# AN INTEGRATED LOGISTICS PERFORMANCE MEASUREMENT SYSTEM FOR LOGISTICS MANAGEMENT

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By

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The undersigned, appointed by the Dean of the Graduate Faculty, have examined the thesis entitled

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And hereby certify that, in their opinion, it is worthy of acceptance.

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# ABSTRACT

In the 1980's there was a revolution that changed the nature of traditional performance measurement systems. Since then there has been an explosion in the number of scholars and practitioners seeking new and better ways of measuring organizational performance. Performance measurement systems (PMS) specialized for logistics management caught attention much later when more enterprises began to focus on logistics to reduce operational cost and increase profits. Meanwhile, there are more demands on logistics performance measurement systems (LPMSs). The role of an LPMS is beyond monitoring logistics performance, but also to provide logistics improvement suggestions, resolve trade-offs between different logistics activities and so on.

To design an LPMS, this thesis addresses the following four objectives: 1) review the evolution of performance measurement systems (PMS) for logistics since 2000; 2) determine the requirements for the design an ILPMS; 3) propose an ILPMS that satisfies these requirements; and 4) apply the ILPMS to a case study.

The ILPMS consists of three components: 1) a hybrid performance measurement framework, combining a hierarchical and process-based structure, to facilitate developing logistics performance measures and metrics; 2) different strategies for developing logistics performance measures and logistics activity metrics; 3) a hybrid multi-criteria decision making methodology, analytic network process (ANP) and decision-making trial and evaluation laboratory (DEMATEL), to prioritize performance measures and metrics for managerial purposes.

The ILPMS developed illustrates the procedures to establish a logistics performance measurement system for a manufacturing company. The results from the ILPMS provide effective feedback for performance management process and suggestions about performance improvement for managers.

Keywords: integrated logistics performance measurement framework (ILPMS), performance measures/metrics, multi-criteria decision making methodology (MCDM)

# CHAPTER 1 INTRODUCTION

The purpose of this chapter is to describe the background, motivation, and objectives of this research. The chapter begins by providing the research background of logistics performance measurement systems. Then briefly introduces the current state-of-the-art of research for logistics performance measurement and issues to be solved, which provides the motivation for this research. The research objectives and research processes are also briefly described. Finally, to provide a clear guideline for readers, the thesis organization is provided.

## 1.1. Research Background

The role of performance measurement performance systems (PMSs) has been changing. The main objectives of PMSs were to collect business operational results and provide feedback for the performance management process where the company manages its performance in line with its corporate and functional strategies (Bititci et al., 1997). To fulfill this role, PMSs used to be defined as a system consisting of a set of performance measures and metrics which quantify efficiency or effectiveness of actions (Neely, 1994). In the past twenty years, a revolution in performance measurement has been witnessed. The impetus for such revolution came from both the bottom and the top of the organization (Neely, 2004). Because of organizations' new requirements for better monitoring and controlling operational activities, more and more non-financial measures are integrated into performance measurement systems. The increasing number of performance measures and metrics in PMSs challenges decision makers in the organization on how to manage and make use of such amount of performance measures. Thus, more requirements are imposed on PMSs nowadays.

Logistics performance measurement systems encountered the same changes. Since theoretically, logistics performance can be regarded as a portion of the larger notion of firm or organizational performance (Chow et.al, 1994). For a long time, the measurement of logistics performance was evaluated through a few financial measures, such as profit, cost, return on asset, because logistics was regarded as a supporting activity and evaluated as a cost center (Fawcett and Cooper, 1998). Nevertheless, with the dramatic changes in business environment, companies, especially in mature industries where products tend to be similar from a technical point of view, began to heavily turn to logistics to improve customer service, differentiate from their competitors and finally develop a key competency for the firm (Keebler and Plank 2009). The old-fashioned logistics performance measuring methods that heavily focus on financial measures cannot meet its new role within an organization any longer.

## 1.2. Research Motivation and Objectives

Even though logistics is getting more and more attention, the research on logistics performance measurement systems is very limit. Currently, there are three main topics that arouse great interest in research about logistics performance measurement systems. One of the topics is how to establish LPMSs that integrate different stakeholders' interests on logistics. According to Chow et al., (1994), a LPMS needs to deal with numerous interdependencies and conflicts between goals or interests. The second topic is also about design LPMSs, but from a different perspective. Researchers seek to establish

LPMSs that enable decision makers to extract useful information for logistics performance improvement. The last topic is how to develop effective performance measures that provide needed information so that the quantity of performance measures and metrics is manageable.

The objective of this research is to develop an integrated logistics performance measurement system (ILPMS) to deal simultaneously with the three above issues. Lohman et al. (2002) define performance measurement systems as frameworks that integrate performance measures in a dynamic and accessible way to achieve consistent and complete performance measurements. The definition suggests that PMSs include at least two basic elements: performance measures and a framework. A performance measurement framework not only determines the scope of measurement, but also facilitates the development of performance measures. Hence, in this research, the logistics performance measurement framework will be established first. Then methodologies of developing logistics performance measures and metrics will be proposed.

What's more, a multi-criteria decision making (MCDM) methodology will be incorporated, since neither the performance measurement framework nor performance measures are capable of resolving the interdependency or conflicting goals. Many researchers have already applied multi-criteria decision making (MCDM) methodologies to prioritize logistics goals or third party logistics providers. The main benefits of applying MCDM methodologies is that they allow decision makers to quantify the relationships between performance measures/criteria, which makes the decision more direct.

To design the ILPMS, this research adopts a four-step procedure as follows:

Step 1: Review academic papers about performance measurement frameworks and performance measures from the year 2000 to 2016.

Many research papers adopt and adjust business performance measurement frameworks to establish performance measurement frameworks for logistics measurement purposes. Therefore, existing logistics performance measurement frameworks, as well as business performance measurement frameworks both will be reviewed, discussed and compared. Individual logistics performance measure review is beyond this research, because different companies may define the same logistics measure with different meanings. For example, perfect order delivery may be defined by lead time or by costs or other dimensions. Therefore, only logistics performance measurement dimensions will be reviewed. The purpose for reviewing logistics performance measure dimensions is to establish the basis for the ILPMS.

Step 2: Specify requirements for the integrated logistics performance measurement system to fulfill.

The established ILPMS should fulfill some criteria. Even though researchers have different methodologies to establish PMSs or LPMSs, there are some common criteria to judge whether a PMS or LPMS is good or not. According to the papers of Neely et al. (2005) and Bititci et al.(1997), the integrity of the system and deployment are the two criteria to structure and configure performance measurement systems. Integrity means that the PMS is able to integrate various businesses, while deployment refers to the deployment of business objectives and policies throughout the organization. Detailed requirements for the LPMS will be discussed and summarized as ILPMS development initiatives and assessment criteria.

Step 3: Establish the integrated logistics performance measurement system (ILPMS)

In this step, the logistics performance measurement framework will be established. Then methodologies to develop logistics performance measures at different managerial levels will be explained. An MCDM methodology is selected, along with an example to demonstrate how to apply it. Finally, the ILPMS will be assessed with the requirements from step 2.

Step 4: Apply the integrated logistics performance measurement system (ILPMS)

The effectiveness of the ILPMS will be verified through a real case where information and data about logistics operation come from a US-based manufacturing company. The ILPMS will be applied thoroughly step by step. The results from the system will be thoroughly analyzed for logistics performance management improvement.

## 1.3. Thesis Organization

The first chapter of this thesis has described the research background, motivation, and the objectives, as well as the research procedure. Chapter two reviews literature about logistics performance measures and frameworks. Chapter three, the integrated logistics performance measurement system (ILPMS) is established, including the design of performance measurement framework, the methodologies of developing logistics performance measures at different managerial levels, and the selection and application of a hybrid multi-criteria decision making methodology. The application of the ILPMS is included in the Chapter four. Finally, in Chapter five, the research is summarized and the contribution of this research and future research directions are discussed.

# CHAPTER 2 LITERATURE REVIEW

The purpose of this chapter is to review papers about logistics performance measurement frameworks and logistics performance measurement dimensions. This chapter starts by explaining the reasons to focus on measuring logistics performance in modern enterprises. Then logistics measurement dimensions and logistics measurement frameworks are reviewed and discussed. Finally, frequently used multi-criteria decision making methodologies are also introduced and compared by their strengths and drawbacks.

More and more companies resort to logistics to improve customer service in order to differentiate from their competitors. Thus, logistics is able to provide a key competency for firms (Keebler and Plank 2009). Indeed, logistics capability has emerged as a key determinant of customer value (Stank et al., 2001). How to measure logistic capability has also become a hot topic both in academia and industry. The research on logistics performance measurement systems (LPMSs) is no longer a subset of performance measurement systems (PMSs).

A logistics performance measurement system (LPMS) is a system that integrates all relevant information about logistics activity results and provides feedbacks on how well logistics activities in fulfilling logistics objectives, serving customers etc. (Keebler and Plank, 2009; Domingues, Reis and Macário, 2015). Neely (2002) decomposed a comprehensive performance measurement system into three basic elements: (1) Individual measures that quantify the efficiency and effectiveness of actions; (2) A set of measures that combine to assess the performance of an organization as a whole; (3) A supporting infrastructure that enables data to be acquired, collated, sorted, analyzed, and disseminated. The element (2) requires performance measurement frameworks to integrated measures in a systematic way. The following two sections are devoted to papers about logistics performance measurement dimensions and performance measurement frameworks.

## 2.1. Logistics Measurement Dimensions Review

Performance is multi-dimensional (Chow et.al, 1994) and many different measures have been developed to evaluate different dimensions. Conducting research on individual measures is less meaningful than measurement dimensions since companies may have different definitions for the same measure. Therefore, this review focuses on categories of logistics performance measurement dimensions.

### 2.2.1. Attributes of performance measures

Griffis et al. (2004) claimed that logistics measures have different abilities in revealing information types. Literally, they identify four information types within an organization: responsiveness versus efficiency; strategic versus operational; process orientation versus functional orientation; monitoring versus diagnosing. For instance, delivery lead time reveals more information about responsiveness than efficiency. Neely (1995) identified efficiency and effectiveness as two fundamental performance dimensions. Effectiveness is the extent to which the logistics business's goals are accomplished. And efficiency means how well the resources are utilized. Bobbitt (2004) argued that differentiation is another dimension to measure logistics performance except efficiency and effectiveness.

These three dimensions are used to be thought conflicting. However, Fugate et al. (2010) proved that pursuing one of the above three does not preclude pursuit of the other, but rather the performance dimensions perhaps reinforce each other through their empirical research.

### 2.2.2. Nature of performance measures

Financial measures dominated for a long period of time in performance measure systems since they can be conveniently designed, easily calculated and compared between companies. The need for supplementing traditional accounting measures with non-financial metrics came out in the 1980s and the early 1990s to observe the behavior of the multiple components of a supply chain (Cagliano et al., 2009). Financial measures are used to evaluate cost and price, while non-financial measures deal with resource utilization, time, quality etc. (Brewer and Seph, 2000). The rising of non-financial measures does not mean that financial measures are no longer important, but rather non-financial measures are important in assessing companies' capabilities to compete and revealing more information than financial ones (Gunasekaran, 2004).

To establish a balanced performance measurement system, it is crucial to select both financial and non-financial measures. Said et al. (2003) claimed that firms employing a combination of financial and nonfinancial performance measures have significantly higher levels of returns on assets and market returns. Additionally, the adoption of nonfinancial measures improves firms' current and future stock market performance. Another benefit of integrating of financial and non-financial measures is that it allows the firm to find the best compromise between cost and quality in the supplied service, since each non-financial measures leads to a particular cost (Rafele, 2004).

### 2.2.3. Decision-making levels

Gunasekaran et al. (2001) categorized logistics performance measures according to decision-making levels: strategic, tactical and operational levels. Gunasekaran and Kobu (2007) claimed the success of strategy formulation depends on the degree of alignment of strategies at different levels. According to Rushton et al. (2010), the strategic level measures evaluate top level management decisions (e.g. competitiveness), the tactical level deals with mid-level management decisions (e.g. resource allocation) and operational level measures the low level managers' activities (e.g. achieving delivery correctness). Since this categorization complies with hierarchical organization structures, performance measures at different decision levels can be assigned to managers at different decision levels. Managers are responsible for those performance measures and the responsibilities will further motivate managers to monitor, control and even improve performance measures.

### 2.2.4. Components of performance measures

Neely (2000) argued that deciding what to measure in business performance drives management team to rethink performance priorities and relationships between measures, hence the team is able to observe and resolve any difference of opinions. For instance, the balance between delivery lead time and delivery costs.

Fawcett and Cooper (1998) designed five measure categories to capture performance of logistics: asset management, cost, customer service, productivity, and logistics quality. While Chan and Qi (2003) measured logistics from cost, time, capacity, capability, productivity, utilization and outcome dimension. In the papers of Jothimani and Sarmah

(2014) and Huo and Ji (2008), they both adopted reliability, responsiveness, flexibility, cost measures and asset management efficiency to measure logistics performance, which decomposes logistics quality into reliability, responsiveness and flexibility. Keebler and Plan (2009) interpreted quality as accuracy, completeness and correctness. Franceschini and Rafele (2000) elaborated the criteria of quality dimensions for logistics activities as: lead time, regularity, reliability, completeness, flexibility, correctness, harmfulness and productivity. When outsourcing logistics service, companies tend to also measure relationship, expertise/competence/experience, location, finance, information equipment systems, in addition to cost, quality, flexibility, reliability (Aguezzeoul, 2000).

This type of performance measurement framework provides companies with great flexibility, since decision makers can select components that best meet the demand of measuring logistics operations. For instance, Garcia et al. (2012) employed quality, timeliness, logistics cost, productivity and capacity to measure logistics performance for wine industry. Chen et al. (2005) developed criteria to measure the performance of supply chain for a garment company in Taiwan. The characteristics of the industry require a responsive supply chain. So they emphasized the responsiveness and reliability related to time measures.

### 2.2.4. Bases of performance measures

Chow et al., (1994) categorized logistics performance measures into "hard" and "soft" class. "Hard" measures are those that can measure directly, such as return on assets, order lead time. "Soft" measures refer to measures that are difficult to be measured directly, such as customer satisfaction. They claim that "hard" and "soft" measures have their own strengths and weaknesses. For instance, soft measures complement hard measures, but they may raise comparability problems. Staudt et al., (2015) adopted the same classification, but named differently: direct and indirect measures. The first one treats quantitative measures such as order cycle time, fill rates and costs, while the second deals with qualitative measures like manager's perceptions of customer satisfaction and loyalty (Chow et al., 1994). Quantitative measures are easily computable with some simple mathematical expressions while the qualitative ones require more sophisticated tools of measurement (e.g. regression analysis, fuzzy logic, Data Envelopment Analysis, etc.).

Customer satisfaction is the new soft measure that has been widely discussed. How well logistics increases customer satisfaction is the information that managers desire to know after the role of logistics has been transferred from cost reduction to value added for customers. However, measures that relate to customer satisfaction are hard to acquire in reality. So in order to measure it, managers resort to measures that may affect customer satisfaction, such as logistics quality, embodied by flexibility, reliability, responsiveness and so on. Gunasekaran et al. (2001) argued that post transaction measures of customer service is also crucial for customer satisfaction. For example, timely availability of spares helps companies to provide better customer service, and to trace the problems arising from warranty claims. They also advocate to measure customer perception of service. Except customer perception, other indirect measures mentioned in the paper of Staudt et al. (2015) include: labor, value-added logistics activities, inventory management, warehouse automation, flexibility, maintenance. These indirect measures have big influences on direct measures.

Table 1 summarizes all the above discussed performance measurement dimensions and papers that utilize these categories.

Table 1 Performance measurement dimensions

| Performance measurement dimension categories | Performance measurement dimensions | Papers |
|---|---|---|
| **Attributes of performance measures** | Efficiency, effectiveness, differentiation | ▪ Griffis et al. (2004);<br>▪ Neely (1995);<br>▪ Bobbitt (2004);<br>▪ Fugate et al. (2010); |
| **Nature of performance measures** | Financial and non-financial | ▪ Brewer and Seph (2000);<br>▪ Gunasekaran,( 2004);<br>▪ Said et al. (2003);<br>▪ Rafele (2004); |
| **Decision-making levels** | Strategic, tactical and operational level | ▪ Gunasekaran et al. (2001);<br>▪ Gunasekaran and Kobu (2007);<br>▪ Rushton et al. (2010); |
| **Components of performance measures** | Asset management, cost, customer service, productivity, and logistics quality, customer satisfaction | ▪ Fawcett and Cooper (1998);<br>▪ Chan and Qi (2003) [b];<br>▪ Jothimani and Sarmah (2014);<br>▪ Huo and Ji (2008);<br>▪ Keebler and Plan (2009);<br>▪ Franceschini and Rafele (2000);<br>▪ Aguezzeoul (2000) |
| **Bases of performance measures** | "Hard"/quantitative/Direct VS "soft"/qualitative/Indirect | ▪ Chow et al., (1994);<br>▪ Staudt et al., (2015);<br>▪ Gunasekaran et al. (2001); |

### 2.2.5. Logistics performance measure criteria

There are requirements for individual measure design. Caplice and Sheffi (1994) proposed eight criteria to evaluate individual measures: validity, robustness/comparability, usefulness, integration, economy, compatibility, level of detail, behavioral soundness (Table 2). Yet it is impractical to develop measures that excel in each of the eight criteria, since there are trade-offs between different criteria. For example usefulness tends to go against validity in that a measure capturing all the details of a process are valid, but it becomes more complex thus hard to understand (less useful). So how to solve the trade-offs between criteria is crucial for measure development?

Table 2 Definition of the Eight Evaluation Criteria (from Caplice and Sheffi,1994)

| Criterion | Description |
|---|---|
| **Validity** | The metric accurately capture the events and activities being measured and controls for any exogenous factors. |
| **Robustness** | The metric is interpreted similarly by the users, is comparable across time, location, & organization, and is repeatable. |
| **Usefulness** | The metric is readily understandable by the decision maker and provides a guide for action to be taken. |
| **Integration** | The metric includes all relevant aspects of the process and promotes coordination across functions and divisions. |
| **Economy** | The benefits of using the metric outweigh the costs of data collection, analysis, and reporting. |
| **Compatibility** | The metric is compatible with the existing information, material, and cash flows and systems in the organization. |
| **Level of Detail** | The metric provides a sufficient degree of granularity or aggregation for the user |
| **Behavioral Soundness** | The metric minimizes incentives for counter-productive acts or game-playing and is presented in a useful form. |

Keung (2000) also proposed six requirements for performance indicators that need to be fulfilled: 1) Quantifiability requires measures are quantitative, since quantitative measures are easy to compare. Those that are not quantitative by nature should be transformed. For instance, supplier payment attitude can be measured by number of days between 'invoice sent' and 'payment paid'. 2) Sensitivity refers to the ability of a measure to capture performance changes. 3) Linearity indicates the extent to which performance changes are congruent with the value of a certain measure. 4) Reliability requires measures are robust and free of measurement errors. 5) Efficiency means cost effective. 6) improvement-oriented requires measures reveal valuable information for improvement.

## 2.2. Logistics Performance Measurement Frameworks

As stated in the previous section, there are a vast number of measures available to measure logistics after years of development. So the real challenge for managers is to design appropriate measures and metrics which can provide right information to make right decisions (Gunasekaran, 2007). Companies can utilize frameworks to evaluate measures and then select measures to align to the information needs of the firm (Griffis et al., 2004).

Logistics performance measurement systems (LPMSs) can be regarded as the application of business PMS in logistics industry. Though they have been customized to incorporate the uniqueness of logistics operations, business PMSs contribute enormously to the evolution of LPMSs. So it is necessary to briefly review the main business performance frameworks found in the literature.

Widespread interest in PMS begins from the 1970s (Domingues, et al., 2015). Yet, traditional performance measurement systems receive many critics. Ghalayini and Noble

(1996) noted that there was a fundamental change starting to occur in PMS which others continued to address. Holmberg (2000) summarized the main areas of critique into four aspects:

1) Enterprise's strategy does not connect to measurements, leading to local optimization;
2) Financial orientation. However, financial measures are less useful for proactive actions;
3) Too many isolated and incompatible measures. Measures in the system are not removed or updated timely with the changing strategy and activities;
4) Intra-organization context. More focuses are on internal measures than external ones.

In the paper of Neely et al. (2000), the main PMSs developed during 1980s - 1990s are reviewed which attempt to resolve some or all critics for traditional PMSs summarized by Holmberg (2000).

1) Performance measurement matrix (Keegan, 1989)

   Two dimensions in the framework: internal VS external; financial VS non-financial. It resolves two critics made by Holmberg (2000). Yet, it lacks explicit links between different dimensions of business performance.

2) Results and determinants framework (Fitzgerald et al.,1991)

   Two basic types of performance measures in any organization: results of business operations (e.g. competitiveness, financial performance) and determinants that affect results (e.g. quality, flexibility, resource utilization, innovation). The results can be regarded as business goals, so in this framework, measurements have connection with business goals. Besides, it is extendible to include intra-organization measures as determinants.

3) Measures for time-based competition (Azzone et al., 1991)

   Two dimensions: vertical one is for business operations and the horizontal one is internal VS external. They identify the measures most appropriate for organizations to pursue a strategy of time-based competition. The framework connects the strategy with performance measures.

4) SMART pyramid (Lynch and Cross, 1991)

   It is a hierarchical framework which starts from vision then drills down to market and financial level. At the third level, customer satisfaction and flexibility are measures for market, while productivity is a measure affecting financial performance. At the bottom level, quality and delivery are metrics for customer satisfaction, while cycle time and waste metric relate to productivity. The framework ties business process to performance measurement and makes explicit the difference between measures that are of interest to external parties-customer satisfaction, quality and delivery, and measures that are primarily of interest within the business - productivity, cycle time and waste.

5) Balanced scorecard (Kaplan and Norton, 1992)

   It complements financial perspectives with internal business process perspective, customer satisfaction perspective, innovation and learning perspective. The framework allows managers to look at the business from four important perspectives, so that to avoid local optimization.

6) Performance prism (Neely, 2003 )

It identifies stakeholders as a starting point, including investors, customers and intermediaries, employees, suppliers, regulators and communities. Then ask what strategy to meet stakeholders' needs and what processes to execute strategy, and then what capability to perform processes. Finally, ask what to expect from stakeholders in return. The framework includes a broader view of stakeholders and a top-down deployment of strategy. It also highlights external and internal measures, as well as financial and non-financial measures and measures of efficiency and effectiveness throughout the organization (Neely, 2002).

7) The framework based on Du Pont pyramid of financial ratio (The Institute of Chartered Accountants of Scotland, 1993)

   The framework adapts Du Pont pyramid of financial ratio to integrate non-financial performance measures. Du Pont Pyramid of financial ratio starts with return on investment which concerns two aspects: income-sales percentage and sales-investment ratio. Financial measures and metrics are further developed under these two aspects respectively. Obviously, this framework integrates financial and non-financial measures. Furthermore, the pyramid of financial ratios has an explicit hierarchical structure, linking measures at different organizational levels.

8) Macro Process Model (Brown, 1996)

   The framework develops measures for the elements of a process, namely, inputs, processing system, outputs and outcomes. It falls at one extreme of a continuum stretching from hierarchical to process focused. One of the drawbacks of this framework is that it may lead to local optimization without the incorporation of strategy.

9) Business excellence framework (European Foundation for Quality Management)

   It consists of two distinct subsets of performance factors, broadly classified as enablers and results. Enablers include leadership, people, policy & strategy, partnership & resources and processes. Results consist of people results, customer results, society results and key performance results. The concept of this framework is similar to that of results and determinants framework proposed by Fitzgerald et al. (1991). Yet the terms used in the framework are so open that can be interpreted in so many ways.

These business performance measurement frameworks (PMFs) provide abundant reference for the development of logistics performance measurement frameworks (LPMFs). Some of LPMFs are derived from business PMFs, while some rely on the theories of PMFs.

LPMFs are categorized into five groups: 1) perspective-based performance frameworks; 2) process-based performance frameworks; 3) activity-based performance framework; 4) financial-ratio frameworks; 5) hybrid performance frameworks.

**a) Perspective-based Framework**

The balanced score card (BSC) is the framework that is prevalently applied to measure logistics and supply chain (Brewer and Seph, 2000; Bhagwat and Sharma, 2007; Chen et al., 2005). In the paper of Brewer and Speh (2000), they adjusted the four perspectives of BSC to fit supply chain environment. So instead of financial perspectives, internal business process perspective, customer satisfaction perspective, and innovation and learning perspective, they use supply chain management (SCM) goals, SCM improvement, financial benefits, end customer benefits as the four perspectives to be considered in a BSC framework for supply chain performance measurement. Najmi and Makui (2012) also utilized the BSC model to identify supply chain performance measures. Shaik and Abdul-Kader (2013) integrated BSC model with performance prism (PP) model to integrate more stakeholders to evaluate transportation in reverse logistics enterprise. In their PMS, it comprises of six perspectives instead of original four aspects: financial, stakeholder, process (internal and external), innovation and growth, environmental and social. Krauth et al., (2005) proposed a two-dimension framework to distinguish internal and external measures. The internal measures concerns employees and management's perspective, while the external measures focuses on customer and society's perspective. Additionally, the framework incorporates a time dimension, intending to include short- and long-term measures. The framework is relatively comprehensive.

Perspective-based models force companies to pay their attention on different aspects that are important to the performance of the company (Bhagwat and Sharma, 2007). Yet, it cannot solve conflicts among perspectives, nor issues regarding the alignment between strategy and operations.

**b) Process-based Framework**

The SCOR model is another popular framework and was developed by the Supply Chain Council (SCC), specifically for supply chain performance measurement. It provides a comprehensive toolset linking business process to metrics, best practice and technology

(Stephens, 2001). Four business processes included in the framework, which are **Plan, Source, Make and Delivery**. In Version 4.0 and Version 5.0, the scope of the SCOR Model has been extended to include Return (the return of raw materials to suppliers and the receipt of returns of finished goods from customers) activities. These five management processes are decomposed into three levels of detail. At level 1, supply chain process performance (Plan, Source, Make, Deliver, and Return) is directly tied to. And at Level 2 and Level 3, process elements are used to describe more and more detailed activities.

Gunasekaran (2001) applied SCOR model to develop measures for general supply chain management. Lai et al., (2002) also developed measures for evaluating transport logistics based on SCOR model. However, they group the four processes of a SCOR model in two: customer facing and internal facing process. Customer facing process includes effectiveness-related performance measures, while internal facing process works on efficiency-related performance measures of a firm. A hierarchy structure is employed to identify performance measures at different decision making levels. Jakhar and Barua (2014) proposed a performance model derived from SCOR model, including five processes: supply chain planning, supply chain partnership, production, delivery and logistic and customer service and satisfaction performance.

Supply chain processes in SCOR model are customized for different industries. In the paper of Garcia et al.(2012), they built up a logistics benchmarking framework for the wine industry. The logistics processes for a company in the wine industry consist of Supply, Production and Bottling, Inventory Management, Warehousing, Transportation and Distribution and Customer Response. A three-level hierarchy is implemented to develop measures and metrics at different levels for each performance attribute. Chan and Qi (2003) outlined a process-based PMS for supply chain management by using the same idea of the paper of Garcia et al. (2012) where measures are decomposed at different managerial levels. They identify six core supply chain process as: Supplying, Inbound Logistics, Core Manufacturing, Outbound logistics, Marketing and Sales and end customer. They believe that process-based performance measurement not only fits with the nature of supply chain management (SCM), but also contributes to continuous improvement of SCM.

**c) Activity-based Framework**

Kayakutlut and Biiyiikzkan (2006) developed logistics measures for logistics activities: transportation management, inventory management, order-customer management and demand coordination. Cooper et al. (2012) identify measures along the supply chain of the third party logistics: Incoming Order Management, Transportation to Regional Distribution Center (RDC), Inventory Management, Transportation from the RDC to a Customer Distribution Center (CDC) and Delivery Management in time-phase format. Even though, within these frameworks, it is easy to develop measures for individual logistics activities. However, the framework can easily cause local optimization since it neglects the interdependence between activities. Andersson et al. (1989) incorporated the interactions between functions by considering the impact of the performance of one department on that of other departments. The framework is structured on functions of a supply chain: suppliers, material management, production, physical distribution and customers. They categorize the measures in efficiency measuring function’s internal logistics performance and effectiveness measuring function's external influence on other functions.

#### d) Financial ratio based Framework

Activity-based costing (ABC) and economic value added (EVA) are the two most common frameworks in the literature which apply financial approaches for supply chain performance measurement. Traditional accounting methods focus only on short-term financial results, hence they provide little information about how to generate long-term values to its shareholders. Stern et al. (1995) developed the EVA approach to correct the deficiency of traditional accounting methods in 1990s. Lambert and Pohlen (2001) extended the EVA concept to supplier and customer who are the shareholders that are often dismissed from the object of PMS to measure the performance of supply chain. They adapt Du Pont Pyramid of Financial Ratios to translate process improvements into supplier and customer profitability. Then break down economic value added (EVA) for supplier and customer to measures performance at the lower levels in the organization.

The ABC approach was developed by Kaplan & Burns (1987) which was the very first model that tries to link financial measures to operational performance. Pohlen and Coleman (2005) proposed a framework that employs a dyadic EVA analysis and ABC. Five steps to measure the supply chain are delineated: 1) Establish strategic objectives for the supply chain; 2) Map the firms composing the supply chain; 3) Examine operational decision (i.e. reduce delivery lead time) using EVA analysis; 4) Translate process objectives into cost and operational performance measures using ABC; 5) Measure and extend analysis to other trading partners. Even though, financial measures receive enormous critics, managers, especially at strategic level still pay much attention to them, since financial measures are easily comparable between companies. This framework allows managers to observe the impact of operational measures at lower level on the financial measures at higher level. The improvement in financial performance drives managers to focus on operations.

The summary table includes all the frameworks discussed above, including discussions about merits and demerits of each individual category.

Table 3 Performance measurement framework summary

| **Performance measurement framework category** | **Papers** | **Merits and demerits** |
|---|---|---|
| **Perspective-based** | 1) Balanced Score Card (BSC) (Brewer and Seph, 2000; Bhagwat and Sharma, 2007; Chia et al.,2009; Najmi and Makui, 2012)<br>2) Four perspectives: manager, employee, customer and society (Krauth et al., 2005)<br>3) Integration of BSC and Performance Prism to envelope more stakeholders (Shaik and Abdul-Kader, 2013) | BSC model forces companies to pay their attentions on aspects that can improve the performance of the company (Bhagwat and Sharma, 2007).<br>It communicates and links strategic objectives and measures (Kaplan, Norton, 1996)<br>The demerits of BSC remain in the multi-objective and mulita-criteria evaluation of the objects (Shaik and Abdul-Kader, 2013). It provides no theories about how to solve conflicts among perspectives. |
| **Process-based** | 1) SCOR (Gunasekaran,2001; Lai et al., 2002; Jakhar and Barua, 2014; Jothimani and Sarmah,2014; Chia et al, 2009)<br>2) Logistics Processes (Garcia et al.,2012; Chan and Qi[a],2003; Chan and Qi[b], 2003; Kurien and Qureshi, 2011) | It encourages horizontal integration, but discourages the linkage between strategy and operation (vertical integration). Some frameworks employ hierarchical structure to reinforce vertical integration |

| | | |
|---|---|---|
| **Activity-based** | 1) Logistics functions: transportation Mgmt, inventory Mgmt, order-customer Mgmt and demand coordination (Kayakutlut and Biiyiikzkan, 2006; Cooper et al., 2012) | Easy to develop measures for individual logistics activities. But it encourages local optimization by neglecting the interdependence between logistics activities. |
| **Financial ratio based** | 1) Economics value added (EVA) (Lambert and Pohlen,2001)<br>2) Integration of ABC and EVA (Pohlen and Coleman, 2005) | These frameworks well connect financial with non-financial measures, so that managers have strong motivations to improve non-financial measures. |

## 2.3. Multi-criteria Decision Making Methodologies

One of the solutions found in the literature to resolve trade-offs between metrics is to utilize multi-criteria decision making (MCDM) methodologies. In the following section, the most often utilized MCDM methodologies are presented and compared.

Except for the ability to resolve trade-offs, two other main reasons lie behind the popularity of MCDM methodologies: 1) decision makers require quantitative performance scores (Cook and Bala, 2007); 2) multiple criteria should be considered for evaluation (Domingues et al., 2015).

MCDM approaches can be categorized into two classes: individual approaches, which use one method or technique; and integrated approaches, which integrate two or more models (Alkhatib et al., 2015). According to Ho et al. (2015), date envelopment analysis (DEA) is pervasive in evaluating suppliers during 2003-2008. While analytic hierarchy process (AHP) and analytic network process (ANP) are the most used methods during 2008-2013 (Alkhatib et al., 2015). Other methods, such as fuzzy AHP, fuzzy ANP, decision making trial and evaluation laboratory (DEMATEL) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) catch the attention recently.

### a) Individual approach

The AHP approach was developed by Saaty (1980) which has three basic principles, namely decomposition, comparative judgment, and synthesis of priorities. Since it is relatively straightforward to use, it has been widely used in multi-criteria decision making situations. For example, So et al. (2006) applied AHP to evaluate the service quality of 3PL service provider.

One of the drawbacks of AHP approach is that it eliminates the interaction among criteria which however is always the real situation. For instance, a focus on transportation costs may directly influence another metrics, such as on-time percentages (Cooper et al., 2012). In 1996, Satty proposed a higher version of AHP – analytic network process (ANP) approach. ANP is able to integrate interdependent relationships between criteria, leading to more precise and accurate analysis. So literally, ANP is capable of modelling more complex decision/evaluation environment than AHP. Kayakutlu and Buyukozkan (2006, 2011), Jharkharia and Shankar (2007), Cooper et al. (2012) all applied ANP to select the effective performance attributes for 3PL providers.

AHP and ANP approach are criticized for their requirements on managers to have enough knowledge about relationships between measures. Bai and Sarkis (2012) believed that these relationships are not clearly known or defined in most cases. They integrate a ‘neighborhood’ rough-set approach into a PMS. Instead of focusing on relationship between performance measures, rough-set approach deals with vagueness and ambiguity by focusing on relationship between performance measures and outcomes, based on which they classified performance measures into clusters. The other approach to deal with vagueness of relationship between performance measures is to use fuzzy theory

(Alkhatib et al., 2015). Fuzzy logic ensures a mathematical precise approach to cope with the situation when the importance of performance criteria is vague (Bottani and Antonio Rizzi, 2006). Hanaoka and Kunadhamraks (2008) evaluated logistics performance for intermodal transportation by using a fuzzy-AHP methodology.

Another drawback of AHP is that it only allows one output to be considered at a time, which also limits its application. Data Envelop Analysis (DEA) is a non-parametric linear programming technique used to evaluate the utilization efficiency of decision-making units (DMUs) where multiple inputs (resources, such as labor hours, space, and materials) and multiple outputs are involved. DEA identifies the most efficient DMU and measures the efficiency of other units based on the deviation from the efficient DMU (Hamdan and Rogers, 2007). Hamdan and Rogers (2007) employed a restricted data envelopment analysis (DEA) model to evaluate the efficiency of a group of 3PL providers involving in warehouse logistics operations. Four inputs are incorporated in the model, which are total annual man-hours, total warehouse space feet, total annual cost of technology and total annual cost of material handling equipment. Outputs are total annual boxes shipped, total annual boxes filled and total cubic feet utilized. DEA can also be used to identify and select factors that have impacts on outputs. De Koster and Balk (2008) measured customer perception by using Data Envelop Analysis (DEA). The authors verify the contribution of some activities (like cross-docking, cycle counting and return handling) to the increase of customer perception. Andrejić et al., (2016) employed DEA to select main factors that affect transport efficiency.

Unlike AHP or simple weighted sum methods, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) first introduced by Chen and Hwang (1992) is based on the logical consideration that the most suitable solution should be the closest to the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). So TOPSIS approach can avoid complex pairwise comparisons which are tedious when a large number of criteria are involved. Bottani and Rizzi (2006) integrated fuzzy theory with TOPSIS to select the most appropriate 3PL partner.

Decision-making trial and evaluation laboratory (DEMATEL) method employed by Fontela and Gabus in 1976 can extract mutual and effective relations of factors by using graph theory so that each relation can be expressed numerically. The big advantage of the approach is that it can consider all available factors at all levels (same, upper and lower) in the model to determine the importance and weight of each factor. Shaik and Abdul-Kader (2014) adopted DEMATEL methodology to measure transportation performance considering the interdependence between factors.

**b) Hybrid Approaches**

Hybrid approaches aim to reap the benefits of individual approaches by complementing each other. For instance, Najmi and Makui (2012) use the composition of AHP and DEMATEL methodology to measure supply chain performance. AHP has strength to quantify the relative weight of measures, while it is unable to deal with interconnections between measures at same level, while DEMATEL can well deal with the interdependence between factors. Supeekit et al. (2016) applied the integration of ANP and DEMATEL approach to measure the performance of internal hospital supply chain.

Jakhar and Barua (2014) applied an integrated methodology of structural equation modeling (SEM) and fuzzy analytic hierarchy process (FAHP) to measure the supply chain performance of an Indian apparel company. SEM is used to weight the criteria and sub-criteria, while FAHP is used to obtain the relative weightage of the decision level with respect to each criterion and sub-criterion. Jothimani and Sarmah (2014) applied fuzzy AHP to analyze the hierarchy and priority of performance measures and use TOPSIS approach to determine the benchmark for these logistics operations.

Joshi et al. (2011) composed a Delphi-AHP-TOPSIS methodology to establish a benchmarking performance measurement framework for a cold chain. Delphi is used to identify, synthesize and prioritize measures; AHP is to evaluate performance of a company against competitors; while TOPSIS is to search for possible alternatives for the continuous improvement of the company.

Table 4 summarizes all the MCDM methodologies discussed above, as well as merits and demerits of each methodology.

Table 4 Multi-Criteria Decision Making (MCDM) methodology summary

| MCDM methodologies | Papers | Merits and demerits |
|---|---|---|
| **Analytic hierarchy process (AHP)/ Fuzzy AHP** | So et al. (2006); Shaik and Abdul-Kader (2013); Hanaoka and Kunadhamraks (2008) | It is easy to implement, but requires managers to have knowledge about relationship between different measures.<br>Fuzzy-AHP overcomes the demerit<br>The methodology assumes independence between criteria which is often not the case in real world |
| **Analytic Network Process (ANP)/ Fuzzy ANP** | Jharkharia and Shankar (2007); Cooper et al. (2012) | It is able to incorporates interdependence between criteria at the same decision level and different level as well |

| | | |
|---|---|---|
| **Data envelop analysis (DEA)** | Ross and Dorge (2002); Hamdan and Rogers (2007); De Koster and Balk (2008); Andrejić et al., (2016) | DEA helps to identify the most efficient DMU(s) and further investigation can reveal the reasons behind its success, thus becomes a model for other DMUs.<br>DEA has a limitation on the number of relationships that can be analyzed between the input and output units. Besides, only likeable units can be compared hence all the decision making units must have same strategic goals and objectives. |
| **Decision-making trial and evaluation laboratory (DEMATEL) methodology** | Shaik and Abdul-Kader (2014); | It solves the interdependence between factors to measure at different decision levels |
| **TOPSIS/Fuzzy TOPSIS** | Bottani and Rizzi (2006) | It is intuitive, easy to understand and implement.<br>It avoids complex pairwise comparisons.<br>By integrating fuzzy theory, it allows the straight linguistic definition of weights and ratings under each criterion. |
| **Hybrid approach** | 1) composition of AHP and DEMATEL (Najmi and Makui, 2012)<br>2) Integration of SEM AND FAHP (Jakhar and Barua, 2014)<br>3) Combination of fuzzy AHP and TOPSIS (Jothimani and Sarmah, 2014)<br>4) Delphi-AHP-TOPSIS methodology (Joshi et al., 2011) | They reap the benefits of individual approaches and complement each other. |

## 2.4. Requirements for LPMSs

Many researchers discuss requirements for PMSs. These requirements are applicable to LPMSs as well. Criteria for PMSs and LPMSs are reviewed and summarized into six main aspects as follow:

1) Comprehensiveness

Tangen (2004) argued that a PMS ought to include performance measures that cover all important aspects impacting the success of a company. For example, the important aspects in the interpretation of Kaplan and Norton (1995) are the four different perspectives in the BSC framework: financial, internal business process, customer satisfaction, and innovation and learning perspective. Neely et al., (2005) believed that PMSs should have all the appropriate elements (internal, external, financial, non-financial) been covered.

2) Causal orientation

Caplice and Sheffi (1995) believed that a PMS should capture the drivers of performance rather than just the end results. Neely et al., (2005) also claimed that a well PMS should introduce measures related to performance improvement.

Furthermore, Bititci et al. (1997) identified two critical elements: integrity and deployment with respect to the content and structure of the PMS.

3) Integrity

According to Bititci et al. (1997), integrity refers to the ability of the performance measurement system to promote integration between various areas of the business. Caplice and Sheffi, (1995) also regarded integrity as a main criterion of a PMS. In their perspective, integrity means a PMS includes all pertinent activities, functions, and departments along the process.

4) Deployment

Deployment means that performance measures in a PMS used at various levels of the organization reflect the business objectives and policies (Bititci et al., 1997) which is also called vertical integration by Caplice and Sheffi (1995). Besides the deployment of business strategy, in the opinion of Caplice and Sheffi (1995), a PMS is vertical integrated if it is able to connect metrics at each level to the appropriate reward system.

5) Internally comparability

A PMS should have the ability to recognize and resolve trade-offs between different dimensions of performance (Caplice and Sheffi, 1995). Financial metrics are easy to do sensitivity analysis, for example, the increase in costs should gain some increase in revenues. However, for non-financial metrics, such as lead time, it becomes hard to answer how much increase in customer satisfaction is affected by the reduction in delivery lead time. The key to solve this issue is to understand the trade-offs between metrics.

6) Usefulness

Usefulness is easy to comprehend. It means that the PMS is readily understandable by the decision makers and provides a guide for action to take.

These requirements interact with each other. For example, deployment is a function of integrity in practice (Bititci et al., 1997). Causal orientation facilitates internal comparability. And all the other five criteria make sure the PMS is useful.

## 2.5. Discussions about Literature

The current LPMSs can hardly meet the requirements on LPMSs. First of all, many papers directly applied PMSs to measure logistics performance without considering the different contexts of logistics as a subset of business and as an individual measurement entity. Logistics as one of company's business units affect the operation of other business units, while at the meantime, it is influenced by the operation of other business units. Therefore, the interdependency between logistics and other business units should be considered to establish LPMSs. Secondly, the development of logistics performance measures which are basic elements of LPMS is not based on performance measurement frameworks (PMFs). PMFs not only determine the scope of logistics performance, but also facilitate to develop and manage performance measures. Lacking appropriate PMFs may lead to undesired performance measures included in the system or miss desired performance measures from the system. For instance, some papers developed performance measures relying on attribution of performance measurement which includes efficiency, effectiveness and differentiation dimension. However, they either do not clearly define what to measure or measure something less significant for logistics performance management. Furthermore, even though many researchers noticed the interaction between performance measures, they did not propose effective solutions to resolve the issue. Finally, one of the new requirements from decision makers is that LPMSs should be able to provide information on how to improve logistics performance, since logistics becomes a key competence for companies nowadays. However, there are no current LPMSs that can meet this requirement. These unresolved issues for LPMSs provide motivations to conduct researches on them.

# CHAPTER 3 INTEGRATED LOGISTICS PERFORMANCE MEASUREMENT SYSTEM DESIGN

The purpose of this chapter is to develop an integrated logistics performance measurement system (ILPMS) for manufacturing companies. The chapter starts with defining the scope and objectives of the ILPMS, followed by three sections: logistics performance measurement framework design, logistics performance measures and metrics development strategies and multi-criteria decision methodology selection and application. Additionally, the system is evaluated by the requirements for LPMS to conclude whether it is eligible to implement. Finally, the procedure to implement the ILPMS is given to provide guidance for decision makers.

## 3.1. The Scope and Objectives of the ILPMS

The ILPMS aims to help companies in manufacturing industries where logistics is one of their business units to better monitor, control and to improve logistics performance. Therefore, the ILPMS functions as an information system to collect performance information for all regular logistics activities and also provide the capability to evaluate the information for logistics performance improvement.

The design of the ILPMS begins with the six requirements set for PMS and LPMS, explained at the end of last chapter.

First of all, ***comprehensiveness*** means that the ILPMS is able to identify and incorporate all relevant stakeholders and logistics activities into the system. The Council of Logistics Management (CLM) in 1998 defines logistics management as part of supply chain management that plans, implements, and controls the efficient forward and reverse flow and storage of goods, services, and related information between the point of origin and point of consumption in order to meet customer requirements (CLM, 1998). Since logistics in a manufacturing serves manufacturing (internal) as well as customers (external), the ILPMS will include internal and external logistics performance measures. In addition, the ILPMS needs to balance the number of financial and non-financial logistics performance measures.

Secondly, the system provides a mechanism to demonstrate the ***causal relationships*** between different perspectives/or objectives and between different performance measures. The information will facilitate decision makers to know which objectives or performance measures should focus on in order to improve logistics performance. On the other hand, Clarified causal relationships will facilitate the integrity of the system.

Thirdly, ***integrity*** requires that the ILPMS is capable of promoting coordination of objects in the system. The ILPMS particularly aims to understand and coordinate the following two types of interrelationships that probably exist in the system:

1) Interrelationships between different stakeholders/or perspectives

Logistics as a business unit in a manufacturing company is influenced by the operation of other business units, such as manufacturing, accounting, human resources etc.. The influences can be expressed by requirements or expectations on logistics operations. These requirements, however, may be contradictory or supplement.

2) Interactions between logistics activity

Measures and metrics in a performance measurement system are not independent since logistics activities are correlated. For example, on time delivery measure can be affected by material handling efficiency. Which performance measures should have more focus than others is the issue to be solved in the system.

Fourthly, ***deployment*** means the ILPMS has a system structure to develop logistics performance measures that reflect logistics strategy and objectives. Decision makers at higher level may have a broader view over the logistics operation than those at lower level. Nevertheless, decision makers at operational level probably have more knowledge and practical experience about logistics activities management than those at higher level. Therefore, it is highly possible that people from different managerial levels have different perspectives over logistics operation objectives. The coordination among these different perspectives will align information provided to information needed and the number of performance measures is under control.

Fifth, ***internal comparability*** is the requirement for non-financial measures. The system is able to answer questions, such as which non-financial measures should pay more attention than others when resources are limited.

Finally, ***usefulness*** means that the ILPMS is readily understandable by the decision makers and is able to provide suggestions for logistics performance improvement.

## 3.2. Logistics Performance Measurement Framework Design

A logistics performance measurement framework not only facilitates the development of logistics measures and metrics, but also ensures that all the logistics measures and metrics are organized in a systematic way. So the performance measurement framework design is set as the first step to establish the ILPMS.

To meet the requirement of deployment, the framework is designed to be hierarchically including four decision levels: strategic level, business unit level, logistics process level and logistics activity level. The hierarchical structure ensures that company's strategic objectives at top level direct and influence logistics strategic objectives. And logistics strategic objectives are reflected by objectives at lower level.

In addition, to fulfil the comprehensiveness requirement, at the business level, all relevant stakeholders (internal and external) are recognized and comprised at business unit level. According to Mendelow (1983), stakeholders are those who depend on the organization to realize their goals, in turn, the organization requires their contributions for the full realization of its goals. The benefit of identifying stakeholders is that each performance measure can be designated to a or a group of stakeholder(s) who has interest in getting information on the performance of logistics or are able to improve logistics performance through their work (Kueng, 2000). The stakeholders can be from external and should be considered (Neely et al., 2005). For instance, the government legislature about emission rules should be considered for measurement, so the government is a stakeholder in the system.

In the framework, a logistics process level is added, which aims to tackle with the integrity requirement. Process-based performance framework can resolve the interactions between performance measures to some extent. When all the interacted logistics activities are organized into one process, the interactions between these performance measures will be well checked and balanced. Since logistics activities belonging to the same process now have a common purpose and share a set of goals (Chan and Qi, 2003). Therefore, the logistics performance measurement framework is a combination of hierarchical and process-based structure.

Figure 1 exemplifies the logistics performance measurement framework designed for measuring logistics operation in a typical manufacturing company. In the framework, the enterprise strategy and objectives are at the top level. At the business unit level, four main business units: human resources, manufacturing, accounting, sales & marketing, plus external environment are identified to have impact on logistics operations. Logistics activities are categorized in four logistics processes: supplying, inbound logistics, warehousing and outbound logistics. Supplying process aims to source raw materials or other resources needed. Inbound logistics realizes the physical movement of raw materials or other resources from supplier’s place to company’s warehouse. And warehousing process is to maintain inventory and prepare finished product for outbound. Outbound logistics helps to physically move finished product from company’s warehouse to customers’ places. According the scope of four processes, logistics activities are clustered under each logistics process.

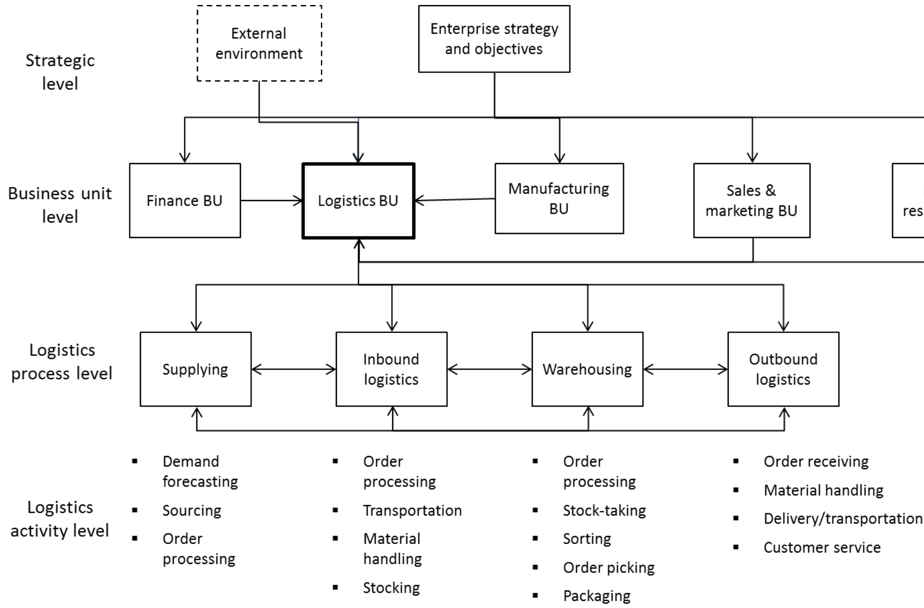


Figure 1 Logistics performance measurement framework

In the framework, strategic objectives influence every business unit in the company, including logistics. The logistics processes' objectives are directly influenced by logistics objectives and indirectly by requirements from other business units. The objectives of each logistics process are then shared with logistics activities clustered in each process.

## 3.3. Logistics Measure and Metric Development

In this section, we will explain how to utilize the performance framework to develop logistics performance measures and metrics. One of the requirements for an ILPMS is usefulness and the performance measures and metrics are crucial to determine whether the ILPMS is useful or not.

Different strategies are adopted to develop logistics performance measures and logistics activity metrics respectively (Table 5).

Table 5  Performance measure and metric development methods

| Decision Making Level | Development Strategy |
|---|---|
| Logistics performance measures | Logistics’ objectives identification |
| Logistics activity metrics | Decomposition |

### 3.3.1 Logistics Performance Measures Development

To develop logistics performance measures, the first step is to identify logistics objectives, which according to Kueng (2000) can be derived mainly from three sources: the enterprise-wide objectives/strategic objectives, the business competitors and the stakeholders.

After the logistics objectives are discussed and confirmed, corresponding performance measure(s) reflecting these objectives can be developed. The criterion to finish the development process is to check whether all defined performance measure(s) are directly or indirectly quantifiable or not (Figure 2). For example, transportation cost is quantifiable, while customer service is not. However, customer service can be measured by customer complaint rate, return rate etc., which is called indirectly quantifiable.

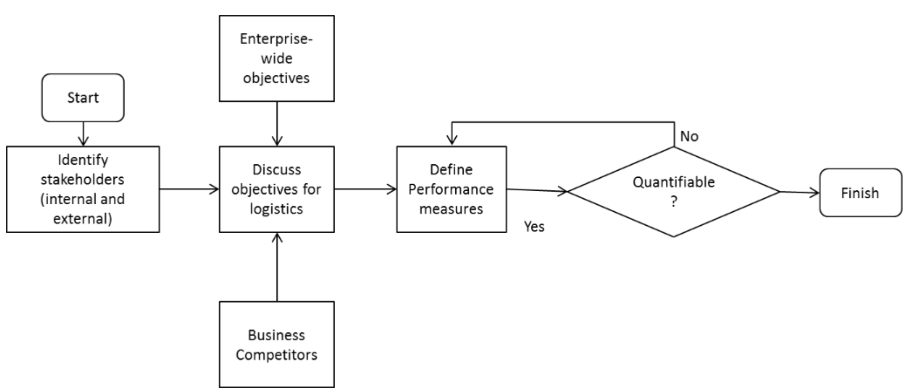


Figure 2  Performance measures development process

Table 6 is an application of the performance measures development processes. In the example, we identified stakeholders at different decision making levels: five business units and four process owners. For each stakeholder, we think about their expectations on logistics operations from eight aspects: ***time, cost, reliability, responsiveness, flexibility, customer service, productivity, asset management/utilization*** (Fawcett and Cooper, 1998; Jothimani and Sarmah, 2014). Here asset could be tangible, like equipment, human resources, inventory, information management system etc., and intangible, such as intellectual property. These eight aspects include financial and non-financial measures. Also it is better to attach performance measure definitions or formula for implementation.

Table 6 Logistic performance measures development process application

| **Decision making level** | **Stakeholders** | **Logistics objectives** | **Performance measures** | **Definition/Formula** |
|---|---|---|---|---|
| **Business unit level** | Financial | 1. Controlled logistics cost<br>2. High asset utilization | 1. Total logistics cost<br>2. Inventory turnover | 1. The total logistics cost occurred at every process<br>2. Cost of goods sold/average inventory |
| | Sales & marketing | High customer service | Complaint rate over a period of time | Complaints received for delivery quality issue over a period of time |
| | Manufacturing | Supplying responsiveness | Lead time for raw material | The time between request for raw material sent and raw material moved at manufacturing cite |
| | Human resources | 1. Low employee safety issue<br>2. High Employee utilization | 1. Accident rate<br>2. Employee utilization | 1. Accident happened within certain period related logistics operations<br>2. Number of hours worked/available working hour |
| | Logistics | Growing investment in logistics | Capital amount invested in logistics annually | Investment in logistics processes |
| | Supplying process | Responsiveness | Supplying lead time | The time between receiving order from warehousing and raw material arrival at warehouse |

| | | | | |
|---|---|---|---|---|
| **Logistics Process level** | Inbound logistics | Moving Efficiency | 1.Transportation efficiency<br>2. Material handling efficiency | 1. Miles per gallon<br>2. Finished moving workload/Designed moving workload |
| | warehousing | 1. Low stock out rate<br>2. High asset Utilization | 1. Stock out rate<br>2. Inventory turnover<br>3. Space utilization | 1. Stock out happened times over a period of time<br>2. Cost of goods sold/average inventory<br>3. Space utilized/space available |
| | Outbound logistics | 1. High customer service<br>2. High logistics delivery quality<br>3. Short lead time | 1. Order fulfill rate<br>2. Delivery flexibility<br>3. Delivery lead time | 1. Order completed/order enter in the system within a certain time<br>2. The ability of the service systems to meet particular customer needs (Special customer orders/total orders within a certain time<br>3. The time between customer placing an order and receiving the order |

### 3.3.2 Logistics Activity Metrics Development

The method to develop logistics activity metrics is called decomposition. The process is simple and straightforward. Logistics measures from business unit level that cover multiple processes need to be decomposed to logistics process measures, for instance total logistics cost. Then logistics process measures, including those derived from business unit level are further decomposed into logistics activity metrics. For instance, total logistics cost is decomposed into supplying cost, inbound logistics cost, warehousing cost and outbound logistics cost which are logistics process measures. Then each process cost is further decomposed to detailed logistics activity cost. For example, supplying cost is divided into order processing cost and sourcing cost. Refer to Table 7 for a complete list of logistics metrics of the example.

Table 7 Logistics activity metrics development process

| Logistics process | Performance aspects | Logistics metrics |
|---|---|---|
| **Supplying** | Supplying cost | order processing cost |
| | | sourcing cost |
| | Supplying time | average lead time for order processing |
| | | average lead time for sourcing |
| | Supplying asset management | supplying employee utilization |
| | | capital investment in information system |
| **Inbound logistics** | Inbound cost | shipping cost |
| | | material handling cost |
| | Inbound lead time | average lead time for shipping |
| | | average lead time for material handling |
| | | average order processing |
| | Inbound productivity | transportation efficiency |
| | | material handling efficiency |
| | Inbound asset management | capital investment in human resources and equipment |
| | | inbound employee utilization |
| | | inbound employee accident rate |
| **Warehousing** | Warehousing cost | stock keeping cost |
| | | sorting cost |
| | | order picking cost |
| | | packaging cost |
| | Warehousing reliability | stock out rate |
| | | stocking accuracy |
| | Warehousing asset utilization/ management | space utilization |
| | | warehousing employee utilization |
| | | inventory turnover |
| | | warehousing employee accident rate |
| | | capital investment in facility |
| | | warehousing accident rate |
| **Outbound logistics** | Customer service | customer complaint rate |
| | Outbound asset utilization/ management | outbound accident rate |
| | | employee utilization |
| | | capital investment in transportation vehicles |

| | | |
|---|---|---|
| | Outbound productivity | order fulfil rate |
| | Delivery flexibility | delivery flexibility |
| | Outbound lead time | average delivery lead time |
| | | average order processing time |
| | | average material handling time |

## 3.4. Multi-criteria Decision Making (MCDM) Methodologies

From the example presented above, one may be impressed by the quantity of measures and metrics. However, in the real case, the quantity is most likely larger than the example. Given limited energy and resources for performance measurement, it is imperative to identify measures or metrics that are paramount or the most beneficial to invest more resources. On the other hand, a performance measurement system should be able to suggest where and how to improve operations for managerial purposes, besides provide feedback about current logistics performance. The objective of this section is to select a MCDM methodology in order to accomplish two goals at once.

In the literature review section, quite a few multi-criteria decision making (MCDM) methodologies were discussed, such as Analytical Hierarchy Process, Data Envelop Analysis etc.. Some of them are able to prioritize performance measures by assigning weights. And some of them can categorize performance measures based on different rules. Table 8 compares the discussed some common methodologies with respect to their abilities.

Table 8 Ability comparison among MCDM methodologies

| Ability Comparison | AHP/Fuzzy AHP | ANP/Fuzzy ANP | DEA | DEMATEL | TOPSIS |
|---|---|---|---|---|---|
| **Evaluate interdependencies between performance measures at the same or different decision levels** | × | √ | × | √ | × |
| **Evaluate and formulate intertwined cause and effect relationships** | × | × | × | √ | × |
| **Without pair-wise comparisons** | × | × | √ | × | √ |

The ability to evaluate interdependencies between performance measures is advantageous to solve interactions between performance measures; while distinguishing cause and effect measures can facilitate decision makers' ability to understand which performance measures are critical for logistics performance improvement. From Table **8**, we observe that there is no single MCDM methodology which can solve the two issues at the same time. Therefore, in order to fulfil the two requirements, we explore a hybrid MCDM methodology, the integration of Analytical Network Process (ANP) and The Decision Making Trial and Evaluation Laboratory (DEMATEL). ANP is able to deal with the interdependencies between criteria by assigning relative weights. While DEMATEL is capable of exploring casual relationships among the criteria by dividing critical measures into cause and effect group and visualizing the causal relationships through network relationship map (NRM). The integration of DEMATEL and ANP can perfectly tackle the two issues at the same time. The outputs of this methodology are the degrees of dependencies between performance measures.

The integration of the two multi-criteria decision making technologies, DEMATEL and ANP, can complement each other. First of all, in the traditional ANP, the level of interdependencies between criteria is treated as reciprocal values, which is not always the case in the real world. DEMATEL, on the contrary, treats level of interdependencies individually. Secondly, DEMATEL is used to examine the causal relationships between performance groups and between performance aspects within each group. On the other word, DEMATEL is difficult to estimate interdependencies between performance measures crossing clusters. The ANP is able to consider interactions within clusters (inner dependence) and between clusters (outer dependence) (Gölcük and Baykasoglu, 2016). Thirdly, ANP requires too many pairwise comparisons which might be time consuming and difficult to obtain. Also for particular situations, pairwise comparison in the same cluster might be meaningless or difficult to interpret. DEMATEL can help to estimate interdependencies between criteria in the same cluster. What's more, though DEMATEL is a useful method for analyzing cause-effect relationships. It is not able to determine the weights of individual criteria, where ANP can make effects.

Even though the methodology of integrating of ANP and DEMATEL has been applied before, such as health care (Supeekit et al., 2016), energy resources (Büyüközkan and Güleryüz, 2016), to our knowledge, there is no application of this methodology in logistics to manage logistics performance measures.

In the following sections, the procedure to apply the methodology is described and an example to apply the methodology is demonstrated.

### 3.4.1 Methodology Description

The methodology is implemented by four main steps:

Step 1: Define clusters and performance measures/criteria in each cluster;

Step 2: DEMATEL processes; (Büyüközkan, and Güleryüz (2016)

Step 3: ANP processes; (Satty, 1996)

Step 4: Combination and result analysis (Supeekit et al., 2016)

**Step 1: Define clusters and performance measures and metrics**

Define clusters based on the developed logistics performance measurement framework and design logistics performance measure and metrics by applying the logistics performance measures and metrics development strategies.

**Step 2: DEMATEL Processes**

The DEMATEL process is to deal with interactions between performance measures/metric within each cluster (inner dependency). The outputs are inner dependence matrices of clusters and performance measures/criteria.

**Step 2.1: Build the initial direct-relation (Average) matrix**

Assume there are H experts and n factors (performance measures/criteria) to be considered. Each expert answers the certain questions to illustrate the degree of a criterion i effecting criterion j due to her or his beliefs. Four scales are used to determine the values of relationships between different factors:

0 = no influence

1 = low influence

2 = high influence

3 = very high influence

For now $x_{ij}$ denotes pair wise comparisons between any two criteria, which is assigned integer score ranging from 0, 1, 2, 3. Each expert gives their score $X^1$ $X^2$ …$X^H$ and form the n × n non-negative matrix $X^k = \left[x_{ij}^k\right]_{n\times n}$, where $1 \leq k \leq H$. Then calculate the n × n average matrix A on account of all expert's opinions by averaging their scores as given in Eq. 1.

$$\left[a_{ij}\right]_{n\times n} = \frac{1}{H}\sum_k^H \left[x_{ij}^k\right]_{n\times n} \quad (1)$$

The average matrix $\left[a_{ij}\right]_{n\times n}$ is called the initial direct-influenced matrix which indicates the initial direct effects each criterion exerts on and receives from other criteria.

**Step 2.2: Normalize the initial direct-relation matrix**

Normalized initial direct relation matrix D is obtained by normalizing the average matrix A as in Eq. 2 and Eq.3.

$$s = max\{max_{1\leq i\leq n}\sum_{j=1}^n a_{ij}, max_{1\leq j\leq n}\sum_{i=1}^n a_{ij}\} \quad (2)$$

$$D = \frac{A}{S} \quad (3)$$

$max_{1\leq i\leq n}\sum_{j=1}^n a_{ij}$ represents the total direct effects that criterion j receives the most direct effects from other criteria, while $max_{1\leq j\leq n}\sum_{i=1}^n a_{ij}$ represents the most total direct effect of criterion j exerting on other criteria. The positive numerical s takes the bigger of the two and the matrix D is obtained by dividing each element of A by the scalar s. Each element $d_{ij}$ of matrix D should be between zero and1, $0 \leq d_{ij} \leq 1$.

**Step 2.3: Calculate the total-relation matrix**

A continuous reducing of the indirect effects of problems by raising the powers of matrix D guarantees convergent solutions to the matrix inversion (Falatoonitoosi et al., 2013). The total-relation matrix $T_{n\times n}$ is obtained as in Eq.4.

$T = \sum_{m=1}^{\infty} D_i = D + D^2 + D^3 \dots D^m$

$= \mathrm{D}(\mathrm{I} + D +^2 + D^3 + D^{m-1})$

$= \mathrm{D}(1 - D)^{-1}(\mathrm{I} - \mathrm{D})(\mathrm{I} + D +^2 + D^3 + D^{m-1})$

$= \mathrm{D}(1 - D)^{-1}(I - D^m) = D(I - D)^{-1}$ (4)

*I: Identity matrix

*$t_{ij}$ denotes influence of criterion i on criterion j in the total relation matrix T.

**Step 2.4: Calculate cause and effect group**

The sum of rows and sum of columns of the total relation matrix T are computed as an **r and c** n vectors respectively.

$[r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}$ (5)

$[c_j]_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)_{1\times n}$ (6)

$[r_i]_{n\times 1}$ demonstrates the total effects, both direct and indirect, given by criterion i to the other criteria j = 1, 2, ... , n, similarity $[c_j]_{1\times n}$ represents total effects, direct and indirect, received by criterion j from the other criteria i = 1, 2, ...,n. As a result, while i = j the sum ($r_i$ + $c_i$) is called "Prominence'' denoting the degree of importance of criterion i in system. It also gives an index that shows the total effects both given and received by criterion i. Likewise, the (ri-ci) called "Relation" shows the net effect that criterion i denotes to the system. When (ri-ci) is positive, criterion i will be assigned to the cause group since it gives more effect than receives. When (ri-ci) is negative, criterion i is identified as criteria in the effect group because it receives effect more than gives. The causal relationship can be represented by network relationship (NRM) which is drawn by plotting dataset of the (ri + ci, ri-ci) in a coordinate axis where ri + ci is the horizontal axis, and ri-ci is the vertical axis.

**Step 2.5 (Optional): Set a threshold value and construct the network relationship map (NRM)**

It is, sometimes, necessary to set a threshold value p to filter out some negligible effects in matrix T in order to explain the structural relation among the criteria and keep the complexity of the system to a manageable level (Yang and Tzeng, 2011). There are many ways to obtain the p value in the papers. The most common way to obtain p value is through discussion with experts to make a choice. Li and Tzeng (2009) use the maximum mean de-entropy algorithm to set a threshold. Pai (2014) use arithmetic mean of effects for convenience.

Criteria, whose effect in matrix T is greater than the threshold value, are chosen and shown in a network relationship map (NRM) for effect analysis. The NRM is useful for ANP phase, owing to its indication of the outer dependencies between clusters.

**Step 2.6 Normalize total relationship matrix to form inner dependency matrix**

Assume that the total relationship matrix T is obtained from DEMATEL method as given in Eq. 7.

$$\mathrm{T} = \begin{bmatrix} t_{11} \cdots & t_{1j} \cdots & t_{1n} \\ \vdots & \vdots & \vdots \\ t_{i1} \cdots & t_{ij} \cdots & t_{in} \\ \vdots & \vdots & \vdots \\ t_{n1} \cdots & t_{nj} \cdots & t_{nn} \end{bmatrix} \tag{7}$$

$t_{ij}$ represents the degree of influence that the criterion i exerts on the criterion j. To be analyzed in supermatrix, it should be first normalized and then transposed. For normalization, the row sums are calculated as given in Eq. 8.

$$d_i = \sum_{j=1}^{n} t_{ij} \tag{8}$$

Each entry of the total relation matrix T is divided by the corresponding row sums as given in Eq. 9

$$T^{\alpha} = \begin{bmatrix} t_{11}/d_1 \cdots & t_{1j}/d_1 \cdots & t_{1n}/d_1 \\ \vdots & \vdots & \vdots \\ t_{i1}/d_i \cdots & t_{ij}/d_i \cdots & t_{in}/d_i \\ \vdots & \vdots & \vdots \\ t_{n1}/d_n \cdots & t_{nj}/d_n \cdots & t_{nn}/d_n \end{bmatrix}$$

$$= \begin{bmatrix} t_{11}^{\alpha} \cdots & t_{1j}^{\alpha} \cdots & t_{1n}^{\alpha} \\ \vdots & \vdots & \vdots \\ t_{i1}^{\alpha} \cdots & t_{ij}^{\alpha} \cdots & t_{in}^{\alpha} \\ \vdots & \vdots & \vdots \\ t_{n1}^{\alpha} \cdots & t_{nj}^{\alpha} \cdots & t_{nn}^{\alpha} \end{bmatrix} \tag{9}$$

Finally, transpose of the $T^{\alpha}$is seen in Eq. 10

$$(T^{\alpha})' = \begin{bmatrix} t_{11}^{\alpha} \cdots & t_{i1}^{\alpha} \cdots & t_{n1}^{\alpha} \\ \vdots & \vdots & \vdots \\ t_{1j}^{\alpha} \cdots & t_{ij}^{\alpha} \cdots & t_{nj}^{\alpha} \\ \vdots & \vdots & \vdots \\ t_{1n}^{\alpha} \cdots & t_{in}^{\alpha} \cdots & t_{nn}^{\alpha} \end{bmatrix} \tag{10}$$

Once $(T^{\alpha})'$ is obtained, it is eligible be put into the appropriate place in supermatrix.

**Step 3: ANP Processes**

**Step 3.1: Establish pair-wise comparison matrices**

For the pair-wise comparisons, the 9-point priority measurement scale by Saaty (1980) is used. A decision maker can declare the relative dominance between each pair of elements verbally as: equally important, moderately more important, strongly more important, very strongly more important, and extremely more important. These judgments can be translated into numerical values of 1, 3, 5, 7, and 9 respectively. Values of 2, 4, 6 and 8 are intermediate values for comparisons between two successive points. Reciprocals of these values are used for the corresponding transpose judgments. **Note** that only outer dependencies are considered in ANP procedure. For instance, there are two clusters: cluster 1 is named costs, and cluster 2 is named ergonomics. The one criterion in cluster 1 is purchasing cost and there are two criteria in cluster 2, which are appearance, durability. To construct pairwise comparisons for outer dependency, decision makers are asked the question: for the criterion of purchasing cost, how much more important the criteria of appearance than durability.

**Step 3.2: Calculate the eigenvalues and eigenvectors of the comparison matrix to obtain relative weights**

Assume there are n criteria ($C_1$, $C_2$, … Cn) and the pair-wise comparison matrix $A=a_{ij}$, where $a_{ij}$ stands for the relative importance of criteria $C_i$ over $C_j$. For all i and j, it is necessary that $a_{ii}=1$ and $a_{ij} = 1/a_{ij}$. The row vector average method, introduced by Saaty, is used to normalize the results, and the approximate weight $W_i$ is calculated in Eq. 11.

$$W_i = \frac{\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)}{n}, \forall \text{ i, j} = 1, 2, \ldots\text{n} \tag{11}$$

The comparison matrix A completely responds to $a_{ik}=a_{ij}.a_{jk}$ ∀ I, j, k. The Eq. 12 is applied to obtain the approximate value of the largest eigenvalue $\lambda_{max}$.

$$\text{AW} = \lambda\text{W}$$

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \tag{12}$$

**Step 3.3: Check consistency of the matrix**

The consistency index (C.I) and consistency ratio (C.R) are used to estimate the consistency of the pair-wise comparisons via Eq. (13) and (14).

$$\text{C.I} = \frac{\lambda_{max}-n}{n-1} \tag{13}$$

*n is the number of factors in the matrix

$$\text{C.R} = \frac{C.I}{R.I} \tag{14}$$

R.I is the average index for randomly generated weights. Its value is obtained according to the number of levels in the hierarchy (Table 9). A matrix with C.R value less than or equal to 0.1 is believed to be consistent.

Table 9 Random Index (R.I)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| **0.00** | 0.00 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

**Step 4: Integration**

The integration section aims to integrate inner dependency and outer dependency matrices and obtain relative weights for all measures.

**Step 4.1: Form the unweighted supermatrix**

The unweight matrix is formed by inner dependency matrices from DEMATEL procedure and outer dependency matrices from ANP procedure.

**Step 4.2: Calculate the weighted supermatrix**

The unweighted supermatrix from step1 assumes the same weight for all clusters, which is not always the real case. The weight supermatrix considers the different weights for clusters by combing the inner dependency matrix for clusters. The weighted supermatrix can be obtained in Eq.15.

$$W_w = \begin{bmatrix} t_{11}^{\alpha} \times W_{11} \cdots & t_{i1}^{\alpha} \times W_{12} \cdots & t_{n1}^{\alpha} \times W_{1n} \\ \vdots & \vdots & \vdots \\ t_{1j}^{\alpha} \times W_{i1} \cdots & t_{ij}^{\alpha} \times W_{ij} \cdots & t_{nj}^{\alpha} \times W_{in} \\ \vdots & \vdots & \vdots \\ t_{1n}^{\alpha} \times W_{n1} \cdots & t_{in}^{\alpha} \times W_{nj} \cdots & t_{nn}^{\alpha} \times W_{nn} \end{bmatrix} \quad (15)$$

**Step 4.3: Limit the weighted supermatrix**

Limit the weighted supermatrix by raising it to a sufficiently large power k in Eq. 16, until the supermatrix has converged and become a long-term stable supermatrix to get the global priority vectors.

$$\lim_{k \to \infty} W_w^k \tag{16}$$

The whole procedure of the ILPMS implementation is illustrated in Figure 3.

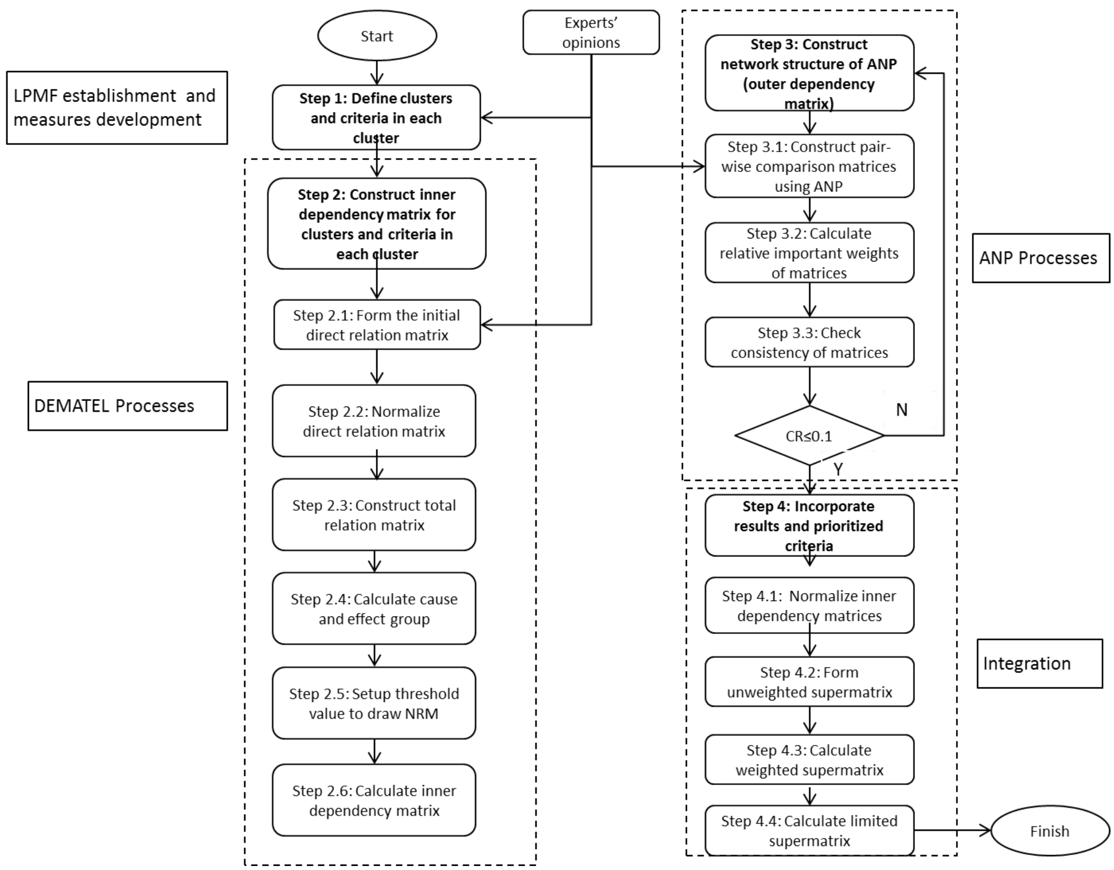


Figure 3 The hybrid MCDM Methodology implementation procedure

### 3.4.2 Example

The example is provided to show how to apply the hybrid MCDM methodology.

Step1: Define clusters and performance measures

The performance measurement framework adopts the balanced scorecard (BSC) which includes four perspectives/clusters: financial perspective, customer perspective, learning and growth perspective, internal perspective. Based on BSC model for supply chain performance measurement, four classes of criteria are developed (Amiri et al., 2011) (Table 10).

Table 10 Performance measures for the example

| **BSC perspectives** | **Performance measures** |
|---|---|
| Financial | Profitability<br>Delivery cost<br>Investment in chain |
| Customer | Customer satisfaction<br>Sales volume<br>Reach new customer |
| Learning & growth | Innovation<br>Logistics information system<br>Skilled worker |
| Internal | Equipment<br>Quality improvement<br>On time delivery |

**Step 2: DEMATEL Processes**

**Step 2.1: Build the direct-relation (Average) matrix**

Table 11 Initial direct relation matrix for the four perspectives

| | Financial | Customer | Learning& growth | Internal |
|---|---|---|---|---|
| Financial | 0 | 2 | 2 | 2 |
| Customer | 3 | 0 | 1 | 1 |
| Learning & growth | 2 | 3 | 0 | 2 |
| Internal | 3 | 2 | 2 | 0 |

**Step 2.2: Normalize the initial direct-relation matrix**

Table 12 The normalized direct relation matrix for the four perspectives

| | Financial | Customer | Learning & growth | Internal |
|---|---|---|---|---|
| Financial | 0.000 | 0.25 | 0.25 | 0.25 |
| Customer | 0.375 | 0.000 | 0.125 | 0.125 |
| Learning & growth | 0.25 | 0.375 | 0.000 | 0.25 |
| Internal | 0.375 | 0.25 | 0.25 | 0.000 |

**Step 2.3: Calculate the total-relation matrix**

Table 13 The total relation matrix for the four perspectives

| | Financial | Customer | Learning& growth | Internal | $r_i$ | $c_i$ | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|---|
| Financial | 0.830 | 0.936 | 0.766 | 0.766 | 3.298 | 4.149 | 7.447 | -0.851 |
| Customer | 0.979 | 0.617 | 0.596 | 0.596 | 2.787 | 3.681 | 6.468 | -0.894 |
| Learning & growth | 1.128 | 1.098 | 0.626 | 0.826 | 3.677 | 2.830 | 6.506 | 0.847 |
| Internal | 1.213 | 1.030 | 0.843 | 0.643 | 3.728 | 2.830 | 6.557 | 0.898 |

**Step 2.4 Calculate the cause and effec group**

Based on the calculation in Table 13, the financial perspective has the highest prominence, meaning that financial perspective has the most attention in the performance system. In addition, learning & growth perspective and internal perspective belong to cause group and customer perspective and financial perspective is in effect group. Therefore, if the company wishes to reach a high level of performance in terms of the effect group strategies, it must first control and pay much attention to the cause group criteria, namely learning & growth and Internal perspective. Draw the network relationship map for the four clusters based on the total relation matrix (Figure 4).

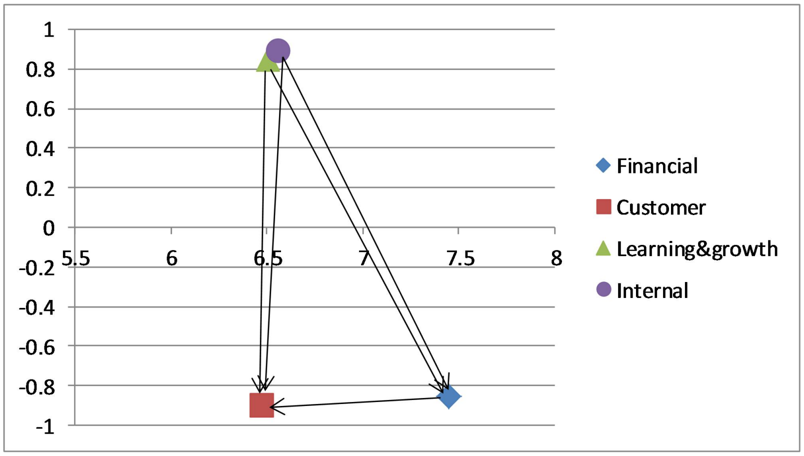


Figure 4 The network relationship map of the four perspectives

The same procedure is implemented repeatedly for criteria under each perspective. The following tables demonstrate the initial direct relation matrix, total relation matrix for performance measures in each perspective respectively.

Table 14 Initial direct relation matrix for measures in financial perspectives

| | Profit | Delivery cost | Investment |
|---|---|---|---|
| Profit | 0 | 0 | 2 |
| Delivery cost | 2 | 0 | 1 |
| Investment | 1 | 2 | 0 |

Table 15 The total relation matrix for measures in financial perspective

| | **Profit** | **Delivery cost** | **Investment** | **$r_i$** | **$c_i$** | **$r_i+c_i$** | **$r_i-c_i$** |
|---|---|---|---|---|---|---|---|
| **Profit** | 0.713 | 0.430 | 1.285 | 2.426 | 3.783 | 6.209 | -1.357 |
| **Delivery cost** | 1.499 | 0.499 | 1.450 | 3.498 | 2.070 | 5.567 | 3.498 |
| **Investment** | 1.571 | 1.142 | 1.428 | 4.141 | 4.212 | 8.353 | 4.141 |

Table 16 Initial direct relation matrix for customer perspectives

| | Customer satisfaction | Sales volume | New customer |
|---|---|---|---|
| Customer satisfaction | 0 | 3 | 2 |
| Sales volume | 0 | 0 | 0 |
| New customer | 0 | 2 | 0 |

Table 17 The total relation matrix for customer perspective

| | **Customer satisfaction** | **Sales volume** | **New customer** | $r_i$ | $c_i$ | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|
| **Customer satisfaction** | 0 | 0.76 | 0.4 | 1.16 | 0 | 1.16 | 1.16 |
| **Sales** | 0 | 0 | 0 | 0 | 1.16 | 1.16 | -1.16 |
| **New customer** | 0 | 0.4 | 0 | 0.4 | 0.4 | 0.8 | 0 |

Table 18 Initial direct relation matrix for learning and growth perspectives

| | Innovation | Logistics info system | Skilled worker |
|---|---|---|---|
| Innovation | 0 | 0 | 1 |
| Logistics Info system | 0 | 0 | 1 |
| Skilled worker | 3 | 2 | 0 |

Table 19 The total relation matrix for learning and growth perspective

| | Innovation | Logistics info system | Skilled worker | $r_i$ | $c_i$ | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|
| Innovation | 0.75 | 0.5 | 0.75 | 2 | 3.75 | 5.75 | -1.75 |
| Logistics Info system | 0.75 | 0.5 | 0.75 | 2 | 2.5 | 4.5 | -0.5 |
| Skilled worker | 2.25 | 1.5 | 1.25 | 5 | 2.75 | 7.75 | 2.25 |

Table 20 Initial direct relation matrix for internal perspectives

| | **Equipment** | **Quality improvement** | **On time delivery** |
|---|---|---|---|
| **Equipment** | 0 | 2 | 2 |
| **Quality improvement** | 0 | 0 | 0 |
| **On time delivery** | 0 | 2 | 0 |

Table 21 The total relation matrix for internal perspective

| | Equipment | Quality improvement | On time delivery | $r_i$ | $c_i$ | $r_i + c_i$ | $r_i - c_i$ |
|---|---|---|---|---|---|---|---|
| Equipment | 0 | 0.75 | 0.5 | 1.25 | 0 | 1.25 | 1.25 |
| Quality improvement | 0 | 0 | 0 | 0 | 1.25 | 1.25 | 1.25 |
| On time delivery | 0 | 0.5 | 0 | 0.5 | 0.5 | 1 | 0 |

### Step 2.6 Calculate inner dependency matrix

The following tables demonstrate inner dependency matrices for the four clusters and performance measures in each perspective respectively based on the normalization method.

Table 22 Inner dependency matrix for the four clusters

| | **Financial** | **Customer** | **Learning& growth** | **Internal** |
|---|---|---|---|---|
| **Financial** | 0.252 | 0.351 | 0.307 | 0.325 |
| **Customer** | 0.284 | 0.221 | 0.299 | 0.276 |
| **Learning& growth** | 0.232 | 0.214 | 0.17 | 0.226 |
| **Internal** | 0.232 | 0.214 | 0.225 | 0.172 |

Table 23 Inner dependency matrix for measures in financial perspective

| | **Profit** | **Delivery cost** | **Investment** |
|---|---|---|---|
| **Profit** | 0.293 | 0.429 | 0.379 |
| **Delivery cost** | 0.176 | 0.143 | 0.276 |
| **Investment** | 0.527 | 0.429 | 0.345 |

Table 24 Inner dependency matrix for measures in customer perspective

| | **Customer satisfaction** | **Sales volume** | **New customer** |
|---|---|---|---|
| **Customer satisfaction** | 0 | 0 | 0 |
| **Sales volume** | 0.655 | 0 | 1 |
| **New customer** | 0.345 | 0 | 0 |

Table 25 Inner dependency matrix for measures in learning and growth perspective

| | **Innovation** | **Logistics info system** | **Skilled worker** |
|---|---|---|---|
| **Innovation** | 0.375 | 0.375 | 0.45 |
| **Logistics Info system** | 0.25 | 0.25 | 0.3 |
| **Skilled worker** | 0.375 | 0.375 | 0.25 |

Table 26 Inner dependency matrix for measures in internal perspective

| | **Equipment** | **Quality improvement** | **On - time delivery** |
|---|---|---|---|
| **Equipment** | 0 | 0 | 0 |
| **Quality improvement** | 0.6 | 0 | 1 |
| **On time delivery** | 0.4 | 0 | 0 |

**Step 3: ANP Processes**

**Step 3.1: Establish pair-wise comparison matrices**

The NRM suggests that all four clusters have outer dependencies with other clusters. To conduct pairwise comparisons for modelling outer dependency, decision makers are asked questions, for example, with respect to profitability, how much more important is the criterion of customer satisfaction than sales volume. Table 27 is a pair-wise comparison matrix within customer perspectives with respect to profitability.

Table 27 Weights of measures within customer perspective w.r.t profitability

| | Customer | Sales volume | New customer |
|---|---|---|---|
| Customer | 1 | 5 | 3 |
| Sales volume | 1/5 | 1 | 1/2 |
| New customer | 1/3 | 2 | 1 |

**Step 3.2 – 3.3: Calculate the eigenvalues and eigenvectors of the comparison matrix to obtain relative weights**

The ANP processes are completed in the software named *SuperDecisions* which helps to figure out relative weights between criteria and also compute matrix consistency at the same time.

**Step 4: Integration**

**Step 4.1:** Incorporate inner **dependency matrices and outer dependency matrices to form the unweighted supermatrix (Table 28)**

Table 28 Unweighted supermatrix

| | Delivery cost | Investment in chain | Profitability | Customer satisfaction | Reach new customer | Sales volume | Innovation | Logistics info system | Skilled worker | Equipment | On time delivery | Quality improvement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delivery cost | 0.143 | 0.276 | 0.176 | 0.263 | 0.570 | 0.691 | 0.167 | 0.683 | 0.474 | 0.625 | 0.280 | 0.100 |
| Investment in chain | 0.429 | 0.345 | 0.527 | 0.659 | 0.333 | 0.149 | 0.667 | 0.117 | 0.149 | 0.137 | 0.627 | 0.433 |
| Profitability | 0.429 | 0.379 | 0.293 | 0.079 | 0.097 | 0.160 | 0.167 | 0.200 | 0.376 | 0.238 | 0.094 | 0.466 |
| Customer satisfaction | 0.625 | 0.627 | 0.729 | 0.000 | 0.000 | 0.000 | 0.558 | 0.625 | 0.674 | 0.333 | 0.333 | 0.614 |
| Reach new customer | 0.137 | 0.280 | 0.163 | 0.345 | 0.000 | 0.000 | 0.320 | 0.137 | 0.226 | 0.333 | 0.333 | 0.117 |
| Sales volume | 0.238 | 0.094 | 0.109 | 0.655 | 1.000 | 0.000 | 0.122 | 0.238 | 0.101 | 0.333 | 0.333 | 0.268 |
| Innovation | 0.100 | 0.117 | 0.280 | 0.571 | 0.614 | 0.122 | 0.375 | 0.375 | 0.450 | 0.122 | 0.097 | 0.625 |
| Logistics info system | 0.433 | 0.268 | 0.094 | 0.143 | 0.117 | 0.558 | 0.250 | 0.250 | 0.300 | 0.320 | 0.333 | 0.137 |
| Skilled worker | 0.466 | 0.614 | 0.627 | 0.286 | 0.268 | 0.320 | 0.375 | 0.375 | 0.250 | 0.558 | 0.570 | 0.238 |
| Equipment | 0.333 | 0.320 | 0.122 | 0.117 | 0.082 | 0.117 | 0.094 | 0.117 | 0.000 | 0.000 | 0.000 | 0.000 |
| On time delivery | 0.570 | 0.122 | 0.320 | 0.614 | 0.550 | 0.268 | 0.280 | 0.268 | 0.200 | 0.400 | 0.000 | 0.000 |
| Quality improvement | 0.097 | 0.558 | 0.558 | 0.268 | 0.368 | 0.614 | 0.627 | 0.614 | 0.117 | 0.600 | 1.000 | 0.000 |

**Step 4.2: Multiply unweighted supermatrix by cluster weights to form weighted supermatrix (Table 29)**

Table 29 Weighted supermatrix

| | Delivery cost | Investment in chain | Profitability | Customer satisfaction | Reach new customer | Sales volume | Innovation | Logistics info system | Skilled worker | Equipment | On time delivery | Quality improvement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delivery cost | 0.036 | 0.070 | 0.044 | 0.092 | 0.200 | 0.242 | 0.051 | 0.210 | 0.146 | 0.203 | 0.091 | 0.033 |
| Investment in chain | 0.108 | 0.087 | 0.133 | 0.231 | 0.117 | 0.052 | 0.205 | 0.036 | 0.046 | 0.044 | 0.204 | 0.141 |
| Profitability | 0.108 | 0.096 | 0.074 | 0.028 | 0.034 | 0.056 | 0.051 | 0.061 | 0.116 | 0.078 | 0.030 | 0.152 |
| Customer satisfaction | 0.178 | 0.178 | 0.207 | 0.000 | 0.000 | 0.000 | 0.167 | 0.187 | 0.201 | 0.092 | 0.092 | 0.170 |
| Reach new customer | 0.039 | 0.079 | 0.046 | 0.076 | 0.000 | 0.000 | 0.096 | 0.041 | 0.067 | 0.092 | 0.092 | 0.032 |
| Sales volume | 0.068 | 0.027 | 0.031 | 0.145 | 0.221 | 0.000 | 0.036 | 0.071 | 0.030 | 0.092 | 0.092 | 0.074 |
| Innovation | 0.023 | 0.027 | 0.065 | 0.122 | 0.131 | 0.026 | 0.064 | 0.064 | 0.077 | 0.028 | 0.022 | 0.141 |
| Logistics info system | 0.100 | 0.062 | 0.022 | 0.031 | 0.025 | 0.120 | 0.043 | 0.043 | 0.051 | 0.072 | 0.075 | 0.031 |
| Skilled worker | 0.108 | 0.143 | 0.145 | 0.061 | 0.057 | 0.068 | 0.064 | 0.064 | 0.043 | 0.126 | 0.129 | 0.054 |
| Equipment | 0.077 | 0.074 | 0.028 | 0.025 | 0.018 | 0.025 | 0.021 | 0.026 | 0.000 | 0.000 | 0.000 | 0.000 |
| On time delivery | 0.132 | 0.028 | 0.074 | 0.131 | 0.118 | 0.057 | 0.063 | 0.060 | 0.045 | 0.069 | 0.000 | 0.000 |
| Quality improvement | 0.023 | 0.130 | 0.130 | 0.057 | 0.079 | 0.131 | 0.141 | 0.138 | 0.026 | 0.103 | 0.172 | 0.000 |

**Step 4.3: Limit weighted supermatrix to form the stable weighted supermatrix (Table** 30**)**

Table 30 The stable weighted supermatrix

| | Delivery cost | Investment in chain | Profitability | Customer satisfaction | Reach new customer | Sales volume | Innovation | Logistics info system | Skilled worker | Equipment | On time delivery | Quality improvement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delivery cost | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0020 | 0.0025 | 0.0025 | 0.0022 | 0.0025 | 0.0025 | 0.0021 |
| Investment in chain | 0.0030 | 0.0030 | 0.0030 | 0.0030 | 0.0029 | 0.0024 | 0.0030 | 0.0030 | 0.0026 | 0.0030 | 0.0029 | 0.0025 |
| Profitability | 0.0019 | 0.0018 | 0.0018 | 0.0018 | 0.0018 | 0.0015 | 0.0019 | 0.0018 | 0.0016 | 0.0018 | 0.0018 | 0.0016 |
| Customer satisfaction | 0.0031 | 0.0030 | 0.0030 | 0.0030 | 0.0030 | 0.0024 | 0.0031 | 0.0030 | 0.0026 | 0.0030 | 0.0030 | 0.0026 |
| Reach new customer | 0.0014 | 0.0014 | 0.0013 | 0.0013 | 0.0013 | 0.0011 | 0.0014 | 0.0014 | 0.0012 | 0.0013 | 0.0013 | 0.0011 |
| Sales volume | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0014 | 0.0017 | 0.0017 | 0.0015 | 0.0017 | 0.0017 | 0.0014 |
| Innovation | 0.0017 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0013 | 0.0016 | 0.0016 | 0.0014 | 0.0016 | 0.0016 | 0.0014 |
| Logistics info system | 0.0014 | 0.0013 | 0.0013 | 0.0013 | 0.0013 | 0.0011 | 0.0014 | 0.0014 | 0.0012 | 0.0013 | 0.0013 | 0.0011 |
| Skilled worker | 0.0022 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0017 | 0.0022 | 0.0021 | 0.0019 | 0.0021 | 0.0021 | 0.0018 |
| Equipment | 0.0007 | 0.0007 | 0.0007 | 0.0007 | 0.0007 | 0.0006 | 0.0007 | 0.0007 | 0.0006 | 0.0007 | 0.0007 | 0.0006 |
| On time delivery | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0016 | 0.0013 | 0.0016 | 0.0016 | 0.0014 | 0.0016 | 0.0016 | 0.0014 |
| Quality improvement | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0017 | 0.0021 | 0.0021 | 0.0018 | 0.0021 | 0.0021 | 0.0018 |

The weights of performance measures showing in the second column in Table 30 are further normalized to obtain global relative weights (Table 31).The importance of performance measures is ranked based on their values of relative weights.

Table 31 Relative weights for performance measures

| **Performance perspectives** | **Relative weight of performance perspectives** | **Performance measures** | **Relative weight** | **Rank of importance** |
|---|---|---|---|---|
| **Financial** | 0.523 | Profitability | 0.107 | 1 |
| | | Delivery cost | 0.129 | 4 |
| | | Investment in chain | 0.082 | 6 |
| **Customer** | 0.362 | Customer satisfaction | 0.133 | 8 |
| | | Sales volume | 0.06 | 11 |
| | | Reach new customer | 0.073 | 2 |
| **Learning & growth** | 0.037 | Innovation | 0.073 | 5 |
| | | Logistics information system | 0.06 | 7 |
| | | Skilled worker | 0.094 | 9 |
| **Internal** | 0.076 | Equipment | 0.031 | 10 |
| | | Quality improvement | 0.069 | 12 |
| | | On time delivery | 0.09 | 3 |

Based on inner dependency matrices and the results in Table 31, we can make some analysis for managerial purposes (Table 32). First of all, performance measures are grouped into cause and effect. Then, performance measures are further divided into high and low group by their relative weighs. Performance measures in cause group with high relative weights should give more resources when given limited resources to improve logistics performance. The secondary focus is on performance measures in cause group with lower relative weights.

Table 32 Degrees of dependencies matrix

| Causal | Weight | Performance measures | Implication |
|---|---|---|---|
| Cause | High | Delivery cost; on time delivery | Delivery cost and on time delivery is critical to the performance of supply chain. Reducing delivery cost or improving performance of on time delivery will have a big positive effect on profitability |
| | Low | Investment in chain; Customer satisfaction; Skilled worker; Equipment | Improve one of them can't improve measures in effect group too much, but still if improve some of them together will be effective. |
| Effect | High | Profitability; Innovation; Reach new customer | These three measures are important indictors of the wellness of logistics. |
| | Low | Sales volume; Logistics info system; Quality improvement | These measures are less important as indictors of logistics performance. |

Note that even though reach new customer and on time delivery cannot be directly divided into cause and effect groups, they have big relative weights. Based on business sense, on time delivery is categorized in high-cause class and reach new customer is categorized in high-effect group.

Based on the above the ILPMS has been established completely. Now it's necessary to examine whether the requirements proposed for the ILPMS all have been satisfied.

## 3.5. The ILPMS Assessment

The five criteria to evaluate the ILPMS are:

- Comprehensiveness – the ILPMS includes all relevant stakeholders, internal and external, who have interests in logistics operation. In addition, the number of profit and non-profit measures are at balance in the system.
- Demonstrate causal relationship among performance objectives/perspectives and among performance measures.

  The multi-criteria decision making methodology – integration DEMATEL and ANP is able to prioritize performance perspectives and performance measures by assigning weights and dividing them into cause and effect group.
- Integrity – the ILPMS is horizontal integrated by applying a process-based performance measurement framework. The framework eliminates the potential conflicts between logistics activities (logistics activity metrics) so that they coordinate with each other to realize process objectives. What's more, the relative weights of clusters obtained from the hybrid MCDM methodology indicate which performance perspectives should pay more attention in order to maximize logistics performance.
- Deployment – the ILPMS adopt a hierarchy structure which deploys enterprise's strategic objectives along decision making levels, so that strategic objectives, business objectives and process objectives are coordinated to realize company's strategy and mission.
- Comparability – the importance of performance measures and logistics metrics

are evaluated by relative weights. Therefore, decision makers can clearly know which measures or metrics should pay more attention than others to improve logistics performance.

- Usefulness – the system is easy to understand and adjust based on companies' real operation situation. Also the ILPMS is able to provide suggestions of how to improve logistics performance.

So according the above examination, we can safely conclude that all the criteria are fulfilled by the ILPMS and the ILPMS is effective to measure logistics performance.

## 3.6. Procedures to Implement the ILPMS

The following procedure provides a clear guidance about how to implement the ILPMS.

Step1: Form a team including logistics experts, logistics operation specialists, general manager and business unit managers

The diverse team is able to incorporate difference voices to make the ILPMS as thorough as possible.

Step 2: Define the firms' logistics strategic objectives

Define logistics strategic objectives by incorporating companies' mission as well as business strategic objectives. They may be also affected by competitors' logistics strategy (profitability, market share, quality, cost, flexibility, dependability, and innovation) (Lohman et al., 2004) since firms desire to survive in a competitive market have to compete with its opponents.

Step 3: Identify stakeholders/business units influencing or influenced by logistics operations and clarify their expectations/ or objectives on logistics operations

Step 4: Define logistics performance measures to reflect these expectations or objectives by incorporating experts' opinions

Step 5: Decompose logistics performance measures to logistics process measures or logistics metrics

Step 6: Understand objectives of process owners and develop logistics process measures/logistics metrics

Step 7: Decompose process measures to logistics metrics as well

Step 8: Apply the hybrid multi-criteria decision making methodology to prioritize and categorize logistics performance measures and metrics

Step 9: Collect logistics operation data to calculate metrics and measures, and compare them to standards or competitors'.

Logistics managers analyze reasons behind the difference between current operational results and targets for those prioritized performance measures and work out improvement plans.

Step 10: Periodically re-evaluate the appropriateness of the ILPMS in view of the current competitive environment

# CHAPTER 4 APPLICATION OF THE ILPMS

The purpose of this chapter is to apply the ILPMS to a case study. The implementation includes: 1) the application of logistics performance measurement framework development; 2) the usage of logistics performance measure development methodologies; and 3) the implementation of the hybrid MCDM methodology to prioritize performance measures.

A US-based aviation enterprise is selected as the case study target. A logistics specialist from the company's middle management level and a logistics expert are involved to provide all necessary information. Surveys are the main method to collect information for the case. All the surveys are attached in the Appendices A, B and C. The information collection is segmented into four questionnaires.

## 4.1. Logistics Performance Measurement Framework Development

As the first step, the logistics specialist helps to identify stakeholders/business units that have effects on or are influenced by logistics performance. He is also required to figure out expectations/objectives of each stakeholder/business unit on the logistics performance. According to the survey result, manufacturing, sales and marketing and finance business units are identified to be three inside stakeholders that have relationship with the logistics operations. Additionally, two outside stakeholders, supplier and customers, are also considered as stakeholders in the system. Secondly, logistics activities within each logistics process: supplying, inbound logistics, warehousing and outbound logistics are identified. The business units, logistics processes and logistics activities are organized in a hierarchical structure (Figure 5).

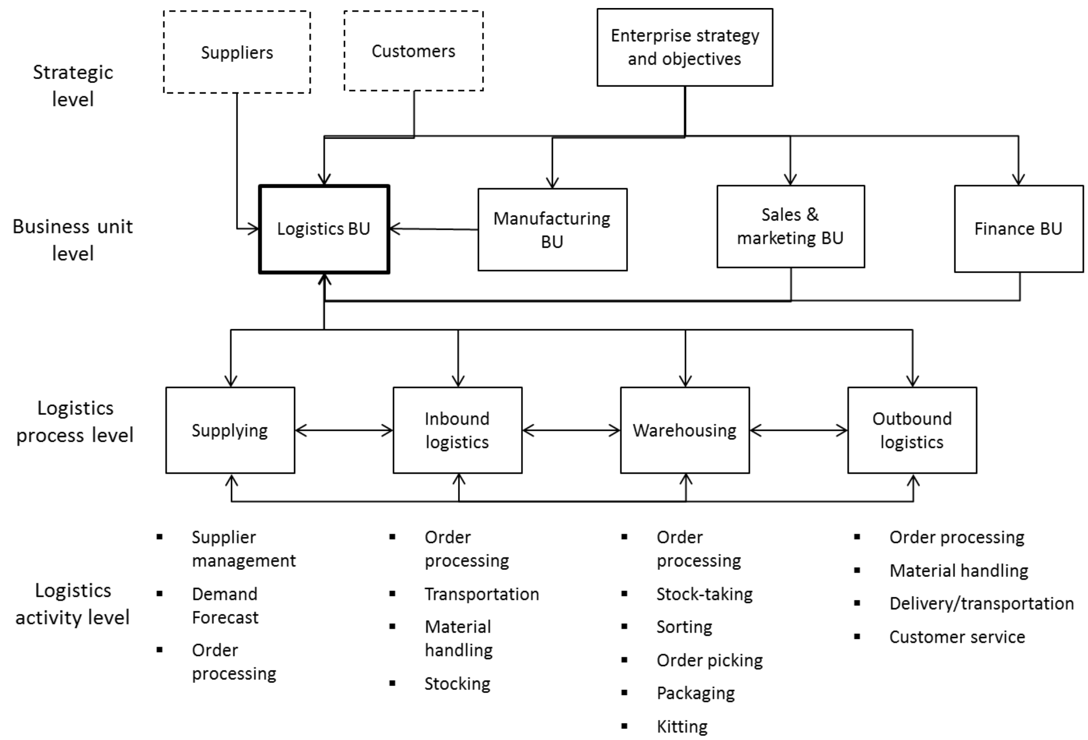


Figure 5 Logistics performance measurement framework – Case study

## 4.2. Logistics Performance Measure Development

The logistics specialist helped to list objectives/expectations for six stakeholders. The objectives are carefully analyzed and decomposed into logistics process performance measures.

In the survey's questionnaire, we ask responders to identify stakeholders of logistics operations and their objectives.

Table **33** lists the stakeholders in the ILPMS and their objectives on logistics operation. The corresponding logistics performance measures are also developed.

Table 33 Performance measures development – case study

| **Logistics stakeholders** | **Logistics Objectives** | **Logistics Performance Measures** |
|---|---|---|
| **Financial business unit** | Financial control | Total cost to serve |
| | | Cash-to-cash cycle time |
| | | Return on supply chain fixed assets |
| | | Return of working capital |
| **Customer** | Customer service | Delivery to contract/ on-time delivery |
| | | Order fill rate |
| **Supplier** | Supplier management | Supplier assessment |
| | | Supplier contracting |

The performance measures are further decomposed into logistics activity performance metrics applying the method described in Chapter 3.3.2. For instance, the manager desires to control total costs to serve. To meet the demand, total logistics costs should be measured. All four logistics processes produce logistics costs. So supplying costs, inbound logistics costs, warehousing costs as well as outbound logistics costs all need to be measured. Afterwards, decision makers identify logistics activities that produce costs in each process. The appropriate cost measures for each related logistics activity are defined (Table 34). The list incorporates logistics measures existing in the company and those developed based on its logistic objectives. The definitions for each logistics metric are included for implementation. In total there are 31 logistics performance measures in the ILPMS. We could observe that there is a good balance of financial (32%) and non-financial measures (68%). These non-financial measures will provide better monitoring on logistics operation performance. While financial measures provide feedbacks for financial statement.

Table 34 Logistics performance measures and metrics – case study

| **Logistics process** | **Logistics activity** | **Logistics metrics/KPI** | **Definition/Formula** |
|---|---|---|---|
| Supplying | Supplier Management | Costs of material | Purchasing cost of materials |
| | | Supplier schedule | Supplying flexibility |
| | | Material quality | Defective rate |
| | | Supplier capacity | Supplying capacity |
| | Demand forecasting | Forecast accuracy | Material shortage rate |
| | Order management | Sup. administrative lead time | Time between order received and released to suppliers |
| | | Labor costs | Labor costs per order |
| Inbound Logistics | Order processing | Administrative lead time | Time between order confirmed by supplier and order response |
| | Transportation | Perfect transportation | Order delivered within predefined time window |
| | Material handling (order receiving) | Measure of damage | Damage rate per order |
| | | Material handling facility investment | Facility investment annually |
| | | Material handling Costs | Labor costs + facility depreciation per order |
| | Stocking | Facility investment | Facility investment annually |
| | | Stocking costs | Labor costs + facility depreciation per order |
| Warehousing | Stock-taking | Inventory turnover | Cost of goods sold/average inventory |
| | Order processing | Administrative lead time | Time between order received and order responded by the company |
| | Order picking | Oder picking accuracy | Picking errors per day |
| | | Order picking facility investment | Order picking facility investment annually |
| | | Order picking costs | Labor cost + facility depreciation per order |
| | Packaging | Package/dunnage reused/recycled rate | Package reused rate |
| | | Packaging costs | Packaging purchasing costs |
| | Kitting | Kits created per hour | Kits created per hour |
| | | Kitting accuracy | Kitting mismatch rate |

| | | | |
|---|---|---|---|
| Outbound Logistics | Order processing | Administrative lead time | Time between order received from customers and order responded by the company |
| | Material handling | Measure of damage | Damage rate |
| | | Material handling costs | Labor costs for outbound + facility depreciation per order |
| | Delivery/transportation | On-time delivery | Delivery before contract delivery time |
| | | Account receivable lead time | Lead time between delivery and payment |
| | | Transportation costs | Transportation costs |
| | Customer service | Order fill rate | Order filled within certain period |
| | | Customer service costs | After-sales service costs (labor costs per order) |

## 4.3. Performance Measure Prioritization Methodology Application

To prioritize these logistics metrics, the hybrid multi-criteria decision making methodology is applied based on the procedure presented in Chapter 3. The initial relation matrices for inner dependency analysis and initial pair-wise comparison matrices for outer dependency analysis are put in **Appendices**.

### 4.3.1. Inner Dependency Matrix Establishment

The DEMATEL methodology is applied to analyze inner dependency between logistics performance measures and between logistics performance metrics. The direct-relation matrices rate the influence degrees between performance measures and between metrics. Table 35 demonstrates the total relation matrix of the four clusters/logistics processes.

Table 35 Total Relation Matrix of four logistics processes – case study

| | **Supplying** | **Inbound logistics** | **Warehousing** | **Outbound logistics** | **$r_i+c_i$** | **$r_i-c_i$** |
|---|---|---|---|---|---|---|
| **Supplying** | 0.194 | **0.695** | **0.642** | **0.716** | 3.062 | 1.431 |
| **Inbound logistics** | 0.115 | 0.169 | 0.421 | 0.380 | 2.629 | -0.458 |
| **Warehousing** | 0.294 | 0.507 | 0.333 | **0.728** | 3.540 | 0.184 |
| **Outbound logistics** | 0.213 | 0.172 | 0.282 | 0.206 | 2.902 | -1.157 |

The results ($r_i+c_i$) indicate that supplying and warehousing logistics are relatively more important than the other two factors. The results ($r_i-c_i$) demonstrate that supplying and warehousing belong to the cause group, while inbound logistics and outbound should be in the effect group.

To have an appropriate network relation map (NRM), a threshold value is determined by using the maximum mean de-entropy algorithm (Li and Tzeng, 2009). The threshold is set to 0.642. The values of interdependency in the matrix exceeds the threshold value are in bold and is converted into network relation map (NRM) (Figure 6).

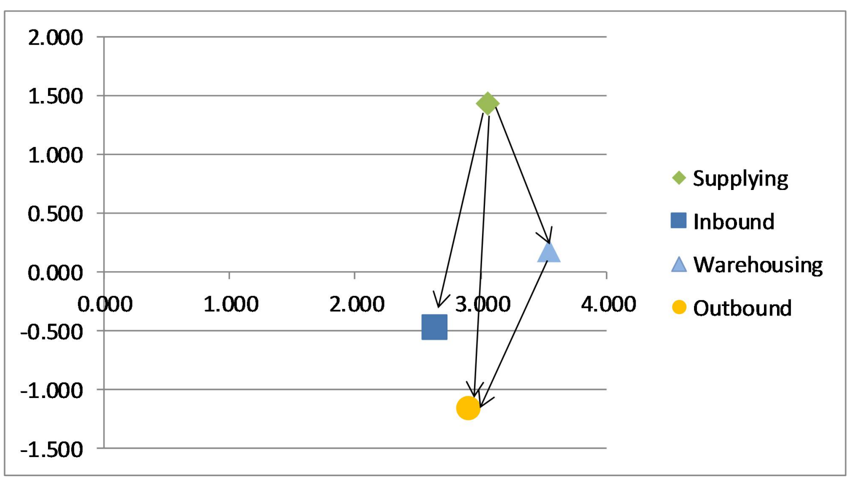


Figure 6 The network relationship map of the four logistics processes

Table 36 Inner dependence matrix for the four logistics processes

| | Supplying | Inbound logistics | Warehousing | Outbound logistics |
|---|---|---|---|---|
| **Supplying** | 0.086 | 0.106 | 0.158 | 0.244 |
| **Inbound logistics** | 0.309 | 0.156 | 0.272 | 0.197 |
| **Warehousing** | 0.286 | 0.388 | 0.179 | 0.323 |
| **Outbound logistics** | 0.319 | 0.350 | 0.391 | 0.236 |

The following tables demonstrate the total relation matrices of performance metrics in each cluster in order to discover the causal relationships between performance metrics.

Table 37 Total relation matrix for measures in supplying

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | O.P. admin. LT | O.P. Labor costs | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|---|---|
| **Costs of material** | 0.067 | 0.161 | 0.152 | 0.023 | 0.000 | 0.007 | 0.024 | 1.278 | -0.411 |
| **Supplier schedule** | 0.161 | 0.080 | 0.023 | 0.154 | 0.000 | 0.045 | 0.161 | 2.007 | -0.759 |
| **Material Quality** | 0.305 | 0.046 | 0.044 | 0.007 | 0.000 | 0.002 | 0.007 | 0.673 | 0.146 |
| **Supplier Capacity** | 0.053 | 0.354 | 0.008 | 0.051 | 0.000 | 0.161 | 0.073 | 1.039 | 0.358 |
| **Forecast accuracy** | 0.206 | 0.383 | 0.029 | 0.055 | 0.000 | 0.183 | 0.224 | 1.079 | 1.079 |
| **Sup.O.P. admin. L.T.** | 0.047 | 0.315 | 0.007 | 0.045 | 0.000 | 0.034 | 0.193 | 1.219 | 0.062 |
| **Sup.O.P. Labor costs** | 0.007 | 0.045 | 0.001 | 0.006 | 0.000 | 0.148 | 0.028 | 0.943 | -0.474 |

*Sup.O.P. admin. L.T. = supplying order process administration lead time

In the supplying cluster, material quality, supplier capacity, forecast accuracy and order process administration lead time are the cause factors, while the others, costs of material, supplier schedule and order process labor costs are effect factors. Additionally, the supplier schedule has the biggest prominence among these measures.

Table 38 Inner dependence matrix for metrics in supplying clusters

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | O.P. admin. LT | O.P. Labor costs |
|---|---|---|---|---|---|---|---|
| **Costs of material** | 0.153 | 0.258 | 0.744 | 0.075 | 0.191 | 0.073 | 0.029 |
| **Supplier schedule** | 0.371 | 0.128 | 0.112 | 0.506 | 0.355 | 0.492 | 0.192 |
| **Material Quality** | 0.352 | 0.037 | 0.106 | 0.011 | 0.027 | 0.010 | 0.004 |
| **Supplier Capacity** | 0.053 | 0.247 | 0.016 | 0.072 | 0.051 | 0.070 | 0.027 |
| **Forecast accuracy** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **O.P. admin. L.T.** | 0.015 | 0.072 | 0.005 | 0.230 | 0.169 | 0.053 | 0.631 |
| **O.P. Labor costs** | 0.055 | 0.258 | 0.017 | 0.105 | 0.207 | 0.301 | 0.117 |

Table 39 Total relation matrix for measures in inbound logistics

| | O.P. admin. LT | Transp. Perfect order | M.H. damage | M.H. facility invst. | M.H. operating costs | Stocking facility invst. | Stocking costs | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|---|---|
| **O.P. admin. LT** | 0.032 | 0.049 | 0.113 | 0.078 | 0.289 | 0.251 | 0.350 | 1.439 | 0.887 |
| **Transp. Perfect order** | 0.038 | 0.088 | 0.263 | 0.222 | 0.338 | 0.308 | 0.410 | 2.465 | 0.867 |
| **M.H. damage** | 0.024 | 0.175 | 0.124 | 0.197 | 0.219 | 0.254 | 0.272 | 2.619 | -0.089 |
| **M.H. facility invst.** | 0.024 | 0.175 | 0.224 | 0.097 | 0.219 | 0.254 | 0.272 | 2.312 | 0.218 |
| **M.H. operating costs** | 0.124 | 0.071 | 0.209 | 0.183 | 0.114 | 0.248 | 0.266 | 2.697 | -0.267 |
| **Stocking facility invst.** | 0.025 | 0.181 | 0.242 | 0.204 | 0.227 | 0.183 | 0.383 | 3.232 | -0.344 |
| **Stocking costs** | 0.008 | 0.060 | 0.179 | 0.067 | 0.075 | 0.291 | 0.115 | 2.862 | -1.273 |

* O.P. admin. L.T. = order process administration lead time; M.H. = material handling; invst = investment

In the inbound logistics cluster, order process administration lead time, transportation perfect order, material handling facility investment are the cause factors, while material handling damage, material operating costs, stocking facility investment and stocking costs are the effect factors. What's more, transportation perfect order has the biggest prominence among all measures.

Table 40 Inner dependence matrix for metrics in inbound logistics clusters

| | O.P. admin. LT | Transp. Perfect order | M.H. damage | M.H. facility invst. | M.H. operating costs | Stocking facility invst. | Stocking costs |
|---|---|---|---|---|---|---|---|
| **O.P. admin. LT** | 0.028 | 0.023 | 0.019 | 0.019 | 0.102 | 0.017 | 0.010 |
| **Transp. Perfect order** | 0.042 | 0.053 | 0.138 | 0.138 | 0.059 | 0.125 | 0.075 |
| **M.H. damage** | 0.097 | 0.158 | 0.098 | 0.177 | 0.172 | 0.167 | 0.225 |
| **M.H. facility invst.** | 0.067 | 0.133 | 0.156 | 0.077 | 0.150 | 0.141 | 0.084 |
| **M.H. operating costs** | 0.249 | 0.203 | 0.173 | 0.173 | 0.094 | 0.157 | 0.094 |
| **Stocking facility invst.** | 0.216 | 0.185 | 0.201 | 0.201 | 0.204 | 0.127 | 0.366 |
| **Stocking costs** | 0.301 | 0.246 | 0.215 | 0.215 | 0.219 | 0.265 | 0.145 |

Table 41 Total relation matrix for measures in warehousing

| | Inv. turnover | Order process admin. LT | O.P. accuracy | O.P. facilit y invst. | O.P. costs | Pkg. reused rate | Pkg. costs | Kits create/ hour | Kitting accuracy | $r_i+c_i$ | $r_i-c_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Inv. turnover** | 0.066 | 0.058 | 0.048 | 0.044 | 0.256 | 0.022 | 0.025 | 0.026 | 0.029 | 1.608 | -0.461 |
| **Order process admin. LT** | 0.143 | 0.062 | 0.051 | 0.047 | 0.275 | 0.024 | 0.027 | 0.027 | 0.031 | 1.359 | 0.013 |
| **O.P. accuracy** | 0.148 | 0.052 | 0.072 | 0.057 | 0.222 | 0.022 | 0.040 | 0.108 | 0.180 | 1.859 | -0.060 |
| **O.P. facility invst.** | 0.043 | 0.099 | 0.096 | 0.022 | 0.121 | 0.011 | 0.013 | 0.018 | 0.025 | 1.257 | -0.363 |
| **OP costs** | 0.310 | 0.271 | 0.222 | 0.205 | 0.196 | 0.102 | 0.118 | 0.119 | 0.134 | 3.213 | 0.140 |
| **Pkg. reused rate** | 0.030 | 0.029 | 0.039 | 0.103 | 0.103 | 0.030 | 0.158 | 0.023 | 0.026 | 0.953 | 0.130 |
| **Pkg. costs** | 0.036 | 0.021 | 0.112 | 0.108 | 0.061 | 0.153 | 0.040 | 0.094 | 0.101 | 1.340 | 0.111 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kits created/ hour** | 0.124 | 0.039 | 0.125 | 0.111 | 0.144 | 0.024 | 0.095 | 0.034 | 0.109 | 1.361 | 0.247 |
| **Kitting accuracy** | 0.134 | 0.042 | 0.196 | 0.115 | 0.159 | 0.025 | 0.098 | 0.108 | 0.054 | 1.618 | 0.243 |

* O.P. = Order picking; invst. = investment; Pkg. = Package

In the warehousing cluster, order process administration lead time, order picking costs, package used rate, package costs, kits created per hour and kitting accuracy are the cause factors. While inventory turnover, order picking accuracy, order picking facility investment are categorized into effect groups. Among all the factors, order picking costs has the most influence.

Table 42 Inner dependence matrix for metrics in warehousing clusters

| | **Inv. turnover** | **Order process admin. LT** | **O.P. accuracy** | **O.P. facility invst.** | **O.P. costs** | **Pkg. reused rate** | **Pkg. costs** | **Kits create/ hour** | **Kitting accuracy** |
|---|---|---|---|---|---|---|---|---|---|
| **Inv. turnover** | 0.116 | 0.208 | 0.165 | 0.096 | 0.185 | 0.056 | 0.050 | 0.154 | 0.144 |
| **Order process admin. LT** | 0.101 | 0.091 | 0.057 | 0.221 | 0.162 | 0.054 | 0.029 | 0.048 | 0.045 |
| **O.P. accuracy** | 0.083 | 0.074 | 0.080 | 0.215 | 0.132 | 0.072 | 0.154 | 0.155 | 0.211 |
| **O.P. facility invst.** | 0.077 | 0.069 | 0.063 | 0.049 | 0.122 | 0.190 | 0.149 | 0.138 | 0.123 |
| **OP costs** | 0.447 | 0.400 | 0.247 | 0.270 | 0.117 | 0.190 | 0.084 | 0.179 | 0.171 |
| **Pkg. reused rate** | 0.038 | 0.034 | 0.024 | 0.023 | 0.061 | 0.055 | 0.211 | 0.030 | 0.027 |
| **Pkg. costs** | 0.044 | 0.040 | 0.044 | 0.030 | 0.070 | 0.292 | 0.055 | 0.119 | 0.105 |
| **Kits created/hour** | 0.045 | 0.040 | 0.120 | 0.041 | 0.071 | 0.043 | 0.129 | 0.042 | 0.116 |
| **Kitting accuracy** | 0.050 | 0.045 | 0.200 | 0.055 | 0.080 | 0.048 | 0.140 | 0.135 | 0.058 |

Table 43 Total relation matrix for measures in outbound logistics

| | Order process LT | MH damage | MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs | ri+ci | ri-ci |
|---|---|---|---|---|---|---|---|---|---|---|
| **Order process LT** | 0.039 | 0.000 | 0.000 | 0.115 | 0.280 | 0.031 | 0.063 | 0.285 | 1.412 | 0.214 |
| **MH damage** | 0.083 | 0.025 | 0.228 | 0.123 | 0.226 | 0.139 | 0.177 | 0.346 | 1.487 | 1.208 |
| **MH costs** | 0.140 | 0.114 | 0.025 | 0.028 | 0.076 | 0.021 | 0.042 | 0.189 | 0.889 | 0.382 |
| **Account receivable LT** | 0.015 | 0.000 | 0.000 | 0.002 | 0.020 | 0.002 | 0.015 | 0.119 | 0.478 | -0.131 |
| **On-time delivery** | 0.032 | 0.000 | 0.000 | 0.004 | 0.068 | 0.119 | 0.136 | 0.155 | 1.792 | -0.767 |
| **delivery costs** | 0.019 | 0.000 | 0.000 | 0.002 | 0.139 | 0.015 | 0.031 | 0.136 | 0.721 | -0.038 |
| **Order fill rate** | 0.138 | 0.000 | 0.000 | 0.015 | 0.289 | 0.032 | 0.053 | 0.185 | 1.367 | 0.055 |
| **Customer service costs** | 0.134 | 0.000 | 0.000 | 0.015 | 0.182 | 0.020 | 0.139 | 0.069 | 2.043 | -0.924 |

* O.P. admin. L.T. = order process administration lead time

In the outbound logistics cluster, order process administration lead time, material handling damage, material handling costs and order fill rate are the cause factors. Account receivable lead time, on-time delivery, delivery costs and customer service costs are effect factors. Furthermore, the measure of customer service costs plays a big role in outbound performance.

Table 44 Inner dependence matrix for metrics in outbound clusters

| | Order process LT | MH damage | MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|
| **Order process LT** | 0.048 | 0.062 | 0.220 | 0.086 | 0.063 | 0.054 | 0.193 | 0.240 |
| **MH damage** | 0.000 | 0.019 | 0.179 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **MH costs** | 0.000 | 0.169 | 0.040 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Account receivable LT** | 0.142 | 0.091 | 0.044 | 0.010 | 0.007 | 0.006 | 0.022 | 0.027 |
| **On-time delivery** | 0.344 | 0.168 | 0.120 | 0.117 | 0.132 | 0.407 | 0.406 | 0.325 |
| **delivery costs** | 0.038 | 0.103 | 0.033 | 0.013 | 0.231 | 0.045 | 0.045 | 0.036 |
| **Order fill rate** | 0.077 | 0.132 | 0.066 | 0.089 | 0.265 | 0.089 | 0.074 | 0.248 |
| **Customer service costs** | 0.351 | 0.256 | 0.297 | 0.686 | 0.301 | 0.398 | 0.260 | 0.124 |

### 4.3.2. Outer dependency matrix

The ANP methodology procedure is applied to analyze interdependency between logistics performance metrics. The pair-wise comparison matrices can be referred in Appendix A. The relative weight calculation is completed in the SuperDecision software. The software checks the consistency index (C.I) and consistency ratio (C.R) at the same time.

### 4.3.3. Integration

The results from DEMATEL and ANP are integrated in this step to form an unweighted supermatrix (Table 45 and Table 46), which is a 31×31 matrix. The weighted supermatrix is obtained by combining the cluster weights from the DEMATEL procedure (Table 47 and Table 48). Lastly, to obtain the limited supermatrix, the weighted supermatrix is raised to the power of 30 (Table 49 and Table 50).

Table 45 Unweighted supermatrix of the case – Part I

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | Sup. order process admin. LT | Sup. Order Process. Labor costs | IL order process admin. LT | Transp. Perfect order | IL MH damage | IL MH facility inves. | MH operating costs | Stocking facility invest. | Stocking costs | Inventory turnover | W. Order process admin. LT | OP accuracy | OP facility invest. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.153 | 0.258 | 0.744 | 0.075 | 0.191 | 0.073 | 0.029 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Supplier schedule | 0.371 | 0.128 | 0.112 | 0.506 | 0.355 | 0.492 | 0.192 | 0.000 | 1.000 | 0.000 | 0.000 | 0.500 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | 0.000 |
| Material Quality | 0.352 | 0.037 | 0.106 | 0.011 | 0.027 | 0.010 | 0.004 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Supplier Capacity | 0.053 | 0.247 | 0.016 | 0.072 | 0.051 | 0.070 | 0.027 | 0.000 | 0.000 | 0.000 | 1.000 | 0.500 | 1.000 | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 |
| Forecast accuracy | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| Sup. order process admin. L.T. | 0.015 | 0.072 | 0.005 | 0.230 | 0.169 | 0.053 | 0.631 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sup.order process Labor costs | 0.055 | 0.258 | 0.017 | 0.105 | 0.207 | 0.301 | 0.117 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| IL OP admin. LT | 0.000 | 0.637 | 0.000 | 0.000 | 0.140 | 0.105 | 0.000 | 0.028 | 0.023 | 0.019 | 0.019 | 0.102 | 0.017 | 0.010 | 0.000 | 0.000 | 1.000 | 0.000 |
| Transp. Perfect order | 0.000 | 0.105 | 0.000 | 1.000 | 0.333 | 0.258 | 0.000 | 0.042 | 0.053 | 0.138 | 0.138 | 0.059 | 0.125 | 0.075 | 0.000 | 1.000 | 0.000 | 0.000 |
| IL MH damage | 0.000 | 0.000 | 0.167 | 0.000 | 0.000 | 0.000 | 0.000 | 0.097 | 0.158 | 0.098 | 0.177 | 0.172 | 0.167 | 0.225 | 0.000 | 0.000 | 0.000 | 0.000 |
| IL MH facility invest. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.250 | 0.067 | 0.133 | 0.156 | 0.077 | 0.150 | 0.141 | 0.084 | 0.000 | 0.000 | 0.000 | 0.000 |
| MH operating costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.249 | 0.203 | 0.173 | 0.173 | 0.094 | 0.157 | 0.094 | 0.000 | 0.000 | 0.000 | 0.000 |
| Stocking facility invest. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.637 | 0.000 | 0.216 | 0.185 | 0.201 | 0.201 | 0.204 | 0.127 | 0.366 | 1.000 | 0.000 | 0.000 | 0.000 |
| Stocking costs | 1.000 | 0.258 | 0.833 | 0.000 | 0.528 | 0.000 | 0.750 | 0.301 | 0.246 | 0.215 | 0.215 | 0.219 | 0.265 | 0.145 | 0.000 | 0.000 | 0.000 | 1.000 |
| Inventory turnover | 0.000 | 0.195 | 0.000 | 0.250 | 0.287 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.116 | 0.208 | 0.165 | 0.096 |
| W. Order process admin. LT | 0.000 | 0.088 | 0.000 | 0.000 | 0.078 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.101 | 0.091 | 0.057 | 0.221 |
| OP accuracy | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.451 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.083 | 0.074 | 0.080 | 0.215 |
| OP facility invest. | 0.000 | 0.000 | 0.000 | 0.750 | 0.000 | 0.081 | 0.750 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 0.000 | 0.077 | 0.069 | 0.063 | 0.049 |
| OP costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.143 | 0.250 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.447 | 0.400 | 0.247 | 0.270 |
| Package reused rate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.038 | 0.034 | 0.024 | 0.023 |
| Packaging costs | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.044 | 0.040 | 0.044 | 0.030 |
| Kits created per hour | 0.000 | 0.717 | 1.000 | 0.000 | 0.635 | 0.326 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.045 | 0.040 | 0.120 | 0.041 |
| Kitting accuracy | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.050 | 0.045 | 0.200 | 0.055 |
| OL Order process LT | 0.000 | 0.183 | 0.000 | 0.105 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.278 | 0.117 |
| OL MH damage | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.542 |
| OL MH costs | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Account receivable LT | 0.000 | 0.053 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| On-time delivery | 0.000 | 0.414 | 0.000 | 0.637 | 0.833 | 0.167 | 0.000 | 0.000 | 0.500 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.709 | 0.393 | 0.213 |
| delivery costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.833 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.188 | 0.081 |
| Order fill rate | 0.000 | 0.350 | 1.000 | 0.258 | 0.167 | 0.833 | 0.167 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.113 | 0.049 | 0.047 |
| Customer service costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.179 | 0.092 | 0.000 |

Table 46 Unweighted supermatrix of the case –Part II

| | OP costs | Package reused rate | Packaging costs | Kits created per hour | Kitting accuracy | OL Order process LT | OL MH damage | OL MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Supplier schedule | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 0.000 |
| Material Quality | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Supplier Capacity | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Forecast accuracy | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| Sup. order process admin. L.T. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sup.order process Labor costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| IL OP admin. LT | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| Transp. Perfect order | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| IL MH damage | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| IL MH facility invest. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 |
| MH operating costs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| Stocking facility invest. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Stocking costs | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Inventory turnover | 0.185 | 0.056 | 0.050 | 0.154 | 0.144 | 0.000 | 0.000 | 0.000 | 0.000 | 0.197 | 0.000 | 0.000 | 0.000 |
| W. Order process admin. LT | 0.162 | 0.054 | 0.029 | 0.048 | 0.045 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| OP accuracy | 0.132 | 0.072 | 0.154 | 0.155 | 0.211 | 0.000 | 0.000 | 0.000 | 0.000 | 0.689 | 0.000 | 1.000 | 0.000 |
| OP facility invest. | 0.122 | 0.190 | 0.149 | 0.138 | 0.123 | 0.000 | 0.000 | 0.000 | 0.000 | 0.115 | 0.000 | 0.000 | 0.000 |
| OP costs | 0.117 | 0.190 | 0.084 | 0.179 | 0.171 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Package reused rate | 0.061 | 0.055 | 0.211 | 0.030 | 0.027 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Packaging costs | 0.070 | 0.292 | 0.055 | 0.119 | 0.105 | 0.000 | 1.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 |
| Kits created per hour | 0.071 | 0.043 | 0.129 | 0.042 | 0.116 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Kitting accuracy | 0.080 | 0.048 | 0.140 | 0.135 | 0.058 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| OL Order process LT | 0.000 | 0.000 | 0.000 | 0.750 | 0.000 | 0.0476 | 0.0619 | 0.2197 | 0.0860 | 0.0630 | 0.0542 | 0.1934 | 0.2400 |
| OL MH damage | 0.000 | 0.000 | 0.729 | 0.000 | 0.000 | 0.0000 | 0.0188 | 0.1792 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| OL MH costs | 0.000 | 1.000 | 0.109 | 0.000 | 0.000 | 0.0000 | 0.1691 | 0.0398 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Account receivable LT | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.1419 | 0.0914 | 0.0444 | 0.0098 | 0.0070 | 0.0062 | 0.0215 | 0.0266 |
| On-time delivery | 0.000 | 0.000 | 0.709 | 0.000 | 0.833 | 0.3442 | 0.1675 | 0.1202 | 0.1166 | 0.1321 | 0.4067 | 0.4060 | 0.3249 |
| delivery costs | 1.000 | 0.000 | 0.163 | 0.000 | 0.000 | 0.0382 | 0.1032 | 0.0332 | 0.0127 | 0.2314 | 0.0451 | 0.0452 | 0.0361 |
| Order fill rate | 0.000 | 0.000 | 0.113 | 0.000 | 0.167 | 0.0772 | 0.1317 | 0.0662 | 0.0889 | 0.2650 | 0.0894 | 0.0740 | 0.2484 |
| Customer service costs | 0.000 | 0.000 | 0.179 | 0.250 | 0.000 | 0.3508 | 0.2565 | 0.2972 | 0.6859 | 0.3015 | 0.3985 | 0.2600 | 0.1240 |

Table 47 Weighted supermatrix of the case – Part I

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | Sup. order process admin. LT | Sup. Order Process. Labor costs | IL order process admin. LT | Transp. Perfect order | IL MH damage | IL MH facility inves. | MH operating costs | Stocking facility invest. | Stocking costs | Inventory turnover | W. Order process admin. LT | OP accuracy | OP facility invest. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.0132 | 0.0222 | 0.0640 | 0.0065 | 0.0164 | 0.0063 | 0.0025 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Supplier schedule | 0.0319 | 0.0110 | 0.0097 | 0.0435 | 0.0305 | 0.0423 | 0.0165 | 0.0000 | 0.1060 | 0.0000 | 0.0000 | 0.0530 | 0.0000 | 0.1060 | 0.0000 | 0.1580 | 0.0000 | 0.0000 |
| Material Quality | 0.0302 | 0.0032 | 0.0091 | 0.0009 | 0.0023 | 0.0009 | 0.0004 | 0.0000 | 0.0000 | 0.1060 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Supplier Capacity | 0.0046 | 0.0213 | 0.0014 | 0.0062 | 0.0044 | 0.0060 | 0.0023 | 0.0000 | 0.0000 | 0.0000 | 0.1060 | 0.0530 | 0.1060 | 0.0000 | 0.1580 | 0.0000 | 0.0000 | 0.1580 |
| Forecast accuracy | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1580 | 0.0000 |
| Sup. order process admin. L.T. | 0.0013 | 0.0062 | 0.0004 | 0.0198 | 0.0145 | 0.0046 | 0.0542 | 0.1060 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Sup.order process Labor costs | 0.0047 | 0.0222 | 0.0014 | 0.0090 | 0.0178 | 0.0259 | 0.0101 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| IL OP admin. LT | 0.0000 | 0.1968 | 0.0000 | 0.0000 | 0.0432 | 0.0324 | 0.0000 | 0.0043 | 0.0035 | 0.0030 | 0.0030 | 0.0159 | 0.0027 | 0.0016 | 0.0000 | 0.0000 | 0.2720 | 0.0000 |
| Transp. Perfect order | 0.0000 | 0.0324 | 0.0000 | 0.3090 | 0.1027 | 0.0798 | 0.0000 | 0.0066 | 0.0082 | 0.0216 | 0.0216 | 0.0091 | 0.0195 | 0.0117 | 0.0000 | 0.2720 | 0.0000 | 0.0000 |
| IL MH damage | 0.0000 | 0.0000 | 0.0515 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0152 | 0.0246 | 0.0153 | 0.0276 | 0.0269 | 0.0261 | 0.0351 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| IL MH facility invest. | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0773 | 0.0105 | 0.0208 | 0.0243 | 0.0119 | 0.0234 | 0.0220 | 0.0132 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| MH operating costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0388 | 0.0317 | 0.0270 | 0.0270 | 0.0147 | 0.0245 | 0.0147 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Stocking facility invest. | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1968 | 0.0000 | 0.0337 | 0.0288 | 0.0313 | 0.0313 | 0.0318 | 0.0197 | 0.0571 | 0.2720 | 0.0000 | 0.0000 | 0.0000 |
| Stocking costs | 0.3090 | 0.0798 | 0.2575 | 0.0000 | 0.1631 | 0.0000 | 0.2318 | 0.0469 | 0.0384 | 0.0335 | 0.0335 | 0.0341 | 0.0414 | 0.0227 | 0.0000 | 0.0000 | 0.0000 | 0.2720 |
| Inventory turnover | 0.0000 | 0.0557 | 0.0000 | 0.0715 | 0.0821 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3880 | 0.0000 | 0.0000 | 0.3880 | 0.0207 | 0.0372 | 0.0295 | 0.0172 |
| W. Order process admin. LT | 0.0000 | 0.0252 | 0.0000 | 0.0000 | 0.0223 | 0.0000 | 0.0000 | 0.3880 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0181 | 0.0162 | 0.0103 | 0.0396 |
| OP accuracy | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1289 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0148 | 0.0133 | 0.0143 | 0.0384 |
| OP facility invest. | 0.0000 | 0.0000 | 0.0000 | 0.2145 | 0.0000 | 0.0231 | 0.2145 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3880 | 0.3880 | 0.0000 | 0.0137 | 0.0123 | 0.0113 | 0.0088 |
| OP costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0408 | 0.0715 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0717 | 0.0442 | 0.0484 |
| Package reused rate | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0068 | 0.0061 | 0.0043 | 0.0042 |
| Packaging costs | 0.2860 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3880 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0079 | 0.0071 | 0.0079 | 0.0053 |
| Kits created per hour | 0.0000 | 0.2051 | 0.2860 | 0.0000 | 0.1816 | 0.0931 | 0.0000 | 0.0000 | 0.3880 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0080 | 0.0071 | 0.0215 | 0.0073 |
| Kitting accuracy | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0090 | 0.0080 | 0.0357 | 0.0098 |
| OL Order process LT | 0.0000 | 0.0583 | 0.0000 | 0.0334 | 0.0000 | 0.0000 | 0.0000 | 0.3500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1087 | 0.0459 |
| OL MH damage | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2118 |
| OL MH costs | 0.3190 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Account receivable LT | 0.0000 | 0.0168 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3910 | 0.0000 | 0.0000 | 0.0000 |
| On-time delivery | 0.0000 | 0.1321 | 0.0000 | 0.2032 | 0.2658 | 0.0532 | 0.0000 | 0.0000 | 0.1750 | 0.3500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2772 | 0.1535 | 0.0833 |
| delivery costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2658 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3500 | 0.0000 | 0.0000 | 0.0734 | 0.0318 |
| Order fill rate | 0.0000 | 0.1117 | 0.3190 | 0.0824 | 0.0532 | 0.2658 | 0.0532 | 0.0000 | 0.1750 | 0.0000 | 0.0000 | 0.0000 | 0.3500 | 0.0000 | 0.0000 | 0.0440 | 0.0193 | 0.0183 |
| Customer service costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0698 | 0.0361 | 0.0000 |

Table 48 Weighted supermatrix of the case – Part II

| | OP costs | Package reused rate | Packaging costs | Kits created per hour | Kitting accuracy | OL Order process LT | OL MH damage | OL MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Supplier schedule | 0.0000 | 0.0000 | 0.0000 | 0.1580 | 0.1580 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2440 | 0.2440 | 0.0000 |
| Material Quality | 0.0000 | 0.1580 | 0.1580 | 0.0000 | 0.0000 | 0.0000 | 0.2440 | 0.2440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2440 |
| Supplier Capacity | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Forecast accuracy | 0.1580 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2440 | 0.0000 | 0.0000 | 0.0000 |
| Sup. order process admin. L.T. | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2440 | 0.0000 | 0.0000 | 0.2440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Sup.order process Labor costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| IL OP admin. LT | 0.0000 | 0.0000 | 0.0000 | 0.2720 | 0.2720 | 0.1970 | 0.0000 | 0.0000 | 0.1970 | 0.0000 | 0.0000 | 0.1970 | 0.0000 |
| Transp. Perfect order | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1970 | 0.0000 | 0.0000 | 0.0000 |
| IL MH damage | 0.0000 | 0.2720 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| IL MH facility invest. | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1970 | 0.1970 | 0.0000 | 0.0000 | 0.1970 | 0.0000 | 0.0000 |
| MH operating costs | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1970 |
| Stocking facility invest. | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Stocking costs | 0.2720 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Inventory turnover | 0.0331 | 0.0101 | 0.0090 | 0.0276 | 0.0258 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0635 | 0.0000 | 0.0000 | 0.0000 |
| W. Order process admin. LT | 0.0289 | 0.0097 | 0.0051 | 0.0086 | 0.0081 | 0.3230 | 0.0000 | 0.0000 | 0.3230 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| OP accuracy | 0.0237 | 0.0128 | 0.0276 | 0.0278 | 0.0377 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2224 | 0.0000 | 0.3230 | 0.0000 |
| OP facility invest. | 0.0219 | 0.0341 | 0.0266 | 0.0247 | 0.0220 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0371 | 0.0000 | 0.0000 | 0.0000 |
| OP costs | 0.0209 | 0.0340 | 0.0150 | 0.0320 | 0.0305 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Package reused rate | 0.0109 | 0.0099 | 0.0377 | 0.0053 | 0.0049 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Packaging costs | 0.0126 | 0.0523 | 0.0099 | 0.0212 | 0.0188 | 0.0000 | 0.3230 | 0.3230 | 0.0000 | 0.0000 | 0.3230 | 0.0000 | 0.0000 |
| Kits created per hour | 0.0127 | 0.0077 | 0.0232 | 0.0075 | 0.0207 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Kitting accuracy | 0.0143 | 0.0085 | 0.0250 | 0.0242 | 0.0104 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3230 |
| OL Order process LT | 0.0000 | 0.0000 | 0.0000 | 0.2933 | 0.0000 | 0.0154 | 0.0200 | 0.0710 | 0.0278 | 0.0204 | 0.0175 | 0.0625 | 0.0775 |
| OL MH damage | 0.0000 | 0.0000 | 0.2849 | 0.0000 | 0.0000 | 0.0000 | 0.0044 | 0.0423 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| OL MH costs | 0.0000 | 0.3910 | 0.0426 | 0.0000 | 0.0000 | 0.0000 | 0.0399 | 0.0094 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Account receivable LT | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0335 | 0.0216 | 0.0105 | 0.0023 | 0.0017 | 0.0015 | 0.0051 | 0.0063 |
| On-time delivery | 0.0000 | 0.0000 | 0.2772 | 0.0000 | 0.3258 | 0.0812 | 0.0395 | 0.0284 | 0.0275 | 0.0312 | 0.0960 | 0.0958 | 0.0767 |
| delivery costs | 0.3910 | 0.0000 | 0.0636 | 0.0000 | 0.0000 | 0.0090 | 0.0243 | 0.0078 | 0.0030 | 0.0546 | 0.0106 | 0.0107 | 0.0085 |
| Order fill rate | 0.0000 | 0.0000 | 0.0440 | 0.0000 | 0.0652 | 0.0182 | 0.0311 | 0.0156 | 0.0210 | 0.0625 | 0.0211 | 0.0175 | 0.0586 |
| Customer service costs | 0.0000 | 0.0000 | 0.0698 | 0.0978 | 0.0000 | 0.0828 | 0.0605 | 0.0702 | 0.1619 | 0.0711 | 0.0940 | 0.0613 | 0.0293 |

Table 49 The stable weighted supermatrix of the case – Part I

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | Sup. order process admin. LT | Sup. Order Process. Labor costs | IL order process admin. LT | Transp. Perfect order | IL MH damage | IL MH facility inves. | MH operating costs | Stocking facility invest. | Stocking costs | Inventory turnover | W. Order process admin. LT | OP accuracy | OP facility invest. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| Supplier schedule | 0.071 | 0.067 | 0.067 | 0.067 | 0.067 | 0.067 | 0.068 | 0.066 | 0.067 | 0.070 | 0.068 | 0.068 | 0.067 | 0.068 | 0.067 | 0.067 | 0.067 | 0.068 |
| Material Quality | 0.027 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.027 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 | 0.026 |
| Supplier Capacity | 0.022 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.022 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 |
| Forecast accuracy | 0.041 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 | 0.041 | 0.039 | 0.040 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 | 0.039 |
| Sup. order process admin. L.T. | 0.037 | 0.034 | 0.035 | 0.034 | 0.034 | 0.034 | 0.035 | 0.034 | 0.034 | 0.036 | 0.035 | 0.035 | 0.035 | 0.035 | 0.034 | 0.034 | 0.034 | 0.035 |
| Sup.order process Labor costs | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| IL OP admin. LT | 0.092 | 0.087 | 0.087 | 0.087 | 0.087 | 0.087 | 0.088 | 0.086 | 0.087 | 0.091 | 0.088 | 0.089 | 0.087 | 0.088 | 0.087 | 0.087 | 0.087 | 0.088 |
| Transp. Perfect order | 0.063 | 0.059 | 0.060 | 0.059 | 0.059 | 0.059 | 0.060 | 0.059 | 0.059 | 0.062 | 0.060 | 0.061 | 0.059 | 0.060 | 0.059 | 0.059 | 0.059 | 0.060 |
| IL MH damage | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 |
| IL MH facility invest. | 0.020 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.020 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 |
| MH operating costs | 0.017 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.017 | 0.016 | 0.017 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| Stocking facility invest. | 0.031 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.030 | 0.029 | 0.030 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 |
| Stocking costs | 0.047 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.045 | 0.044 | 0.044 | 0.046 | 0.045 | 0.045 | 0.044 | 0.045 | 0.044 | 0.044 | 0.044 | 0.045 |
| Inventory turnover | 0.051 | 0.048 | 0.049 | 0.048 | 0.048 | 0.048 | 0.049 | 0.048 | 0.048 | 0.051 | 0.049 | 0.050 | 0.049 | 0.049 | 0.048 | 0.048 | 0.048 | 0.049 |
| W. Order process admin. LT | 0.077 | 0.072 | 0.073 | 0.072 | 0.072 | 0.072 | 0.074 | 0.072 | 0.072 | 0.076 | 0.074 | 0.074 | 0.073 | 0.073 | 0.072 | 0.072 | 0.072 | 0.073 |
| OP accuracy | 0.062 | 0.059 | 0.059 | 0.059 | 0.059 | 0.059 | 0.060 | 0.059 | 0.059 | 0.062 | 0.060 | 0.060 | 0.059 | 0.060 | 0.059 | 0.059 | 0.059 | 0.060 |
| OP facility invest. | 0.035 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.034 | 0.033 | 0.033 | 0.035 | 0.033 | 0.034 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| OP costs | 0.019 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.019 | 0.018 | 0.018 | 0.019 | 0.019 | 0.019 | 0.018 | 0.019 | 0.018 | 0.018 | 0.018 | 0.018 |
| Package reused rate | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Packaging costs | 0.033 | 0.031 | 0.032 | 0.031 | 0.031 | 0.032 | 0.032 | 0.031 | 0.031 | 0.033 | 0.032 | 0.032 | 0.032 | 0.032 | 0.032 | 0.031 | 0.032 | 0.032 |
| Kits created per hour | 0.062 | 0.058 | 0.059 | 0.058 | 0.058 | 0.058 | 0.059 | 0.058 | 0.058 | 0.061 | 0.059 | 0.060 | 0.058 | 0.059 | 0.058 | 0.058 | 0.058 | 0.059 |
| Kitting accuracy | 0.021 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.021 | 0.020 | 0.020 | 0.021 | 0.021 | 0.021 | 0.020 | 0.021 | 0.020 | 0.020 | 0.020 | 0.021 |
| OL Order process LT | 0.078 | 0.073 | 0.074 | 0.073 | 0.073 | 0.073 | 0.074 | 0.073 | 0.073 | 0.077 | 0.074 | 0.075 | 0.074 | 0.074 | 0.073 | 0.073 | 0.073 | 0.074 |
| OL MH damage | 0.024 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.024 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 | 0.023 |
| OL MH costs | 0.011 | 0.010 | 0.011 | 0.010 | 0.010 | 0.010 | 0.011 | 0.010 | 0.010 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.010 | 0.011 |
| Account receivable LT | 0.025 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.025 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 |
| On-time delivery | 0.117 | 0.110 | 0.111 | 0.110 | 0.110 | 0.110 | 0.112 | 0.110 | 0.110 | 0.116 | 0.112 | 0.113 | 0.111 | 0.111 | 0.110 | 0.110 | 0.110 | 0.111 |
| delivery costs | 0.042 | 0.039 | 0.040 | 0.039 | 0.039 | 0.039 | 0.040 | 0.039 | 0.039 | 0.042 | 0.040 | 0.040 | 0.040 | 0.040 | 0.039 | 0.039 | 0.039 | 0.040 |
| Order fill rate | 0.075 | 0.070 | 0.071 | 0.070 | 0.070 | 0.071 | 0.072 | 0.070 | 0.070 | 0.074 | 0.072 | 0.072 | 0.071 | 0.072 | 0.071 | 0.071 | 0.071 | 0.071 |
| Customer service costs | 0.047 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.045 | 0.044 | 0.044 | 0.046 | 0.045 | 0.045 | 0.044 | 0.045 | 0.044 | 0.044 | 0.044 | 0.045 |

Table 50  The stable weighted of the case – Part II

| | OP costs | Package reused rate | Packaging costs | Kits created per hour | Kitting accuracy | OL Order process LT | OL MH damage | OL MH costs | Account receivabl e LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Costs of material | 0.004 | 0.004 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| Supplier schedule | 0.068 | 0.070 | 0.076 | 0.067 | 0.067 | 0.067 | 0.070 | 0.071 | 0.067 | 0.067 | 0.070 | 0.067 | 0.068 |
| Material Quality | 0.026 | 0.027 | 0.029 | 0.026 | 0.026 | 0.026 | 0.027 | 0.028 | 0.026 | 0.026 | 0.027 | 0.026 | 0.026 |
| Supplier Capacity | 0.021 | 0.022 | 0.024 | 0.021 | 0.021 | 0.021 | 0.022 | 0.022 | 0.021 | 0.021 | 0.022 | 0.021 | 0.021 |
| Forecast accuracy | 0.040 | 0.041 | 0.044 | 0.039 | 0.039 | 0.039 | 0.041 | 0.041 | 0.039 | 0.039 | 0.041 | 0.039 | 0.040 |
| Sup. order process admin. L.T. | 0.035 | 0.036 | 0.039 | 0.034 | 0.034 | 0.034 | 0.036 | 0.037 | 0.035 | 0.035 | 0.036 | 0.035 | 0.035 |
| Sup.order process Labor costs | 0.003 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.004 | 0.004 | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 |
| IL OP admin. LT | 0.088 | 0.091 | 0.099 | 0.087 | 0.087 | 0.087 | 0.092 | 0.093 | 0.087 | 0.087 | 0.091 | 0.088 | 0.089 |
| Transp. Perfect order | 0.060 | 0.062 | 0.067 | 0.059 | 0.059 | 0.059 | 0.062 | 0.063 | 0.059 | 0.059 | 0.062 | 0.060 | 0.060 |
| IL MH damage | 0.008 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.008 | 0.008 | 0.009 | 0.008 | 0.008 |
| IL MH facility invest. | 0.019 | 0.019 | 0.021 | 0.019 | 0.019 | 0.019 | 0.020 | 0.020 | 0.019 | 0.019 | 0.020 | 0.019 | 0.019 |
| MH operating costs | 0.016 | 0.017 | 0.018 | 0.016 | 0.016 | 0.016 | 0.017 | 0.017 | 0.016 | 0.016 | 0.017 | 0.016 | 0.017 |
| Stocking facility invest. | 0.029 | 0.030 | 0.033 | 0.029 | 0.029 | 0.029 | 0.030 | 0.031 | 0.029 | 0.029 | 0.030 | 0.029 | 0.029 |
| Stocking costs | 0.045 | 0.046 | 0.050 | 0.044 | 0.044 | 0.044 | 0.046 | 0.047 | 0.044 | 0.044 | 0.046 | 0.044 | 0.045 |
| Inventory turnover | 0.049 | 0.051 | 0.055 | 0.048 | 0.048 | 0.048 | 0.051 | 0.052 | 0.049 | 0.049 | 0.051 | 0.049 | 0.049 |
| W. Order process admin. LT | 0.074 | 0.076 | 0.083 | 0.072 | 0.072 | 0.072 | 0.076 | 0.077 | 0.073 | 0.073 | 0.076 | 0.073 | 0.074 |
| OP accuracy | 0.060 | 0.061 | 0.067 | 0.059 | 0.059 | 0.059 | 0.062 | 0.063 | 0.059 | 0.059 | 0.062 | 0.060 | 0.060 |
| OP facility invest. | 0.034 | 0.034 | 0.038 | 0.033 | 0.033 | 0.033 | 0.035 | 0.035 | 0.033 | 0.033 | 0.035 | 0.033 | 0.034 |
| OP costs | 0.019 | 0.019 | 0.021 | 0.018 | 0.018 | 0.018 | 0.019 | 0.019 | 0.018 | 0.018 | 0.019 | 0.018 | 0.019 |
| Package reused rate | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Packaging costs | 0.032 | 0.033 | 0.036 | 0.031 | 0.031 | 0.032 | 0.033 | 0.034 | 0.032 | 0.032 | 0.033 | 0.032 | 0.032 |
| Kits created per hour | 0.059 | 0.061 | 0.066 | 0.058 | 0.058 | 0.058 | 0.061 | 0.062 | 0.058 | 0.058 | 0.061 | 0.059 | 0.059 |
| Kitting accuracy | 0.021 | 0.021 | 0.023 | 0.020 | 0.020 | 0.020 | 0.021 | 0.022 | 0.020 | 0.020 | 0.021 | 0.020 | 0.021 |
| OL Order process LT | 0.075 | 0.076 | 0.084 | 0.073 | 0.073 | 0.073 | 0.077 | 0.078 | 0.073 | 0.073 | 0.077 | 0.074 | 0.075 |
| OL MH damage | 0.023 | 0.024 | 0.026 | 0.023 | 0.023 | 0.023 | 0.024 | 0.024 | 0.023 | 0.023 | 0.024 | 0.023 | 0.023 |
| OL MH costs | 0.011 | 0.011 | 0.012 | 0.010 | 0.010 | 0.010 | 0.011 | 0.011 | 0.010 | 0.010 | 0.011 | 0.011 | 0.011 |
| Account receivabl e LT | 0.024 | 0.025 | 0.027 | 0.024 | 0.024 | 0.024 | 0.025 | 0.026 | 0.024 | 0.024 | 0.025 | 0.024 | 0.024 |
| On-time delivery | 0.112 | 0.115 | 0.126 | 0.110 | 0.110 | 0.110 | 0.116 | 0.117 | 0.110 | 0.110 | 0.115 | 0.111 | 0.112 |
| delivery costs | 0.040 | 0.041 | 0.045 | 0.039 | 0.039 | 0.039 | 0.042 | 0.042 | 0.040 | 0.040 | 0.041 | 0.040 | 0.040 |
| Order fill rate | 0.072 | 0.074 | 0.081 | 0.070 | 0.070 | 0.071 | 0.074 | 0.075 | 0.071 | 0.071 | 0.074 | 0.071 | 0.072 |
| Customer service costs | 0.045 | 0.046 | 0.050 | 0.044 | 0.044 | 0.044 | 0.046 | 0.047 | 0.044 | 0.044 | 0.046 | 0.044 | 0.045 |

### 4.3.4. Results Analysis

The vectors in the stable weighted supermatrix (Table 49,

Table **50**) represent the relative weights of the performance measures, which is local to clusters. To obtain the goal relative weights, they are further normalized by the sum of the first column. Table 51 summarizes the relative weights of the four logistics processes, relative weights of performance measures, as well as the rank of importance. From the Table 51, we can observe that outbound logistics is more critical than the other three logistics processes. This importance of the outbound logistics is also reflected by high rank of importance of performance measures in it.

Table 51 Relative weights of performance measures – case study

| **Logistics process** | **Relative weights of processes** | **Performance measures** | **Relative weights** | **Rank of Importance** |
|---|---|---|---|---|
| **Supplying** | 0.162 | Costs of material | 0.0035 | 29 |
| | | Supplier schedule | 0.0559 | 7 |
| | | Material Quality | 0.0216 | 20 |
| | | Supplier Capacity | 0.0172 | 23 |
| | | Forecast accuracy | 0.0325 | 15 |
| | | Sup. order process admin. L.T. | 0.0289 | 16 |
| | | Sup. order process Labor costs | 0.0028 | 30 |
| | | IL OP admin. LT | 0.0727 | 3 |
| | | Transp. Perfect order | 0.0496 | 8 |

| | | | | |
|---|---|---|---|---|
| **Inbound Logistics** | 0.228 | IL MH damage | 0.0069 | 28 |
| | | IL MH facility invest. | 0.0156 | 25 |
| | | MH operating costs | 0.0135 | 27 |
| | | Stocking facility invest. | 0.0241 | 19 |
| | | Stocking costs | 0.0368 | 13 |
| **Warehousing** | 0.29 | Inventory turnover | 0.0406 | 11 |
| | | W. Order process admin. LT | 0.0607 | 5 |
| | | OP accuracy | 0.0493 | 9 |
| | | OP facility invest. | 0.0276 | 17 |
| | | OP costs | 0.0153 | 26 |
| | | Package reused rate | 0.0025 | 31 |
| | | Packaging costs | 0.0264 | 18 |
| | | Kits created per hour | 0.0487 | 10 |
| | | Kitting accuracy | 0.0169 | 24 |
| **Outbound Logistics** | 0.32 | OL Order process LT | 0.0614 | 4 |
| | | OL MH damage | 0.0191 | 22 |
| | | OL MH costs | 0.0087 | 2 |
| | | Account receivable LT | 0.0200 | 21 |
| | | On-time delivery | 0.0922 | 1 |
| | | delivery costs | 0.0331 | 14 |
| | | Order fill rate | 0.0591 | 6 |
| | | Customer service costs | 0.0368 | 12 |

*sup.=supplying; LT=lead time; IL=inbound; OL=outbound; OP=order picking; admin.=administration

To obtain the degrees of dependency matrix, we further categorize the performance measures into two groups: high relative weights and low relative weights. Performance measures ranking above 15 are grouped in high relative weight group, otherwise, low relative weight group. Then according to the results from DEMATEL analysis, performance measures are put into cause and effect groups. The degrees of dependency matrix (Table 52) are obtained by combining these two categorizations. The implications for managerial purposes are also attached in the table.

Table 52 Degrees of dependency matrix – case study

| **Causal** | **Weight** | **Performance measures** | **Implication** |
|---|---|---|---|
| **Cause** | High | Forecast accuracy, IL OP admin. LT, Transp. Perfect order, W. Order process admin. LT, Kits created per hour, OL Order process LT, OL MH costs, Order fill rate | Managers' attentions need to focus on improving these measures if the company wants to effectively improve the whole performance of logistics. |
| | Low | Material Quality, Supplier Capacity, Sup. order process Labor costs, IL MH facility invest., OP costs, Package reused rate, Packaging costs, Kitting accuracy, OL MH damage | These measures are less important in improving logistics performance. |
| **Effect** | High | Supplier schedule, Stocking costs, Inventory turnover, OP accuracy, On-time delivery, Delivery costs, Customer service costs | These measures are relatively more critical in understanding how is the logistics performance of the company. |
| | Low | Costs of material, Sup. order process admin. L.T., IL MH damage, MH operating costs, Stocking facility invest., OP facility invest., Account receivable LT | These measures are less significant as indictors of logistics performance. |

To improve logistics performance, managers should give priority to the cause measures with high relative weighs. To have a better understanding of logistics performance, managers can focus on the performance measures in the effect group with high relative weights.

The outputs of the ILPMS provide a global picture for mangers to make decisions, avoiding local optimization. For instance, to speak of order picking cost measure in the warehousing cluster, it is regarded as a cause factor that has the biggest prominence, meaning that it has the biggest impact on the warehousing performance. However, when considering all the performance measures as a whole, it no longer takes the priority to improve logistics performance.

Furthermore, the outputs sabotage some common senses in operation management. Taking order picking cost as an example again, it is normally believed as an effect measure, which is opposite in our results. Order picking cost, to some extent, is an operation result. Nevertheless, the high or low order picking costs may impact the decision of whether to increase order picking investment. Once it gives more effect than it receives, it becomes an effect factor.

Finally, for performance measures in the same category with high relative weights and cause group, they have different priorities in improving logistics performance. Measures with a higher rank of importance should take the priority to be improved if the resources are limited. Likewise, for those in high and effect group, the rank of importance is the criteria to prioritize measures to be closely monitored once resources are constrained.

# CHAPTER 5 CONCLUSIONS AND FUTURE RESEARCH

## 5.1. Summary

This study began with a literature review about performance measurement systems and logistics performance measurement systems. The evolution of PMSs and requirements for new LPMSs are summarized, which became the motivation for this research.

To fulfill the requirements, the research established an integrated logistics performance measurement system. The integration was embodied through a performance framework that combines hierarchical and process-based structures. One of the advantages of this framework is that it is able to solve different types of interrelationships between logistics objectives and between performance measures. Another benefit is its expandability. All stakeholders that are identified to be relevant to logistics performance can be incorporated in the system. The framework also ensures the connection between logistics organization's measurement needs and the information reporting capabilities covering performance measures chosen by the firm.

On the basis of the framework, logistics performance measures and metrics were developed at each decision level. In the ILPMS, each measure/metric is assigned to specific manager(s). The desire of manager(s) to better monitor and control measure(s)/metric(s) will improve logistics performance.

To address the large number of performance measures in the ILPMS, a hybrid multi-criteria decision making methodology (the integration of DEMATEL and ANP) is adopted. The outputs of this methodology are the degrees of dependencies among performance measures. The "dependency" information categorizes measures into cause and effect group, while "degree" informs the relative importance of performance measures. Based on the outputs, decision makers are able to prioritize performance measures and emphasize those measures that are more effective to improve logistics performance.

Finally, the ILPMS was applied to data and information from a manufacturing company. The system helped the company build a sophisticated logistics performance measurement system to manage logistics. The results not only provided the company feedback about logistics performance, but also suggestions for future logistics improvement.

## 5.2. Contributions

First of all, based on the literature, we found that research about logistics performance measurement system is very limited, which is unable to meet the increasingly important role of logistics in manufacturing companies. This paper contributes to the research field by providing a systematic methodology to establish logistics performance measurement systems for manufacturing companies. What's more, the ILPMS deals with some of the unsolved issues in this research field, especially the interrelationships between performance measures. Thirdly, the ILPMS integrates the hybrid MCDM methodology to manage logistics performance measures, which, to our knowledge, is the first time in the logistics research field. In most cases, MCDM methodologies, including this one, are utilized to select potential logistics providers. Fourthly, the ILPMS was applied to a real case and the outputs support its validity. Therefore, the ILPMS is very practical and valuable.

## 5.3. Limitations and Future Research

The framework of the ILPMS is based on a process-based structure, which rules out companies that manage logistics based on functions. What's more, both ANP and DEMATEL methodology require decision makers having knowledge about relationships about performance measures to rate, which may not the case in reality. Thirdly, in the case study, only logistics experts are included to collect information and data about logistics activities. It would be valuable if customers' opinions are included in the survey. Since logistics performance is becoming increasingly more customer-oriented.

The expandability of the ILPMS indicates the possibilities to adapt the ILPMS to logistics companies. Therefore, it would be very interesting to see the effectiveness of the system if applied to a logistics company. Furthermore, it may be also worthwhile to develop a performance measurement system for supply chain management based on this ILPMS.

It would also be valuable to form a diverse team to collect difference voices, from logistics experts, logistics professional to customers. The prioritization of performance measures may be totally different from that of an insider only.

Finally, the amount of performance measures and metrics developed according to the ILPMS could become too many, especially when more stakeholders are involved. A large number of performance measures will lead to an enormous workload to rate the relationships between performance measures. Hence, finding an effective method to eliminate some less important performance measures as a first step before the implementation of hybrid MCDM would be desirable.

# REFERENCES

Aguezzoul, A. (2010). Multi-Criteria Decision Making Methods for Third-Party Logistics Evaluation. In. *Second International Conference on Engineering System Management and Applications.* IEEE.

Alkhatib, S.F., Darlington, R. & Nguyen, T.T. (2015). Logistics Service Providers (LSPs) evaluation and selection: Literature review and framework development. *Strategic Outsourcing: An International Journal*, 8(1), pp.102-134.

Amiri, M., Sadaghiyani, J. S., Payani, N. & Shafieezadeh, M. (2011). Developing a DEMATEL method to prioritize distribution centers in supply chain. *Management Science Letters*, 1, pp.279–288.

Andersson, P., Aronsson, H. & Storhagen, N.G. (1989). Measuring logistics performance. *Engineering Costs and Production Economics*, 17, pp. 253-262.

Andrejić, M., Bojović, N. & Kilibarda, M.(2016). A framework for measuring transport efficiency in distribution centers. *Transport Policy*, 45, pp.99–106.

Azzone, G., Masella, C. & BerteleÁ, U. (1991). Design of performance measures for time-based companies. *International Journal of Operations & Production Management*, 11(3), pp.77-85.

Bai, C. & Sarkis, J. (2012). Supply-chain performance-measurement system management using neighborhood rough sets, *International Journal of Production Research*, 50(9), pp.2484–2500.

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

Bititci, U. S., Carrie, A.S., & McDevitt, L. (1997). Integrated performance measurement systems: a development guide. *International Journal of Operations & Production Management*, 17(5), pp.522-534.

Bobbitt, L.M. (2004). An Examination of the Logistics Leverage Process: Implication for Marketing Strategy and Competitive Advantage. *Unpublished Ph.D. Dissertation, The University of Tennessee.*

Bottani, E. & Rizzi, A. (2006). A fuzzy TOPSIS methodology to support outsourcing of logistics services. *Supply Chain Management: An International Journal*, 11(4), pp. 294–308.

Brewer, P.C. & Speh, T.W. (2000). Using the Balanced Scorecard to Measure Supply Chain Performance. *Journal of business logistic,*21(1), pp.75-93.

Brown, M. (1996). Keeping Score: Using the Right Metrics to Drive World Class Performance. *Quality Resources*, New York, NY.

Büyüközkan, G. and Güleryüz, S. (2016). An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. *International Journal of Production Economics*, 182, pp.435-448.

Cagliano, A., Carlin, A. & Rafele, C. (2009). Understanding Supply Chain Complexity with Performance Measurement. *IFAC Proceedings*, 42(4), pp.1126-1131.

Caplice, C. & Sheffi, Y. (1995). A Review and Evaluation of Logistics Performance Measurement Systems. *The International Journal of Logistics Management*, 6(1), pp. 61 – 74.

Chan, F. T.S. & Qi, H.J. (2003). Feasibility of performance measurement system for supply chain: a process-based approach and measures. *Integrated Manufacturing Systems*, 14(3), pp.179-190.

Chan, F.T. S. & Qi, H. J. (2003)[b]. An innovative performance measurement method for supply chain management. *Supply Chain Management: An International Journal* 2003, 8(3), pp.209-223.

Chen, R.-C., Du, S.-C., Hu, Y.-F., Lin, S.-B. & Li, S.-S. (2005). Measuring Supply Chain Performance Based on SCOR: A Case Study of a Garment Company in Taiwan. *Proceedings of the Fifth International Conference on Electronic Business*, pp. 896 - 900.

Chow, G., Heaver, T. & Henriksson, L. (1994). Logistics Performance. *International Journal of Physical Distribution & Logistics Management*, 24(1), pp.17-28.

Cook, W.D. & Bala, K. (2007). Performance measurement and classification data in DEA: input-oriented model. *Omega*, 35 (1), 39-52.

Cooper, O., Tadikamalla, P. and Shang, J. (2012). Selection of a Third-Party Logistics Provider: Capturing the Interaction and Influence of Performance Metrics with the Analytical Network Process. *Journal of Multi-Criteria Decision Analysis*, 19(3-4), pp.115-128.

De Koster, M. B. M. & Balk, B.M. (2008). Benchmarking and Monitoring International Warehouse Operations in Europe. *Production and Operations Management,* 17(2), pp.175–183.

Domingues, M.L., Reis, V. & Macário R. (2015). A Comprehensive Framework for Measuring Performance in a Third Party Logistics Provider. *Transportation Research Procedia*, 10, pp.662 – 672.

Falatoonitoosi, E., Leman, Z., Sorooshian, S. & Salimi M. (2013).Decision-Making Trial and Evaluation Laboratory. *Research Journal of Applied Sciences, Engineering and Technology*, 5(13): 3476-3480.

Fawcett, S.E. & Cooper, M. B. (1998). Logistics Performance Measurement and Customer Success. *Industrial Marketing Management*, 27, pp.341–357.

Fitzgerald, L., Johnston, R., Brignall, S., Silvestro, R. & Voss, C. (1991). Performance Measurement in Service Business, CIMA, London.

Franceschini, F. and Rafele, C. (2000). Quality evaluation in logistic services. *International Journal of Agile Management Systems*, 2(1), pp.49-54.

Fugate, B.S., Mentzer, J. T. & Stank, T. P. (2010). Logistics Performance: Efficiency, Effectiveness, and Differentiation. *Journal of business logistics,* 31(1), pp.43.

Garcia, F.A., Marchetta, M.G., Camargo, M., Morel, L. & Forradellas, R.Q. (2012). A Framework for Measuring Logistics Performance in the Wine Industry. *Intl. J. Production Economics,* 135, pp.284–298.

Ghalayini, A.M. and J.S. Noble, 1996, "The Changing Basis of Performance Measurement," *Intl. J of Operations and Production Management*, 16(8), pp. 63-80.

Gölcük, İ & Baykasoglu,A. (2016). An analysis of DEMATEL approaches for criteria interaction handling within ANP. *Expert Systems with Applications*, 46(15). pp. 346-366.

Griffis, S., Goldsby, T., Cooper, M. & Closs, D. (2004). Performance Measurement: Measure Selection Based Upon Firm Goals and Information Reporting Needs. *Journal of Business Logistics,* 25(2), pp.95-118.

Gunasekaran A. (2001). Performance Measures and Metrics in a Supply Chain Environment. *Intl. J of Operations & Production Management*, 21(1/2), pp.71-87.

Gunasekaran, A., Patelb, C. & McGaughey, R. E. (2004). A Framework for Supply Chain Performance Measurement. *Int. J. Production Economics*, 87, pp.333–347.

Gunasekaran, A. & Kobu B. (2007). Performance Measures and Metrics in Logistics and Supply Chain Management: A Review of Recent Literature (1995–2004) For Research and Applications. *International Journal of Production Research*, 45(12), pp.2819-2840.

Hamdan, A. & Rogers, K.J. (Jamie) (2007). Evaluating the efficiency of 3PL logistics operations, *Int. J. Production Economics,* 113, pp. 235–244.

Hanaoka, S. & Kunadhamraks, P. (2009). Multiple Criteria and Fuzzy Based Evaluation of Logistics Performance for Intermodal Transportation. *Journal of Advanced Transportation,* 43(2), pp. 123-153.

Holmberg, S. (2000). A systems perspective on supply chain measurements*, International Journal of Physical Distribution & Logistics Management*, 30(10), pp. 847-868.

Jakhar, S.K. & Barua, M.K. (2014): An integrated model of supply chain performance evaluation and decision-making using structural equation modeling and fuzzy AHP. *Production Planning and Control*, 25(11), pp. 938-957.

Joshi, R., Banwet, D.K. & Shankar, R. (2011). A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain. *Expert Systems with Applications*, 38(8), pp.10170-10182.

Jothimani, D. & Sarmah, S.P. (2014). Supply Chain Performance Measurement for Third Party Logistics. *Benchmarking: An International Journal*, 21(6), pp. 944-963.

Kaplan, R.S. & Norton, D.P. (1992). The balanced scorecard - measures that drive performance, *Harvard Business Review*, January-February, pp. 71-9.

Kaplan, Robert S. & Bruns, William J. (1987). Accounting and Management: Field Study Perspectives. Boston: Harvard Business School Press.

Kayakutlu, G. and Biiyiikzkan, G. (2007). Assessing Performance Factors for Logistics Companies. Troyes, France: IEEE.

Keebler, J. and Plank, R. (2009). Logistics performance measurement in the supply chain: a benchmark. *Benchmarking: An International Journal*, 16(6), pp.785-798.

Keegan, D.P., Eiler, R.G. & Jones, C.R. (1989). Are your performance measures obsolete?. *Management Accounting*, pp. 45-50.

Krauth, Elfriede; Moonen, Hans; and Popova, Viara (2005). Understanding Performance Measurement and Control in Third Party Logistics. *ECIS Proceedings*, 157.

Kueng, P. (2000). Process performance measurement system: a tool to support process-based organizations. *Total Quality Management*, 11(1), pp.67-85.

Lai, K.-H., Ngai, E.W.T. & Cheng, T.C.E. (2002). Measures for evaluating supply chain performance in transport logistics. *Transportation Research Part E*, 38, pp.439–456.

Lambert, D.M. & Pohlen, T.L. (2001). Supply Chain Metrics. *International Journal of Logistics Management.* 12(1), pp.1.

Li, C.-W. & Tzeng, G.-H. (2009). Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall. *Expert Systems with Applications*, 36, pp.9891–9898.

Lohman C., Fortuin L. & Wouters, M. (2002). Designing a Performance Measurement System: a Case Study. *European Journal of Operational Research*, 156, pp.267–286.

Lynch, R.L. & Cross, K.F. (1991), Measure Up!: The Essential Guide to Measuring Business Performance, Mandarin, London.

Mendelow, A. (1983). Information systems for organizational effectiveness: the use of the stakeholder approach, *Proceedings of the IFIP WG8.2 Working Conference on Beyond Productivity*, Minneapolis.

Najmi, A. & Makui, A. (2012). A conceptual model for measuring supply chain's performance. *Production Planning & Control*, 23(9), pp.694-706.

Neely, A., Mills, J.F., Platts, K.W., Gregory, M.J. & Richards, A.H. (1996). Performance measurement system design: should process based approaches be adopted? *International Journal of Production Economics*, 46-47. pp. 423-431.

Neely, A., Bourne, M. Kennerley M. (2000). Performance Measurement System Design: Developing and Testing a Process-Based Approach. *International Journal of Operations & Production Management*, 20(10), pp.1119-1145.

Neely, A. (2003). *Business performance measurement*. Cambridge: Cambridge University Press.

Neely, A., Marr, B., Roos, G., Pike, S. and Gupta, O. (2003). Towards the Third Generation of Performance Measurement. *Controlling*, 15(3-4), pp.129-136.

Neely, A. (2005). The evolution of performance measurement research Developments in the last decade and a research agenda for the next. *International Journal of Operations & Production Management*, 25(12), pp.1264-1277.

Pai, F.-Y. (2014). Analyzing Consumers' Decisions to Select Micro-Invasive Anesthetic Service Providers using a Hybrid method. *App. Math. Inf. Sci,* 8(6), pp.3071-3083.

Pohlen, T. L. & Coleman, B. J. (2005): Evaluating Internal Operations and Supply Chain Performance Using EVA and ABC. *Advanced Management Journal,* 70(2), pp. 45.

Rafele, C. (2004). Logistics Service Measurement: A Reference Framework. *Journal of Manufacturing Technology Management,* 15(3), pp. 280.

Rushton, A., Croucher, P. & Baker, P. (2010). The Handbook of Logistics & Distribution Management (4th ed.). *Kogan Page Limited/ The Chartered Institute of Logistics and Transport (UK)*.

Saaty, T. and Vargas, L. (2013). Decision making with the analytic network process. New York [u.a.]: Springer.

Said, A.A., Hassabelnaby, H.R. & Wier, B. (2003). An Empirical Investigation of the Performance Consequences of Nonfinancial Measures. *Journal of Management Accounting Research*, 15(1), pp.193-223.

Staudt, F. H., Alpan, G, Mascolo, M.D. & Rodriguez, C.M.T. (2015). Warehouse performance measurement: a literature review, *International Journal of Production Research*, 53(18), pp.5524-5544.

Shaik, M.N. & Abdul-Kader, W. (2013). Transportation in reverse logistics enterprise: a comprehensive performance measurement methodology, *Production Planning & Control*, 24(6), pp.495-510.

Shaik, M.N. & Abdul-Kader, W. (2014). Comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise. *Computers & Industrial Engineering*, 68, pp. 87-103.Stephens, S. (2001). Supply Chain Operations Reference Model Version 5.0: A New Tool to Improve Supply Chain Efficiency and Achieve Best Practice. *Information Systems Frontiers,* 3(4), pp.471–476.

Stern, J. M., Stewart, G. B. III & Chew, D. H. Jr. (1995), 'The EVA® Financial System', *Journal of Applied Corporate Finance*, 8(2), pp. 32-46.

So, S.-h., Kim, J., Cheong, K & Cho, G. (2006): Evaluating the Service Quality of Third Party Logistics Service Providers Using the Analytic Hierarchy Process. *Journal of Information Systems and Technology Management,* 3(3), pp. 261-270.

Supeekit, T., Somboonwiwat T. & Kritchanchai, D. (2016). DEMATEL-modified ANP to evaluate internal hospital supply chain Performance. *Computers & Industrial Engineering,*102, pp.318–330.

Tangen,S. (2004).Performance measurement: from philosophy to practice, *International Journal of Productivity and Performance Management*, 53(8), pp.726-737.

Yang, J.L. & Tzeng, G.-H. (2011). An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method. *Expert Systems with Applications*, 38(3), pp.1417-1424.

# APPENDICES

The following provides all of the original survey results received. The survey process is comprised of four sequential surveys.

Survey 1:

## Survey to establish an integrated logistics performance measurement system

The objective of my thesis is to establish an integrated logistics performance measurement system. In order to validate the system, I need input from logistics professionals. The survey should take at most 20-30 minutes to complete. Thanks for your time!

***My recommendation is to look at the APICS Supply Chain Operations Reference (SCOR) model and framework, which has common industry metrics and definitions for the logistics performance measurement system***. *See http://www.apics.org/apics-for-business/products-and-services/apics-scc-frameworks/scor).*

**Please follow these instructions to fill out the corresponding forms.**

### Step 1: Identify stakeholders that have interests in logistics and their associated objectives

Step 1.1 Identify departments/business units that influence or are influenced by logistics operations.

According to the situation in your company, please fill out **Form 1 (page 3)**. In the form, some business units have been listed as examples. If they are the stakeholders in your company, please check “Yes” and think about their expectations/objectives/concerns to logistics. If they are not correct stakeholders, please check “No” and ignore them. You may add more stakeholders in the form as well as their expectations for logistics operations.

Step 1.2 Specify logistics objectives of logistics process owners

Logistics activities are categorized into four logistics processes: supplying, inbound logistics, warehousing and outbound logistics. The four logistics process owners may have different logistics objectives from business managers. Please fill out **Form 2 (page 4)** according to your company’s situation.

## Step 2: Specify logistics metrics to measure logistics activities

Step 2.1: Identify the **main logistics activities** associated within the four logistics processes.

- Supplying process starts from receiving requests from warehousing and ends with order confirmed from suppliers **(page 5)**.
- Inbound logistics starts from receiving confirmation from supplying department and ends with stocking items in warehouse or manufacturing site **(page 6)**.
- Warehousing includes all activities associated with maintaining inventory and preparing items for outbound shipment **(page 7)**.
- Outbound logistics starts from receiving an order from the customer and ends with order delivery **(page 8)**.

In **Form 3 (pages 5-8)** there are some sample activities listed, check "Yes" if it is an activity in your company and "No" if it isn't. You may add more logistics activities in **Form 3**, based on the logistics operations in your company.

Step 2.2: Fill out performance metrics/key performance index (KPIs) that measure corresponding logistics activities in **Form 3**.

**Form 1: Business Stakeholders Objectives**

| **Stakeholder (Department)** | **Yes or No** | **Logistics Objectives** |
|---|---|---|
| Logistics | Yes | (i.e. high order fulfill rate ) |
| Manufacturing | Yes | (i.e. supplying responsiveness) |
| Financial | Yes | (i.e. controlled logistics costs), Total cost to serve, cash-to-cash cycle time, return on supply chain fixed assets, return of working capital |
| Sales & marketing | Yes | (i.e. high customer service) |
| Human Resources | No | (i.e. high employee utilization) |

| | | |
|---|---|---|
| Government/customer | Yes | (i.e. employee safety), delivery to contract (were contract metrics achieved on Government contracts? Metrics are usually fill rate or equipment availability) |
| Supplier Management | Yes | Supplier assessment, supplier evaluation, acting as interface between company and supplier |
| Contracts & Procurement | Yes | Supplier contracting |

### Form 2: Logistics Process Owners Objectives

| **Logistics process owner** | **Logistics objectives** |
|---|---|
| Supplying process owner | i.e. supplying lead time |
| Inbound logistics process owner | i.e. high moving efficiency |
| Warehousing process owner | i.e. low stock out rate; high asset utilization |
| Outbound logistics process owner | i.e. high logistics delivery quality |

**Form 3: Logistics Activity Metrics/KPI**

| **Logistics process** | **Logistics activity** | **Yes or No** | **Logistics metrics/KPI** |
|---|---|---|---|
| Supplying | Sourcing (Supplier Management (SM)) | Yes | i.e. sourcing cost (SM uses an extensive supplier evaluation checklist, to include site visits, in order to qualify suppliers). Cost, schedule, quality, past performance, approved supplier, capacity |
| | Demand forecasting | Yes | i.e. forecasting accuracy (forecast accuracy) |
| | Order processing (Order management) | Yes | Administrative Lead Time |
| **Logistics process** | **Logistics activity** | **Yes or No** | **Logistics metrics/KPI** |
| Inbound Logistics | Order processing | Yes | i.e. order processing time (Administrative Lead Time)_ |
| | Transportation | Yes | i.e. miles/gallon, on time delivery, supply response time (perfect order fulfilment within a delivery window) |
| | Material handling | Yes | Sometimes contracted out to a 3PL |

| | | | |
|---|---|---|---|
| | Stocking | Yes | Sometimes contracted out to a 3PL |
| **Logistics process** | **Logistics activity** | **Yes or No** | **Logistics metrics/KPI** |
| Warehousing | Stock-taking | Yes | i.e. stock-taking frequency. Sometimes contracted out to a 3PL |
| | Order processing | Yes | i.e. order processing time |
| | Order picking | Yes | Accuracy |
| | Sorting | Yes | Usually rolled into order picking accuracy. |
| | Packaging | Yes | Can packaging be reused/recycled? Disposal of dunnage (packaging). |
| | Kitting | Yes | Kits created per hour, and kitting accuracy, where a kit is a group of used to support parts used to support eight hours of assembly by a mechanic on the shop floor. |

| Logistics process | Logistics activity | Yes or No | Logistics metrics/KPI |
|---|---|---|---|
| Outbound Logistics | Order processing | Yes | Administrative lead time |
| | Material handling | Yes | Measure of damage |
| | Delivery/transportation | Yes | On-time delivery |
| | Customer service | Yes | Was order delivered within delivery window? |

Survey 2:

## Survey to establish an integrated logistics performance measurement system

The objective of my thesis is to establish an integrated logistics performance measurement system. In order to validate the system, I need input from logistics professionals. The survey should take at most 20-25 minutes to complete. Thank you for your time!

This survey follows the previous one which aims to develop logistics performance measures. In this survey, we want to collect relationship information between logistics performance measures to set priority for managerial purposes. It is decomposed into two steps:

### Step1: Rate relationship between clusters

In the logistics performance measurement system, logistics operations are divided into four processes: supplying, inbound logistics, warehousing and outbound logistics, which are called "clusters".

- Supplying process starts from receiving requests from warehousing and ends with order confirmed from suppliers, specifically, supplier management, demand forecasting and order management activity.
- Inbound logistics starts from order receiving and ends with stocking items in warehouse or manufacturing site, specifically, order processing, transportation, material handling, and stocking activity.

- Warehousing includes all activities associated with maintaining inventory and preparing items for outbound shipment, specifically, stock-taking, order processing, order picking, packaging and kitting activity.
- Outbound logistics starts from receiving orders from the customers and ends with order delivery, specifically, order processing, material handling, delivery and customer services activity.

Please rate in Table 1 the degree that cluster *i* affecting cluster *j* based on your experience. Four ratings are used to determine the values of relationships between different clusters:

0 = no influence
1 = low influence
2 = high influence
3 = very high influence

**Table 1:**

| | Supplying | Inbound logistics | Warehousing | Outbound logistics |
|---|---|---|---|---|
| Supplying | 0 | 3 | 2 | 2 |
| Inbound logistics | 0 | 0 | 2 | 1 |
| Warehousing | 1 | 2 | 0 | 3 |
| Outbound logistics | 1 | 0 | 1 | 0 |

Step2: Rate relationship between logistics performance metrics **within** each cluster

Corresponding logistics performance metric(s) have been developed for each logistics activity in logistics processes/clusters. Please rate the relationship between logistics performance metrics within each cluster using the four rating values:

0 = no influence
1 = low influence
2 = high influence
3 = very high influence

in Table 2 (page3), table 3 (page4), table 4 (page5) and table 5 (page6) respectively.

a) Supplying cluster

Supplying cluster includes supplier management, demand forecasting and order management activity.

**Table 2**

| | Costs of material | Supplier schedule | Material Quality | Supplier Capacity | Forecast accuracy | OP admin. LT | OP Labor costs |
|---|---|---|---|---|---|---|---|
| Costs of material | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Supplier schedule | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| Material Quality | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Supplier Capacity | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| Forecast accuracy | 1 | 2 | 0 | 0 | 0 | 1 | 1 |
| OP admin. LT | 0 | 2 | 0 | 0 | 0 | 0 | 1 |
| OP Labor costs | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

***LT=Lead time; OP=Order processing**

b) Inbound logistics cluster

Inbound logistics cluster includes order processing, transportation, material handling, and stocking activity.

**Table 3**

| | OP admin. LT | Transp. Perfect order | MH damage | MH facility investment | MH operating costs | Stocking facility investment | Stocking costs |
|---|---|---|---|---|---|---|---|
| OP admin. LT | 0 | 0 | 0 | 0 | 2 | 1 | 2 |
| Transp. Perfect order | 0 | 0 | 1 | 1 | 2 | 1 | 2 |
| MH damage | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| MH facility investment | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| MH operating costs | 1 | 0 | 1 | 1 | 0 | 1 | 1 |
| Stocking facility investment | 0 | 1 | 1 | 1 | 1 | 0 | 2 |
| Stocking costs | 0 | 0 | 1 | 0 | 0 | 2 | 0 |

*OP=Order processing; LT=Lead time; Transp.=Transportation; MH=Material handling

c) Warehousing

Warehousing cluster includes stock-taking, order processing, order picking, packaging and kitting activity.

**Table 4**

| | Inventory turnover | Order process admin. LT | OP accuracy | OP facility investment | OP costs | Package reused rate | Packaging costs | Kits created per hour | Kitting accuracy |
|---|---|---|---|---|---|---|---|---|---|
| Inventory turnover | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| Order process admin. LT | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| OP accuracy | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 2 |
| OP facility investment | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| OP costs | 3 | 3 | 2 | 2 | 0 | 1 | 1 | 1 | 1 |
| Package reused rate | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 0 |
| Packaging costs | 0 | 0 | 1 | 1 | 0 | 2 | 0 | 1 | 1 |
| Kits created per hour | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| Kitting accuracy | 1 | 0 | 2 | 1 | 1 | 0 | 1 | 1 | 0 |

*OP=Order picking; LT=Lead time

d) Outbound logistics

Outbound logistics includes order processing, material handling, delivery and customer services activity.

**Table 5**

| | Order process LT | MH damage | MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|
| Order process LT | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 |
| MH damage | 0 | 0 | 2 | 1 | 1 | 1 | 1 | 2 |
| MH costs | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Account receivable LT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| On-time delivery | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| delivery costs | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Order fill rate | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 1 |
| Customer service costs | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

*LT=Lead time; MH=Material handling

Survey 3:

# Survey to establish an integrated logistics performance measurement system

The objective of my thesis is to establish an integrated logistics performance measurement system. In order to validate the system, I need input from logistics professionals. The survey should take at most 10-15 minutes to complete. Thank you for your time!

In logistics operations, the performance of one logistics activity may have influence on others'. For instance, demand forecast accuracy may affect material costs, order process labor cost, order fill rate etc. These performance measures may or may not belong to different process/clusters. In last survey, the influence between performance measures within processes/clusters (inner dependency) have been identified and rated. **This survey aims to find outer dependency between performance measures across clusters.**

Based on the analysis for last survey, we found that supplying process has strong influence on inbound logistics, warehousing and outbound logistics respectively. And outbound logistics also has a significant effect on warehousing.

Step1: Find performance measures in a supplying cluster that have influence on performance measures in inbound logistics.

**The first column of Table 1 lists all the performance measures in supplying cluster and the first row lists all the performance measures in inbound logistics cluster. Based on your knowledge, if the performance measures in the row have influence over measures in a column, please mark with "Y", otherwise, "N".**

*According to my knowledge, I have made my judgements for you reference. If they are not appropriate, please rectify them.*

Table 1 Influence between supplying and inbound clusters

| | Inbound OP admin. LT | Transp. Perfect order | MH damage | MH facility investment | MH operating costs | Stocking facility investment | Stocking costs |
|---|---|---|---|---|---|---|---|
| Costs of material | N | N | N | N | N | N | Y |
| Supplier schedule | Y | Y | N | N | N | N | Y could |
| Material Quality | N | N | Y | N | N | N | Y could |
| Supplier Capacity | N | Y | N | N | N | N | N |
| Forecast accuracy | Y | Y | N | N | N | Y affects capacity | N |
| Supplying OP admin. LT | Y | Y | N | N | N | Y affect capability | N |
| OP Labor costs | N | N | N | Y related | N | N | Y |

***OP=Order process; Transp.=Transportation; MH=Material handling**

Step1.2: Find performance measures in a supplying cluster that may have influence on performance measures in warehousing.

The first column of Table 2 lists all the performance measures in supplying cluster and the first row lists all the performance measures in warehousing cluster. Based on your knowledge, if the performance measures in first row have influence over measures in first column, please mark with “Y”, otherwise, “N”.

Table 2 Influence between supplying and warehousing clusters

| | Inventory turnover | OP admin. LT | Order picking accuracy | Order picking facility investment | Order picking costs | Package reused rate | Packaging costs | Kits created per hour | Kitting accuracy |
|---|---|---|---|---|---|---|---|---|---|
| Costs of material | N | N | N | N | N | N | Y possible | N | N |
| Supplier schedule | Y | Y | N | N | N | N | N | Y possible | N |
| Material Quality | N | N | N | N | N | N | N | Y possible | N |
| Supplier Capacity | Y | N | N | Y possible | N | N | N | N | N |
| Forecast accuracy | Y | Y | N | N | N | N | N | Y possible | N |
| OP LT | N | N | Y possible | Y possible | Y possible | N | N | Y possible | N |
| OP Labor costs | N | N | N | Y possible | Y possible | N | N | N | N |

*OP=Order process

Step1.3: Find performance measures in a supplying cluster that may have influence on performance measures in outbound logistics.

The first column of Table 3 lists all the performance measures in supplying cluster and the first row lists all the performance measures in outbound logistics cluster. Based on your knowledge, if the performance measures in first row have influence over measures in first column, please mark with “Y”, otherwise, “N”.

Table 3 Influence between supplying and outbound clusters

| | Outbound OP LT | Outbound MH damage | Outbound MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|
| Costs of material | N | N | Y | N | N | N | N | N |
| Supplier schedule | Y possible | N | N | Y possible | Y | N | Y | N |
| Material Quality | N | N | N | N | N | N | Y | N |
| Supplier Capacity | Y possible | N | N | N | Y | N | Y | N |
| Forecast accuracy | N | N | N | N | Y | N | Y | N |
| supplying OP LT | N | N | N | N | Y | N | Y | N |
| supplying OP Labor costs | N | N | N | N | N | Y possible | Y possible | N |

***OP=order process; MH=material handling**

Step2: Find performance measures in warehousing cluster that may have influence on performance measures in outbound logistics cluster.

The first column of Table 4 lists all the performance measures in warehousing cluster and the first row lists all the performance measures in outbound cluster. Based on your knowledge, if the performance measures in first row have influence over measures in first column, please mark with “Y”, otherwise, “N”.

Table 4 Influence between outbound logistics and warehousing clusters

| | Outbound Order process LT | MH damage | MH costs | Account receivable LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|---|---|---|
| Inventory turnover | N | N | N | Y | N | N | N | N |
| Order process admin. LT | N | N | N | N | Y | N | Y | Y |
| OP accuracy | Y possible | N | N | N | Y | Y possible | Y | Y |
| OP facility investment | Y possible | Y possible | N | N | Y | Y possible | Y | N |
| OP costs | N | N | N | N | N | Y possible | N | N |
| Package reused rate | N | N | Y possible | N | N | N | N | N |
| Packaging costs | N | Y possible | Y possible | N | N | Y possible | N | N |
| Kits created per hour | Y possible | N | N | N | N | N | Y possible | N |
| Kitting accuracy | N | N | N | N | Y possible | N | Y possible | N |

***OP=Order picking**

Survey 4:

## Survey to establish an integrated logistics performance measurement system

The objective of my thesis is to establish an integrated logistics performance measurement system. In order to validate the system, I need input from logistics professionals. The survey should take at most 20-25 minutes to complete. Thank you for your time!

This survey follows the previous one which aims to identify influence of performance measures across clusters. The influence of a performance measure in one cluster on other performance measures in another cluster is through rating relative weights between two performance measures.

1=equally important

3=moderately more important

5=strongly more important

7=very strongly more important

9=extremely more important

Values of 2, 4, 6 and 8 are intermediate values for comparisons between two successive points.

***Reciprocals of these values* are used for the corresponding transpose judgements,** i.e. if A is moderately more important than B, then A is 3 times' important than B and B is

1/3 important than A. Therefore, you only need to fill out the ***upper right triangle*** of the comparison tables.

Step1.1 With respect to Supplier schedule in supplying cluster

a) **Table 1 is to rate relative weights between measures in inbound logistics with respect to supplier schedule.** Ask questions, such as with respect to supplier schedule, how much more important the criterion of order processing lead time than transportation perfect order?

Table 1 Relative weights between inbound logistics performance measures

| | Inbound OP admin. LT | Transp. Perfect order | Stocking costs |
|---|---|---|---|
| Inbound OP admin. LT | 1 | 5 | 3 |
| Transp. Perfect order | | 1 | 1/3 |
| Stocking costs | | | 1 |

*OP=Order process; Transp.=Transportation; LT=Lead time

b) **Table 2 is to rate relative weights between measures in warehousing with respect to supplier schedule.** Ask questions, such as with respect to supplier quality, how much more important the criterion of inventory turnover than order process administration lead time?

Table 2  Relative weights between warehousing performance measures

| | Inventory turnover | Order process admin. LT | Kits created per hour |
|---|---|---|---|
| Inventory turnover | 1 | 3 | 1/6 |
| Order process  admin. LT | 1/3 | 1 | 1/3 |
| Kits created per hour | 6 | 3 | 1 |

* LT=Lead time

c) **Table 3 is to rate relative weights between measures in outbound logistics with respect to supplier schedule.** Ask questions, such as with respect to supplier schedule in supplying cluster, how much more important the criterion of account receivable lead time than order fill rate?

Table 3  Relative weights between outbound logistics performance measures

| | Order process LT | Account receivable LT | On-time delivery | Order fill rate |
|---|---|---|---|---|
| Order process LT | 1 | 5 | 1/2 | 1/3 |
| Account receivable LT | 1/5 | 1 | 1/5 | 1/7 |
| On-time delivery | 2 | 5 | 1 | 2 |
| Order fill rate | 3 | 7 | 1/2 | 1 |

***LT=Lead time;**

Step1.2   With respect to Material quality in supplying cluster

a) **Table 4 is to rate relative weights between measures in inbound logistics with respect to Material quality.** Ask questions, such as with respect to Material quality in supplying cluster, how much more important the criterion of material handling damage than stocking costs?

Table 4 Relative weights between inbound logistics performance measures

| | MH damage | Stocking costs |
|---|---|---|
| MH damage | 1 | 5 |
| Stocking costs | 1/5 | 1 |

Step1.3 With respect to Supplier capacity in supplying cluster

a) **Table 5 is to rate relative weights between measures in warehousing with respect to Supplier capacity.** Ask questions, such as with respect to Supplier capacity in supplying cluster, how much more important the criterion of inventory turnover than order picking facility investment?

Table 5 Relative weights between warehousing performance measures

| | Inventory turnover | OP facility investment |
|---|---|---|
| Inventory turnover | 1 | 1/3 |
| OP facility investment | 3 | 1 |

*OP=Order picking;

b) **Table 6 is to rate relative weights between measures in outbound with respect to Supplier capacity.** Ask questions, such as with respect to Supplier capacity in supplying cluster, how much more important the criterion of order process lead time than on-time delivery?

Table 6 Relative weights between outbound logistics performance measures

| | Order process admin. LT | On-time delivery | Order fill rate |
|---|---|---|---|
| Order process admin. LT | 1 | 1/5 | 1/3 |
| On-time delivery | 5 | 1 | 3 |
| Order fill rate | 3 | 1/3 | 1 |

*LT=Lead time;

Step 1.4 With respect to Forecast accuracy in supplying cluster

a) **Table 7 is to rate relative weights between measures in inbound logistics with respect to Forecast accuracy.** Ask questions, such as with respect to Forecast accuracy in supplying cluster, how much more important the criterion of order processing lead time than transportation perfect order?

Table 7 Relative weights between inbound logistics performance measures

| | Inbound OP LT | Transp. Perfect order | Stocking facility investment |
|---|---|---|---|
| Inbound OP LT | 1 | 3 | 3 |
| Transp. Perfect order | 1/3 | 1 | 1/2 |
| Stocking facility investment | 1/3 | 2 | 1 |

*OP=Order processing; LT=Lead time; Transp.=Transportation;

b) **Table 8 is to rate relative weights between measures in warehousing with respect to Forecast accuracy.** Ask questions, such as with respect to Forecast accuracy in supplying cluster, how much more important the criterion of inventory turnover than order process lead time?

Table 8 Relative weights between warehousing performance measures

| | Inventory turnover | Order process admin. LT | Kits created per hour |
|---|---|---|---|
| Inventory turnover | 1 | 5 | 1/6 |
| Order process admin. LT | 1/5 | 1 | 1/3 |
| Kits created per hour | 6 | 3 | 1 |

*LT=Lead time

c) **Table 9 is to rate relative weights between measures in outbound with respect to Forecast accuracy.** For instance, assume Forecast accuracy has influence on order process lead time and material handling costs in outbound logistics , then ask questions, such as with respect to Forecast accuracy in supplying cluster, how much more important the criterion of on-time delivery than order fill rate?

Table 9 Relative weights of outbound logistics performance measures

| | On-time delivery | Order fill rate |
|---|---|---|
| On-time delivery | 1 | 5 |
| Order fill rate | 1/5 | 1 |

Step1.5 With respect to Order process administration lead time in supplying cluster

a) **Table 10 is to rate relative weights between measures in inbound logistics with respect to supplying order process administration lead time.** Ask questions, such as with respect to supplying order process administration lead time in supplying cluster, how much more important the criterion of inbound order processing lead time than transportation perfect order?

Table 10 Relative weights of inbound logistics performance measures

| | Inbound OP admin. LT | Transp. Perfect order | Stocking facility investment |
|---|---|---|---|
| Inbound OP admin LT | 1 | 1/3 | 1/5 |
| Transp. Perfect order | 3 | 1 | 1/3 |
| Stocking facility investment | 5 | 3 | 1 |

*OP=Order processing; LT=Lead time; Transp.=Transportation;

b) **Table 11 is to rate relative weights between measures in warehousing with respect to supplying order process administration lead time.** Ask questions, such as with respect to order process administration lead time in supplying cluster, how much more important the criterion of order picking accuracy than order picking facility investment?

Table 11 Relative weights warehousing performance measures

| | OP accuracy | OP facility investment | OP costs | Kits created per hour |
|---|---|---|---|---|
| OP accuracy | 1 | 3 | 4 | 2 |
| OP facility investment | 1/3 | 1 | 1/3 | 1/5 |
| OP costs | 1/4 | 3 | 1 | 1/3 |
| Kits created per hour | 1/2 | 5 | 3 | 1 |

*OP=Order picking;

c) **Table 12 is to rate relative weights between measures in outbound with respect to supplying order process administration lead time.** Ask questions, such as with respect to order process administration lead time in supplying cluster, how much more important the criterion of on-time delivery than order fill rate?

Table 12 Relative weights between outbound logistics performance measures

| | On-time delivery | Order fill rate |
|---|---|---|
| On-time delivery | 1 | 5 |
| Order fill rate | 1/5 | 1 |

Step1.6 With respect to Order process Labor costs in supplying cluster

a) **Table 13 is to rate relative weights between measures in inbound logistics with respect to Order process Labor costs in supplying cluster.** Ask questions, such as with respect to Order process Labor costs in supplying cluster, how much more important the criterion of material handling facility investment than stocking costs?

Table 13 Relative weights inbound logistics performance measures

| | MH facility investment | Stocking costs |
|---|---|---|
| MH facility investment | 1 | 3 |
| Stocking costs | 1/3 | 1 |

b) **Table 14 is to rate relative weights between measures in warehousing with respect to order process labor costs in supplying cluster.** Ask questions, such as with respect to order process labor costs in supplying cluster, how much more important the criterion of order picking facility investment than order picking costs?

Table 14 Relative weights between warehousing performance measures

| | OP facility investment | OP costs |
|---|---|---|
| OP facility investment | 1 | 3 |
| OP costs | 1/3 | 1 |

*OP=Order picking;

c) Table 15 is to rate relative weights between measures in outbound with respect to process labor costs in supplying cluster. Ask questions, such as with respect to order process labor costs in supplying cluster, how much more important the criterion of delivery costs than order fill rate.

Table 15 Relative weights between outbound logistics performance measures

| | Delivery costs | Order fill rate |
|---|---|---|
| Delivery costs | 1 | 5 |
| Order fill rate | 1/5 | 1 |

Step2.1 With respect to Order process lead time in warehousing cluster

**Table 16 is to rate relative weights between measures in outbound logistics with respect to Order process lead time in warehousing**. Ask questions, such as with respect to order process lead time in outbound logistics cluster, how much more important the criterion of on-time delivery than order fill rate?

Table 16 Relative weights between outbound logistics performance measures

| | On-time delivery | Order fill rate | Customer service costs |
|---|---|---|---|
| On-time delivery | 1 | 3 | 5 |
| Order fill rate | 1/3 | 1 | 1/2 |
| Customer service costs | 1/5 | 2 | 1 |

Step2.2 With respect to order picking accuracy in warehousing

**Table 17 is to rate relative weights between measures in outbound logistics with respect to order picking accuracy in warehousing**. Ask questions, such as with respect to order picking accuracy in warehousing cluster, how much more important the criterion of outbound order process lead time than on-time delivery?

Table 17 Relative weights between outbound logistics performance measures

| | Order process LT | On-time delivery | Delivery costs | Order fill rate | Customer service costs |
|---|---|---|---|---|---|
| Order process LT | 1 | 1/2 | 4 | 4 | 3 |
| On-time delivery | 2 | 1 | 3 | 7 | 3 |
| delivery costs | 1/4 | 1/3 | 1 | 3 | 5 |
| Order fill rate | 1/4 | 1/7 | 1/3 | 1 | 1/3 |
| Customer service costs | 1/3 | 1/3 | 1/5 | 3 | 1 |

*OP=Order picking; LT=Lead time

Step2.3 With respect to order picking facility investment in warehousing

**Table 18 is to rate relative weights between measures in outbound logistics with respect to order picking facility investment in warehousing.** Ask questions, such as with respect to order picking facility investment in warehousing, how much more important the criterion of outbound order process lead time than material handling damage?

Table 18 Relative weights between outbound logistics performance measures

| | Order process LT | MH damage | On-time delivery | Delivery costs | Order fill rate |
|---|---|---|---|---|---|
| Order process LT | 1 | 1/5 | 1/3 | 3 | 2 |
| MH damage | 5 | 1 | 5 | 5 | 7 |
| On-time delivery | 3 | 1/5 | 1 | 3 | 5 |
| Delivery costs | 1/3 | 1/5 | 1/3 | 1 | 3 |
| Order fill rate | 1/2 | 1/7 | 1/5 | 1/3 | 1 |

Step2.4 With respect to packaging cost in warehousing

**Table 19 is to rate relative weights between measures in outbound logistics with respect to packaging cost in warehousing**. Ask questions, such as with respect to packaging cost in warehousing, how much more important the criterion of material handling damage than material handling costs?

Table 19 Relative weights between outbound logistics performance measures

| | MH damage | MH costs | Delivery costs |
|---|---|---|---|
| MH damage | 1 | 5 | 6 |
| MH costs | 1/5 | 1 | 1/2 |
| delivery costs | 1/6 | 2 | 1 |

*MH=material handling

Step2.5 With respect to Kits created per hour in warehousing

**Table 20 is to rate relative weights between measures in outbound logistics with respect to Kits created per hour in warehousing.** Ask questions, such as with respect to Kits created per hour in warehousing, how much more important the criterion of outbound order process lead time than customer service costs?

Table 20 Relative weights between outbound logistics performance measures

| | Order process LT | Customer service costs |
|---|---|---|
| Order process LT | 1 | 3 |
| Customer service costs | 1/3 | 1 |

Step2.6 With respect to Kitting accuracy in warehousing

**Table 21 is to rate relative weights between measures in outbound logistics with respect to Kitting accuracy in warehousing.** Ask questions, such as logistics with respect to Kitting accuracy in warehousing, how much more important the criterion of on-time delivery than order fill rate?

Table 21 Relative weights between outbound logistics performance measures

| | On-time delivery | Order fill rate |
|---|---|---|
| On-time delivery | 1 | 5 |
| Order fill rate | 1/5 | 1 |