCPM-SQ Module: "C"]

- C1. Fill Rate of Change Order (= Approved Hours/Requested Hours)
- C2. Task Defect Rates (= Current Changes/Previous Changes)
  *Number of Changes/Comments/Remarks in association with the change management system of the case company 'JIRA System'
- C3. Schedule Fill Rates (=Delayed / Planned Documents)
- C4. Agility on Demand variation (=Scale 1 to 10)
  *Client Response Time. *Information Sharing Management.
  *Capability of Solving Technical/Commercial Problem.

The Service Quality module is derived from the key performance metrics of responsiveness, reliability, and agility which are linked or interrelated to the relevant influencing sub-criteria.

This module represents a performance of the organizational capabilities and partnership management in supply chain. This module is focusing on the business competitiveness as the perception of customer satisfaction.

3.6 Development of integrated BSC+AHP Modules

The key performance metrics have been developed with an assignment of the relevant priority weight to represent overall performance level of supply chain. The outcomes are transformed to balanced scorecard modules to display the holistic feature of the supply chain performance in the form of key performance indicators (KPIs).

The structure of the key performance criteria and corresponding key performance metric are defined respectively in the subsection 3.3.3.1, 3.3.3.2, 3.3.3.3, and 3.3.3.4.

Each objective module has the key criteria and sub-criteria of the specific performance measures, and they are formulated mathematically to figure out the influences on the specific performance. The details of performance metrics formulation and the transformation to the objective module are presented in the subsection 3.5.1, 3.5.2, and 3.5.3.

3.6.1 Balanced Scorecard-Tactical Operation- [BSC-SCPM-TO Module "A"]

This BSC module for evaluation of Tactical operation is based on the key performance criteria and performance metrics defined in the subsection 3.3.3.2.

In order to facilitate the dynamic measurement and the continuous updated feedback to support managerial decision-making, the module has to provide the updated information at the predefined frequencies between the customer and the supply chains.

Table 13 shows the case study of balance scorecard of Tactical Operation in terms of monthly basis with the corresponding performance measures, measurements, priority weights, and the BSC KPIs.

Table 13 Key Performance Objective of Tactical Operation [AHP_K=0.2790]

Month Operation	Criteria Measures	AHP Weight	Target Plan	Actual Output	SCPM Plan	SCPM Actual	BSC KPIs
Feb-2014	Variation against Budget	0.4461	25 (%)	18 (%)	0.0311	0.0224	72 (%)
	Unit Cost Rate Efficiency	0.3646	45 (€/Hour)	44 (€/Hour)	0.1017	0.0995	98 (%)
	Resource Utilization Rate	0.1309	165 (Hour/P)	172 (Hour/P)	0.0365	0.03807	104 (%)
	Labour to Invoice Cycle	0.0584	48000 (€)	35000 (€)	0.0163	0.0119	73 (%)
	Monthly Average	1.0000			0.1854	0.1719	**92.7 (%)**
Month Operation	**Criteria Measures**	**AHP Weight**	**Target Plan**	**Actual Output**	**SCPM Plan**	**SCPM Actual**	**BSC KPIs**
Mar-2014	Variation against Budget	0.4461	25 (%)	18 (%)	0.0311	0.0224	72 (%)
	Unit Cost Rate Efficiency	0.3646	45 (€/Hour)	44 (€/Hour)	0.1017	0.0995	98 (%)
	Resource Utilization	0.1309	165 (Hour/P)	172 (Hour/P)	0.0365	0.03807	104 (%)

	Rate						
	Labour to Invoice Cycle	0.0584	48000 (€)	35000 (€)	0.0163	0.0119	73 (%)
	Monthly Average	1.0000			0.1854	0.1719	**92.7 (%)**

3.6.2 Balanced scorecard-Order Progress-[BSC-SCPM-OP Module "B"]

This Order progress module is based on the key performance criteria and performance metrics defined in the subsection 3.3.3.3.

In order to facilitate the dynamic measurement and the continuous updated feedback to support managerial decision-making, the module has to provide the updated information as predefined frequencies between customer and supply chains.

Table 14 shows the case study of balanced scorecard of Order Progress in terms of monthly basis with the corresponding performance measures, measurements, priority weights, and the BSC KPIs.

Table 14 Key Performance Objective of Order Progress [AHP_K=0.6491]

Month Operation	**Criteria Measures**	**AHP Weight**	**Target Plan**	**Actual Output**	**SCPM Plan**	**SCPM Actual**	**BSC KPIs**
Feb-2014	Order Progress Fill Rate	0.4899	30 (%)	25 (%)	0.0954	0.0795	83 (%)
	Delivery Lead-Time	0.3161	3750 (Hours)	2860 (Hours)	0.2052	0.1565	-11.8 (Days)
	Task Resource Variation	0.1157	13 (Engineers)	11 (Engineers)	0.0751	0.0635	85 (%)
	Subcontracting Rate	0.0783	1500 (Hours)	2200 (Hours)	0.0508	0.0346	+46 (%)
	Monthly Average	1.0000			0.4265	0.3341	**78.3 (%)**
Month Operation	**Criteria Measures**	**AHP Weight**	**Target Plan**	**Actual Output**	**SCPM Plan**	**SCPM Actual**	**BSC KPIs**
Mar-2014	Order Progress Fill Rate	0.4899	30 (%)	25 (%)	0.0954	0.0795	83 (%)

	Delivery Lead-Time	0.3161	3750 (Hours)	2860 (Hours)	0.2052	0.1565	-11.8 (Days)
	Task Resource Variation	0.1157	13 (Engi-neers)	11 (Engi-neers)	0.0751	0.0635	85 (%)
	Subcontract-ing Rate	0.0783	1500 (Hours)	2200 (Hours)	0.0508	0.0346	+46 (%)
	Monthly Average	1.0000			0.4265	0.3341	**78.3 (%)**

3.6.3 Balanced scorecard-Service Quality- [BSC-SCPM-SQ Module "C"]

This BSC module for evaluation of Service quality is based on the key performance criteria and performance metrics defined in the subsection 3.3.3.4.

In order to facilitate the dynamic measurement and the continuous updated feedback to support managerial decision-making, the module has to provide the updated information as predefined frequencies between customer and supply chains.

Table 15 shows the case study of the balanced scorecard of Service Quality in terms of monthly basis with the corresponding performance measures, measurements, priority weights, and the BSC KPIs.

Table 15 Key Performance Objective of Service Quality [AHP_K=0.0719]

Month Operation	Criteria Measures	AHP Weight	Target Plan	Actual Output	SCPM Plan	SCPM Actual	BSC KPIs
Feb-2014	Change Order Rate	0.0779	175 (Hours)	126 (Hours)	0.0056	0.0040	72 (%)
	Task De-fect Rate	0.4984	17 (EA)	32 (EA)	0.0358	0.0315	+88 (EA)
	Schedule Fill Rate	0.3791	38 (Draw-ings)	22 (Draw-ings)	0.0027	0.0016	-16 (Draw-ings)
	Agility on Demand	0.0446	10 (Level)	7 (Level)	0.0032	0.0022	70 (%)
	Monthly Average	1.0000			0.0473	0.0393	**83.1 (%)**
Month Operation	**Criteria Measures**	**AHP Weight**	**Target Plan**	**Actual Output**	**SCPM Plan**	**SCPM Actual**	**BSC KPIs**
Mar-2014	Change Order Rate	0.0779	175 (Hours)	126 (Hours)	0.0056	0.0040	72 (%)

	Task Defect Rate	0.4984	17 (EA)	32 (EA)	0.0358	0.0315	+88 (EA)
	Schedule Fill Rate	0.3791	38 (Drawings)	22 (Drawings)	0.0027	0.0016	-16 (Drawings)
	Agility on Demand	0.0446	10 (Level)	7 (Level)	0.0032	0.0022	70 (%)
	Monthly Average	1.0000			0.0473	0.0393	**83.1 (%)**

3.6.4 Supply Chain Performance Management Dashboard

From the evaluation of the BSC modules as described in section 3.5.1, 3.5.2, and 3.5.3, supply chain performance dashboard is established for the senior management level with the key performance criteria as shown in Table 16.

To cope with the business objectives and performance target of management, and, to support the information for the managerial decision-making, the supply chain performance dashboard is to be presented with the decision criteria as the agreed KPIs.

Table 16 Supply chain performance management dashboard

Performance/ Month	Tactical Operation	Order Progress	Service Quality	Decision Criteria
Jan.- 2014	93.1 (%)	87.2 (%)	85.5 (%)	If actual performance is >85%, :Accepted
Feb.- 2014	**92.7 (%)**	**78.3 (%)**	**83.1 (%)**	If actual performance is <85%, :NOT Accepted
Mar.- 2014	91.2 (%)	75.7 (%)	87.8 (%)	
1/4Q- 2014	92.3 (%)	80.4 (%)	85.5 (%)	
…				
…				
…				
Half.- 2014 Performance	90.9 (%)	87.2 (%)	81.2 (%)	
…				

…				
…				
Year 2014 Performance	93.3 (%)	86.4 (%)	80.7 (%)	

3.7 Framework of SC Performance Measurement for the case Company

In order to improve the supply chain performance, the successful implementation of the BSC+AHP SC performance measurement Framework is the fundamental requirement and, it has the following prerequisites:

- Strong commitment and feedback from the top management in daily operation on the basis of the performance measurement results
- Motivating the implementation activities and improvement initiatives on performance measurement by rewards
- Deploying a clear strategic objectives through the key performance measurement system and the key performance measures (KPIs)
- Linking the performance measures into the decision-making processes at all levels of the organization
- Setting up a sound and a clear organizational communication system as well as information sharing system

In the long run, it is clear that this BSC+AHP SC performance measurement framework and the corresponding performance measurement dashboard need to be integrated and to be operated as the part of ERP system for a successful implementation.

The procedures and steps of the framework for the SC performance measurement are summarised and proposed for the case company as Figure 10.

Also, the corresponding managerial BSC+AHP supply chain performance measurement dashboard can be generated on the basis of Table 16.

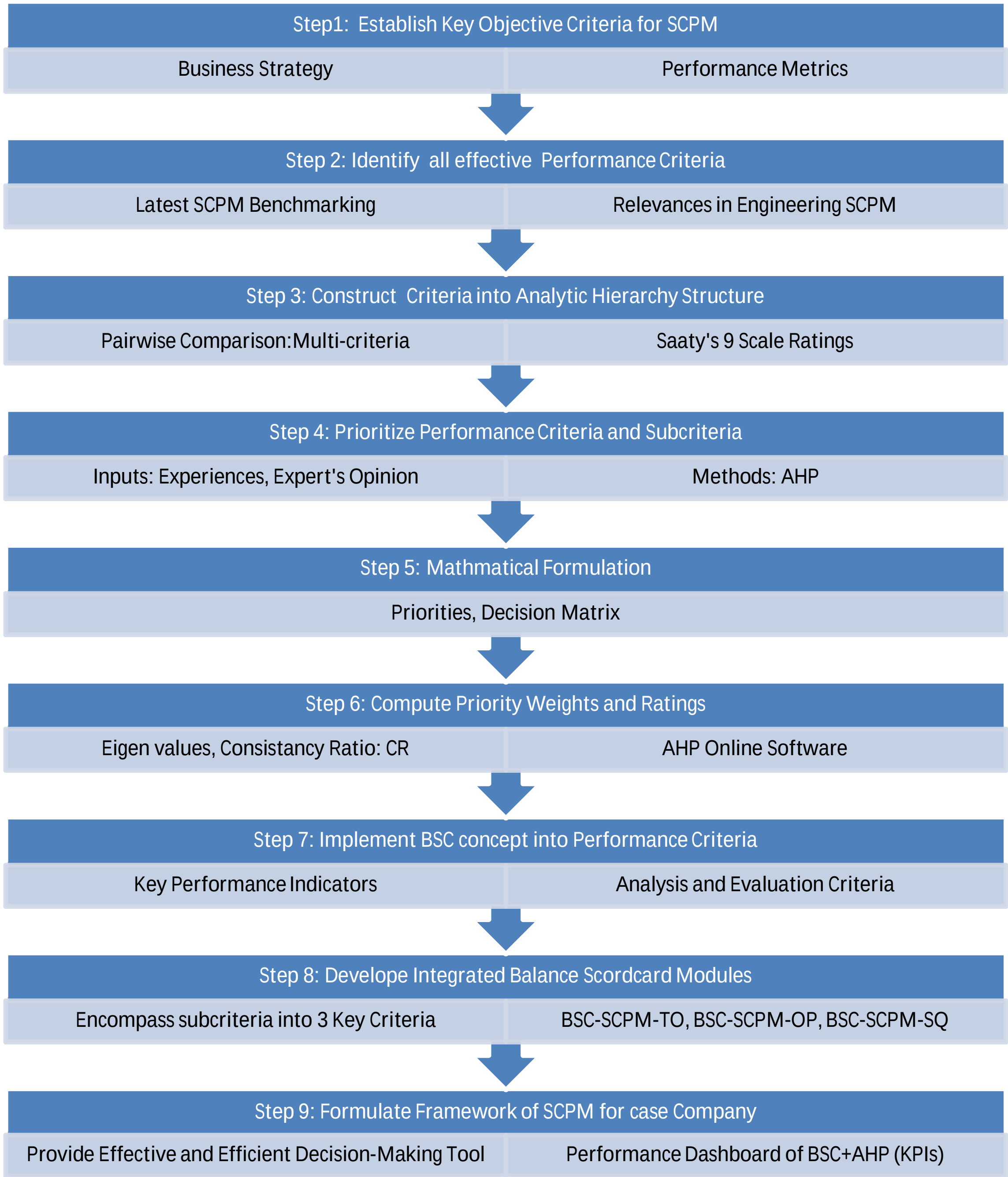

Figure 10 Process Skeleton of BSC+AHP SCPM Framework

4 CONCLUSION AND DISCUSSION

4.1 Research Conclusion

In order to achieve the improved performance in the engineering supply chain management, it has been highlighted the importance of the supply chain performance measurement and the challenges of engineering supply chain performance measurement. The research on efficient and effective performance measurement of engineering service supply chain leads to complexity and fragment issues, and it is becoming a critical topic for both practitioners and academics.

With the recent literature reviews, it has been scrutinized the performance measures and metrics that suit the engineering service supply chain performance. Moreover, a new perspective of performance measurement approaches are developed on how engineering service supply chain processes and performances could be measured, monitored, analyzed and evaluated during the whole progressing periods, to enable the dynamic and progressive management of supply chains.

The three research questions and related research tasks are elaborated and cleared as follows.

Task1. What indicators can represent the performance progress of the engineering supply chain effectively?

1) Scrutinized the effective performance measurement approaches and the appropriate performance measures and metrics for engineering supply chain based on the expertise of case company

2) Structured in hierarchy of the metrics and measures in association with the key performance objectives and criteria to fit AHP analysis.

3) Established three key performance modules to fit BSC+AHP approach in order to represent the performance of the engineering supply chain. The

established key performance modules are BSC-SCPM-TO, BSC-SCPM-OP, and BSC-SCPM-SQ.

The measures and metrics are to be agreed within the internal organization to reflect the strategy of business objectives, and the measurements with the measures are to be agreed with the supply chains during the contract stage.

Task2. How can the performance indicators of the engineering supply chain be measured with what measures and metrics?

1) Three key performance modules (BSC-SCPM-TO, BSC-SCPM-OP, and BSC-SCPM-SQ) have been created to realize BSC+AHP approach as the representing performance indicators of the engineering supply chain.

2) The key performance metric of each BSC+AHP module has been defined the formulation on how to measure and evaluate the influences with the priority weights that are mathematically determined by pair-wise comparison method by Saaty's nine scale ratings.

Analytic Hierarchy Process (AHP) makes this approach possible to integrate the multi-dimensional characteristics of performance metrics. The performance metrics are transformed to the representative key performance modules with the priority weights to identify the influences.

Task3. How can the measured performance metrics of the engineering supply chain be analyzed and utilized to provide as managerial decision-making tool?

1) Three key performance modules (BSC-SCPM-TO, BSC-SCPM-OP, and BSC-SCPM-SQ) are measured and analyzed with the predefined and agreed decision criteria.

2) Matrix calculation and data analysis are conducted by a mathematical software specialized in business application. In this case study, the open source of AHP software in *www.bpmsg.com* has been utilized. The software output provides priorities, decision matrix and consistency ratios.

The AHP calculation and analysis software is well known and readily available for business application. It can be applicable with standalone software, but it is recommended to incorporate with ERP system as IT system of the company.

Nowadays, the engineering service industry is characterized by continuous extension in supply chain outsourcing due to the globalization strategy and technological advancements. Therefore, implementation of effective performance measurement in the engineering supply chain emerges an essential tool to cope with these challenges.

In this context, the performance measurement of global engineering service supply chain is one of the critical topics for improvement of supply chain performance and managerial competitiveness.

This research contributes to the managerial insights as well as the theoretical implementation in the following aspects.

(1) This research provides managerial implication with the physical measures and measurement solution by linking the BSC perception and AHP methodology to articulate the measures and metrics for managers to assess the supply chain processes and to evaluate the performance in a systematic way of approach. The proposed SC performance measurement framework facilitates the managers with the effective and efficient measurement system as a common decision-making tool to align the objectives of company strategy. The system motivates the common perception of goal, sound communication and transparent evaluation criteria for all management level as well as the managers of supply chains.

(2) This research employs the methodological approach by transforming the sub-criteria, key criteria and object module into the hierarchy of AHP model. Three BSC+AHP modules are established for the most proper representation of the relevant key performances of the dedicated supply chains by formulating and integrating the multi-dimensional characteristics into each

BSC+AHP module. The performance metrics are inter-related and influenced each other, and they are eventually affected to the specific performances with the different level of weights. Therefore, the approach of this case study by identifying, formulating, integrating of performance criteria, and transforming of the performance metrics into the BSC+AHP module enables to articulate the supply chain performance more systematically.

(3) This research will devote to motivate researchers and practitioners to develop further in this area. This framework of performance measurement for engineering supply chain will be beneficial to researchers and corporate managers in identifying the opportunities for improvements in engineering supply chain performance.

Performance measurement in engineering supply chain is not much developed and implemented in the actual business environments. Thus, this research is unique in some extent and contributes to the engineering service industry, specifically to the case company.

4.2 Future Research

Supply chain performances measurement and its measures and metrics claim the different issues in the individual organization and also in the specific industries. It is not feasible to apply a common supply chain performance measurement and measures in the other specific business organization without suitable modification of the framework to suit the dedicated business organization.

Therefore, one of remaining issues for future research would be to carry out an empirical case study research that examines this research framework to the other category of engineering organization such as basic design or concept design level. By this empirical research approach, the BSC+AHP modules and SC performance measurement framework could be further developed for the performance measurement of the engineering supply chains.

As a further research, the validity of this framework needs to be examined in other service industries. Moreover, development of the new measures and new framework for evaluating the performance of the engineering supply chain as a whole entity requires a creative effort for both academic researchers and practitioners.

Further in-depth research also can be suggested on the development of evaluation approaches for the measures and metrics of the engineering supply chain, that includes uncertainty, agility, reliability, responsiveness, sustainability, organizational culture, and human resource attributes.

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