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Six Sigma Approach For the Straddle Carrier Routing Problem

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ABSTRACT

This paper discusses how to route straddle carriers in port container terminals. This problem is solved in the context of optimizing transport operations. The contribution of the work lies in the formulation and subsequent development of a Six Sigma Approach solution for the problem. Generating and prioritizing the critical Six Sigma transportation plans, however, are real challenges in practice. This study aims to develop a novel approach based on a combined ANP and DEMATEL technique to help container terminals determine critical Six Sigma transportation plans. An empirical case study is used to explore the effectiveness of the proposed approach.

1. Introduction

Within container terminal different types of material handling equipment are used to transship containers from ships to storage yard, trucks and trains and vice versa. Over the past decades, ships have strongly increased in size, up to 8000 TEU (Twenty feet equivalent unit container). In order to use these big ships efficiently, the docking time at the port must be as small as possible. This means that large amounts of containers have to be loaded, unloaded and transshipped in a short time span, with a minimum use of expensive equipment.

A handling system for the retrieval and transport of containers is the straddle carrier (SC). SC is used for the retrieval of containers from the stack and for the transport to the quay cranes. This paper gives a planning to efficiently route the SC inside a container terminal for loading operations.

One of the success factors of a terminal is related to the time in port for container vessels and the transshipment rates the ship operators have to pay. We focus on the process of container transport by SC between the container ship and the storage yard. The primary objective is the reduction of the time in port for the vessels by maximizing the productivity of the Quay cranes, or in other words, minimizing the delay times of container transports that causes the Quay cranes to stop.

Six Sigma is one of the powerful business strategies that improves quality initiatives in many industries around the world. It is a company-wide systematic approach to achieving continuous process improvements. Not only a technique but also as a philosophy, performing at Six Sigma means producing only 3.4 defects out of every million opportunities for a business process (Pandey, 2007). There has been a significant increase and development of Six Sigma technology and methodology in organizations (Pande, Neumann, & Cavanugh, 2000, Pyzdek, 2003). Especially in the last decade, as a change and improvement strategy, Six Sigma has received considerable attention in global companies to generate maximum business benefit and competitive advantage (Su & Chou, 2008; Yang & Hsieh, 2009). This strategic approach consists of five basic phases: define measure, analyze, improve and control which can also be symbolized by initials, as D-M-A-I-C.

2. Related Works

Container terminals are very specific from a material handling point of view, because of the special characteristics of both the containers and the handling equipment.

Terminals have become increasingly important and more and more scientific literature is devoted to them. This is even truer for the automated terminals which are being established to manage with the increase in costs. The additional increase

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in ship sizes makes productivity perfection in container handling more important and therefore more research is to be expected. In this paper, we have discussed the related routing problems within container handling.

Operations Research has made important contributions for container terminals. The techniques employed vary from Mixed Integer Programming formulations, queuing models and simulation approaches.

In 1993, Dirk Steenken et al. adopted two models to solve the MSCRP. In the first model they reduce the problem to a simple TSP with assumptions that one Straddle Carrier (SC) is engaged. They use the balance and connect heuristic applied to solve the sequencing insertions in printed circuit board assemblies, referencing to Ball and Magazine (1988), various heuristics were investigated to solve this problem like the nearest neighbour heuristic (NN), the successive or cheapest insertion (SUC) and a 2- optimal exchange method (2OP), best results was found using the SUC method.

The expansion of this problem to multiple one is achieved by introducing fictitious vehicle depots and by using an assumption that two jobs should not succeed each other within the same tour if there is a great difference in their due dates. They also reported that they have added another procedure to their initial solution and a new term not explained.

The second model is developed using an analogy to machine scheduling (MAS) mentioned by Maas and Vob (1991). This model is based on some dispatching rules to select insertion positions.

In 2003, V. Franqueira presents a discussion about the multiple straddle carrier routing problem. Two constraints of this routing problem are discussed; the conflicts between SCs must be resolved; and container stock in the storage yard must be shared between all SCs.

The first constraint is divided into two types; a travel conflict exists when SC tries to cross another SC and a space conflict when a SC tries to move the same location where another SC is already placed.

The resolution of these types of conflict between SCs is presented by Ki Young Kim in 1998 for the travel conflict of two SCs. He proposes two strategies; the waiting strategy and the exchanging roles between SC's strategy. For the space conflict he uses a waiting strategy and a substitutive one.

The routing problem of multiple SCs (more than two) was also presented by K. Y. Kim with considering that containers are located in one or multiple blocks according to the assumptions that a pseudo work schedule would be constructed by appending the work schedules of all SCs, and there is no interference between equipments. Therefore the multiple routing is reduced to a single routing one.

By solving the single SC problem for the pseudo work schedule would theoretically solve the overall problem.

However V. Franqueira suggest that these assumptions turn the problem completely artificial, since each SC route will have to be selected manually from the output and each SC routing will have to occur in sequence and never in parallel.

V. Franqueira present a solution to some multiple routing problem, using the single SC routing procedure, by providing (through manual work) the container distribution table for each SC separately.

However, this procedure seems inappropriate since the potential parallelism of multiple SCs is ignored.

The paper presents by L.N. Spasovic et al. in 1999 results of a research designed to evaluate the potential for improving productivity and the quality of service for a straddle carrier operation. A methodology was developed to quantify possible savings from redesigning the straddle operation. The main effort was to develop and evaluate a series of algorithms for straddle assignment and control. The algorithms differ in a manner in which the straddles are given assignments to move containers. Their research focused only on trucks. The productivity of the whole group of straddles is not analyzed. This should include the straddles servicing on-dock rail, the cranes during ship loading and unloading as well as re-warehousing of containers in the yard.

E. Nishimura et al. in 2005 presents in their paper a Genetic Algorithm heuristic to solve the trailer routing problem using a dynamic routing assignment method. They focus on the tours related to one cycle operation of the quay cranes. Experimental results demonstrate that the dynamic assignment is better than static one. The drawback to their solution procedure is the complexity of the trailer routing, which may increase the possibility of human error. Trailer drives may find difficult to follow the complicated itineraries assigned to them, resulting in mistakes in driving.

In this paper we analyzed the routing problem of SCs to support tasks between quay cranes and yard areas. Since inbound containers are usually unloaded into a designated open space, the Straddle Carriers do not have to travel much during the unloading operation. However, the time for loading depends on the loading sequence of containers as well as the number of loaded containers. In this paper we focus on minimizing the travel time of the Straddle Carriers for loading outbound (export) containers. As Six Sigma is is regarded as a well-structured methodology for improving the quality of processes and products.

It helps achieve the container terminal's strategic goal through the effective use of container-driven approach, it is essential to prioritize the set of containers which provide maximum financial benefits to the organization. This study aims to develop a novel approach based on a combined ANP and DEMATEL technique to help terminals determine critical Six Sigma containers and identify the priority of these containers especially in loading process.

There are numerous techniques applied in evaluating Six Sigma methodology. According to De Koning and De Mast (2006), the Six Sigma program offers a wide range of tools and techniques, which might be statistical or non-statistical, that are intended to assist the project leader. Those methods even can be utilized in different phases of the Six Sigma containers. The successful implementation of Six Sigma requires stringent application of tools and techniques at different stages of the methodology (Antony, 2006).

The tools and techniques applied in the evaluation of six sigma phases can be classified as statistical tools like sampling

(Anderson- Cook, Patterson, & Hoerl, 2005; De Koning & De Mast, 2006), ANOVA (Yang, Choi, Park, Suh, & Chae, 2007), statistical process control (Anderson-Cook et al., 2005; Antony et al., 2007; De Koning & De Mast, 2006; Knowles et al., 2005; Nonthaleerak & Hendry, 2008; Yang et al., 2007), regression analysis (Antony, 2006; Antony & Banuelas, 2002; Knowles et al., 2005), correlation studies (Antony, 2006; Antony & Banuelas, 2002; Yang et al., 2007) etc., quality tools like quality function deployment (Antony, 2006; Antony & Banuelas, 2002; Antony et al., 2007; Anderson-Cook et al., 2005; Banuelas, Tennant, Tuersley, & Tang, 2006; De Koning & De Mast, 2006; Dedhia, 2005; Pyzdek, 2000, 2003; Pande et al., 2000; Yang et al., 2007), quality costing (Antony, 2006; Antony & Banuelas, 2002), or multi-criteria decision making methods especially analytic hierarchy process (AHP) (Dinesh Kumar, Crocker, Chitra, & Saranga, 2006; Pyzdek, 2000; Pyzdek, 2003; Yang et al., 2007).

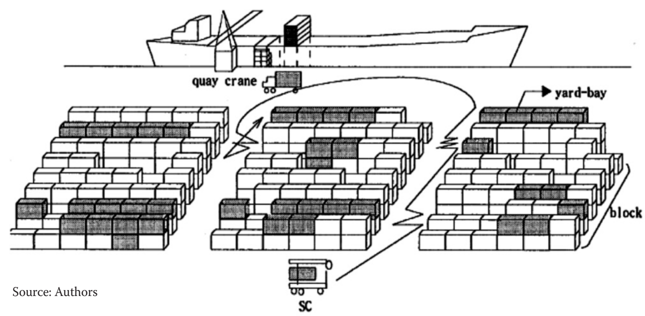
The effectiveness of decision-making depends on the ability of decision-makers to analyze the complex cause–effect relationships (Lin & Wu, 2008). In recent years, DEMATEL and ANP tools have been successfully used in some areas especially including project selection. Both methods are based on a pairwise comparison foundation and allow including the influence of intangibles. According to Wu (2008), DEMATEL is a wise option to calculate inner dependencies since it can produce more valuable information for making decisions. Following this statement, in this study we preferred to use the same approach applying DEMATEL to obtain relations of influence between sub-factors in a pairwise manner when inner dependency occur within an evaluation cluster, and ANP to calculate the weights of elements of evaluation clusters and to select the optimum alternative in selection of the Six Sigma containers framework. DEMATEL method is a potent method that helps in gathering group knowledge for forming a structural model, as well as visualizing the causal relationship of sub-systems through a causal diagram (Wu & Lee, 2007). ANP was used by Saaty (1996) to overcome the problem of dependence and feedback among criteria or alternatives (Liou et al., 2007). Here, DEMATEL is used to detect complex relationships and build relation structure among criteria for selecting Six Sigma containers. Additionally, ANP is adopted to deal with the problem of the subsystems interdependence and feedback; set priorities among goal, strategy and criteria and to determine the most appropriate container.

The rest of the paper is organized as follows. In Section 2, the proposed Six Sigma container evaluation framework is presented. In Section 3, the developed model is detailed. In Section 4, an empirical case study is given to explore the effectiveness of the proposed approach. In the last section, the findings of this research are discussed.

3. Six Sigma transportation plan evaluation framework

3.1. Straddle Carrier definition

By a "subtour" of a SC, we mean a visiting sequence of yard-bays which a SC visits to pick up all the containers which will be loaded onto a cluster of cells in the ship. An overview of a container terminal is presented in Figure 1.



Source: Authors

Figure 1: An overview of a container terminal.

3.2. Optimization model

An optimization model will be developed to display the container arrivals and yard locations and the actual and optimized assignment of straddles to containers.

The main part of this modeling is to develop and evaluate the algorithms for assigning straddles to containers.

The discussion from the previous section illustrates the fact that the manner in which the straddles are assigned container jobs impacts the cost and service quality of operation.

In general, the problem of assigning straddles to containers can be formulated as the assignment problem, a mathematical programming problem presented by L.N. Spasovic et al. in (1999).

$$Min\, Z = \sum_i \sum_j c_{ij} x_{ij} \qquad (1)$$

$s.t$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad for \quad j = 1, 2, \ldots, n \qquad (2)$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad for \quad i = 1, 2, \ldots, n \qquad (3)$$

Where:

i, j= indices

n = number of containers.

$x_{ij} = \begin{cases} 1 \textit{ if the feasible assignment of container“t” to straddle “j” is selected} \\ 0 \textit{ otherwise} \end{cases}$

c_{ij} = cos t *of hte* (i,j) *assignment*

Equation (1) is an objective function that minimizes costs. Constraints (2) and (3) are typical assignment problem restrictions that ensure that a straddle can be assigned to only one container and vice versa.

3.3. The DEMATEL methodology

The DEMATEL method originated for a Science and Human Affairs Program by the Geneva Research Centre of the Battelle Memorial Institute (Fontela & Gabus, 1976; Gabus & Fontela, 1973). It is a comprehensive method for building and analyzing a structural model involving causal relationships between complex factors (Zhou, Zhang, & Li, 2006). It is especially practical and useful for visualising the structure of complicated causal relationships with matrices or diagraphs (Wu, 2008). The matrices or diagraphs portray a contextual relation between the elements of the system (Tseng & Lin, 2008).

According to the above information, the major application of DEMATEL is to investigate the influential status and strength between the factors and transform them into an explicit structural mode of a system (Chiu, Chen, Tzeng, & Shyu, 2006; Lin & Wu, 2008; Tzeng, Chiang, & Li, 2007). The DEMATEL method has been successfully applied in many fields such as R&D project selection (Lin & Wu, 2008); real estate agent service quality expectation (Tseng, 2008a); evaluation of service solutions in service engineering (Shimomura, Hara, & Arai, 2008); introduction of a new product (Fekri, Aliahmadi, & Fathian, 2008; Zhou et al., 2006); airline safety measurement (Liou, Yen, & Tzeng, 2008; Liou et al., 2007); job performance structuring (Fang, Chen, & Hung, 2008); solid waste management (Tseng, 2008b; Tseng & Lin, 2008); evaluation and selection of knowledge management strategies (Wu, 2008); human factors engineering (Hori & Shimizu, 1999); developing global managers' competencies (Wu& Lee, 2007); evaluation of e-learning programs (Tzeng et al., 2007); hotel service quality (Tseng, 2009), safety and security systems analysis (Su & Zhang, 2007; Tamura, Nagata, & Akazawa, 2002); regional development (Dytczak & Ginda, 2008); strategic planning (Dytczak & Ginda, 2008b; Hung, Chou, & Tzeng, 2007); location selection (Chen & Yu, 2008) etc.

This research explains the definition and steps of DEMATEL with reference to studies of relative scholars (Fang et al., 2008; Lin & Tzeng, 2008; Liou et al., 2007; Tseng, 2008b; Tsai & Chou, 2008; Wu, 2008) are as follows:

Step 1: Generating the direct-relation matrix

Measuring the relationship between criteria requires a comparison scale designed as four levels: no influence (0), low influence (1), medium influence (2), high influence (3), very high influence (4). A team of experts is asked to make pairwise comparisons in terms of influence and direction between criteria. The results of these evaluations form a $n \times n$ matrix called direct-relation matrix $\boldsymbol{A}$, in which a_{ij} is denoted as the degree to which the criterion i affects the criterion j.

Step 2: Normalizing the direct-relation matrix

On the basis of the direct-r elation matrix $\boldsymbol{A}$, the normalized direct-relation matrix $\boldsymbol{M}$ can be obtained through formulas (4) and (5):

$$M = k.\mathbf{A} \tag{4}$$

$$k = Min\left(\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n}\left|a_{ij}\right|}\right) \quad i,j \in \{1,2,3,\ldots,n\} \tag{5}$$

Step 3: Obtaining the total-relation matrix

Once the normalized direct relation-matrix $\boldsymbol{M}$ has been obtained, the total relation matrix $\boldsymbol{S}$ can be derived by using formula (6), where the $\boldsymbol{I}$ is denoted as the identity matrix

$$\begin{aligned} S &= M + M^2 + M^3 + \ldots = \sum_{i=1}^{\infty} M^i \\ &= M(I - M)^{-1} \end{aligned} \tag{6}$$

Step 4: Compute dispatcher group and receiver group

Using the values of D–R and D+R where $\boldsymbol{R}$ is the sum of columns and also $\boldsymbol{D}$ is the sum of rows in matrix $\boldsymbol{S}$ as shown in formulas (7)-(9). Criteria having positive values of D–R have higher influence on one another and are assumed to have a higher priority and are called dispatcher; others having negative values of D–R receiving more influence from another are assumed to have a lower priority and are called receiver. On the other hand, the value of D+R indicates degree of relation between each criterion with others and criteria having more values of D+R have more relationship with another and those having little values of D+R have less of a relationship with others.

$$S = \left[S_{ij}\right]_{n\times n}, \quad i,j \in \{1,2,3,\ldots,n\} \tag{7}$$

$$D = \sum_{j=1}^{n} S_{ij} \tag{8}$$

$$R = \sum_{i=1}^{n} S_{ij} \tag{9}$$

Step 5: Set threshold value and obtain the impact-diagraph-map

The impact-diagraph-map also known as causal diagram can be acquired by mapping the dataset of the (D+R, D–R), where the horizontal axis D+R and the vertical axis D–R, providing valuable insight for making decisions. To obtain an appropriate diagram, decision-maker must set a threshold value for the influence level. Only some aspects, whose influence level in matrix $\boldsymbol{S}$ is higher than the threshold value, can be chosen and converted into the impact-diagraph-map. If the threshold value is too low, the map will be too complex to show the necessary information for decision-making. If the threshold value is too high, many aspects will be presented as independent aspects without showing the relationships with other aspects.

Step 6: Obtaining the inner dependence matrix

In this step, the sum of each column in total-relation matrix is equal to 1 by the normalization method, and then the inner dependence matrix can be acquired.

3.4. D. The ANP methodology

When Straddle carrier routing problem is evaluated, a group of opinions needs to be collected to know the interdependence relationship among criteria which can be analyzed as a Multi-Criteria Decision Making (MCDM) problem. To improve the quality of decision-making, a methodology is required for selecting the optimal set of containers to be transported. AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogenous elements with respect to a common criteria or attribute (Saaty, 1994). AHP is first developed to help establishing decision models through qualitative and quantitative processes (Saaty, 1980). According to Wu, Lin, and Chen (2007), AHP qualitatively helps to decompose a decision problem from the top goal to a set of attributes, sub-attributes; criteria, sub-criteria; activities, sub-activities, etc. Quantitatively it uses pairwise comparisons to assign weights to the elements at all levels (Wu et al., 2007). ANP goes beyond linear relationships and allows interrelationships among elements. Instead of a hierarchy, it is a network that replaces single direction relationships with dependence and feedback.

The main object is to determine the overall influence of all the elements (Tuzkaya, Onut, Tuzkaya, & Gulsun, 2008).

The definition and steps of ANP with reference to studies of relative scholars (Cheng & Li, 2005; Lin, Chiu, & Tsai, 2008; Saaty, 2001; Tsai & Chou, 2008; Wu, 2008) are as follows:

Step 1: Developing the decision model structure

The research problem should be stated clearly and decomposed into a rational system like a network. The structure is obtained by decision makers through brainstorming, literature survey or other appropriate methods.

Step 2: Conducting pairwise comparisons on the clusters

Experts are asked to make pairwise comparisons with Saaty's (1980) 9-point priority measurement scale ranging from 1 (equal) to 9 (extreme) where two components are compared in terms of how they contribute to their particular upper level criterion. By doing that, the relative weightings and eigenvectors are obtained.

Step 3: Supermatrix formation and transformation

Supermatrix is a partitioned matrix composed of local priority vectors entered in the appropriate columns of a matrix, where each matrix segment represents a relationship between two nodes (components or clusters). The supermatrix must be transformed first to make it stochastic, meaning each matrix column sums to unity, also known as weighted supermatrix and then must be raised to limiting powers until the weights have been converged and remain stable. This new matrix is called the limit supermatrix. The final priorities of all matrix elements can be obtained by normalizing each supermatrix block.

Step 4: Selecting the best alternative

When the supermatrix covers the whole network, the final priorities of elements are found in the corresponding columns in the limit supermatrix. The alternative with the largest overall priority should be the one selected.

4. Model development for six sigma transportation plan selection

Considering the appropriate selection, containers should be linked to the operational needs and priorities of the container terminal. The selection of the right container is a vital factor for gaining early and long-term acceptance of the Six Sigma program. Leading the needs of the container terminal and the customers, appropriate containers is chosen to be transported aiming to improve the performance and reach an optimum solution.

After making a detailed literature survey we can constitute numerous dimensions in selecting the right Six Sigma set of containers.

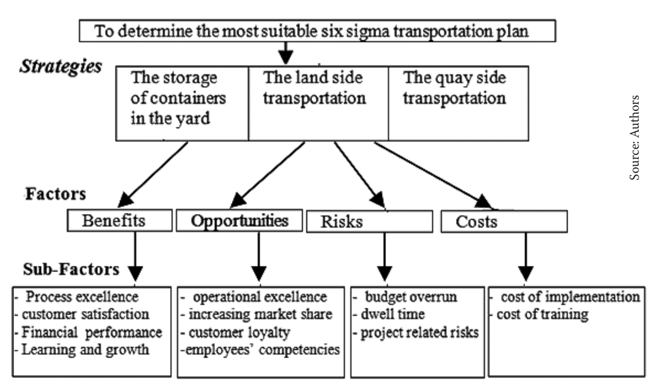
The purpose is to compare at operational level different strategies to assign straddle carriers (SC) to concrete tasks in a marine container terminal.

There are four types of tasks for straddles carriers: to transport a container to the quay crane to be loaded in the ship (LQ), to pick up an unloaded container from the quay zone and deliver it to the storage yard (ULQ), to pick up a container from the storage yard to dispatch it through the truck gates (LT) and to receive a container from a truck and transport it to the storage yard (ULT).

In this study, we investigate dispatching strategy for SCs to containers by categorizing them under three strategies (The storage of containers in the yard, The land side transportation, and The quay side transportation), four factors (benefits, opportunities, risks, costs) and a total number of 14 sub-factors all defined below. The general evaluation model of Six Sigma transportation plan selection is given in Fig. 2.

Three problems are analyzed in detail; the land side transportation (LS) defined as the side where the straddle carrier is affected to trucks, the quay side transportation (QS) is the side where the straddle carrier is affected to Quay cranes and the storage of containers in the yard (SY) means the side where the straddle carrier is affected to the storage yard.

Benefits (B) can be one of the factors that affect Six Sigma transportation plan selection and it is analyzed in four subfactors: process excellence (PE), customer satisfaction (CS), financial performance (FP) and learning and growth (LG). Process excellence can simply regard to the systematic improvement of transport process which is one of the main targets of the Six Sigma program.



Source: Authors

Figure 2: General Six Sigma transportation plan evaluation model.

Process excellence requires the ensemble of activities of planning and monitoring the performance of a transportation process. It is a systematic approach in the Six Sigma projects to help any organization optimize its underlying processes to achieve more efficient results (Snee & Rodebaugh, 2002). Customer satisfaction is a measure of how products and services supplied by a company meet or surpass customer expectation. As a major objective of Six Sigma program, it is seen a key differentiator and increasingly has become a primary element of business strategy (Anderson-Cook et al., 2005; Fundin & Cronemyr, 2003; Harry & Schroeder, 2000). In terms of retaining existing customers and targeting non-customers, measuring customer satisfaction provides an indication of how successful the company is at providing product and/or services (Antony, 2006; Banuelas et al., 2005).

As a following sub-factor, financial performance is one of the most important aspects of business management in an organization (Goldstein, 2001). It is a subjective measure of how well a firm can use assets from its primary mode of business and generate revenues over a given period of time. Financial performance generally involves balancing risk and profitability, while attempting to maximize an entity's wealth and the value of its stock which is one of the major criteria applying Six Sigma methodology (Breyfogle, Cupello, & Meadows, 2001; Pyzdek, 2003).

The final sub-factor of Benefits is learning and growth. It is a perspective that includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement.

Learning and growth refers to implementation of Six Sigma process in company and adaptation of employees and knowledge workers (Antony, 2004; Banuelas et al., 2006). In any case, learning and growth constitute the essential foundation for successful Six Sigma projects of any knowledge-worker organization (Pande et al., 2000; Snee & Rodebaugh, 2002).

Opportunities (O) is another factor including the sub-factors operational excellence (OE), increased market share (MS), customer loyalty (CL) and employees' competencies (EC). Operational excellence is a philosophy of leadership and teamwork resulting in continuous improvement throughout the organization by focusing on the needs of the customer, empowering employees, and identifying wasteful activities from its process which is one of the strategies of the Six Sigma application (Adams, Gupta, & Wilson, 2003).

Employees' competency is the last sub-factor analyzed under the Opportunities factor. It is the ability of employees' to perform a specific task, action or function successfully and it is one of the major intentions of implementing Six Sigma in an organization (Lynch & Soloy, 2003). By visualizing the strengths and weaknesses of each team member and worker leads to refine their skills for their highest level of performance (Gijo & Rao, 2005). This approach can be optimized by well-written job descriptions taking into account the employees' education and experiences.

The following factor Risks (R) consists of the sub-factors budget overrun (BO), dwell time (TD) and plan related risks (PJ). Under the factor of risks, budget overrun can be defined as excess of actual budget which plays a very important role for decision making in any project applied Six Sigma (Pande et al., 2000). Dwell time is the shift of time to a forward date which directly affects the process (Harry & Schroeder 2000).

Last factor stated is costs (C) and it is examined in three different sub-factors as cost of implementation (CI), cost of training (CT) and cost of human resources (HR). Cost of implementation is the cost needed in realization of the Six Sigma program in the container terminal.

It is already a proven fact that the benefits obtained from Six Sigma implementation outweigh the investment costs (Antony, 2007).

Cost of training is the cost utilized in instructional Six Sigma process for employees and workers of the container terminal. Regarding the type of container, cost of training is directly related with the duration scheduled.

Cost of human resources refers to the total charge used in orientation of Six Sigma project phases for employees and workers. The number of managers running the Six Sigma program and the number of departments the project is initiated help to embody the cost involved for staffing (Gijo & Rao, 2005).

5. Application of the proposed framework

In this section, a case study is presented to prove the proposed approach's applicability and validity in order to make it more understandable especially for decision-makers in container terminals.

In this study, we evaluate three six sigma transportation plans named as transportation plan A (improving the assignment processes), transportation plan B (improving customer relations) and transportation plan C (optimizing storage spaces).

Improving the assignment processes can implicate any kind of development in the travel of the straddle carriers such as improving first time delivery, developing operational routines, educating employees and workers, minimizing the dwell times of the containers etc. Improving customer relations deals with all terms concerning customers, especially increasing customer satisfaction, making forward surveys on customer needs and expectations, offerings to keep customer loyalty and so on.

Optimizing storage spaces is directly related with the service levels and arranging containers in the storage yard, forecasting accuracy lead to better inventory flows, preventing overstocks and this eventually helps controlling commercial plan, increasing financial performance, market share and cash flow.

To measure the inner dependency between decision criteria, DEMATEL is employed. According to the pairwise comparisons obtained from DEMATEL method, the inner dependency is structured and symbolized on the model by looped arcs. Additionally, according to the total-relation matrix the impact-diagraph map is formed.

Following that, for obtaining the relative influence between factors and sub-factors, a series of pairwise comparisons is presented. The results gathered and the inner dependences occurred within an evaluation cluster obtained by DEMATEL method are both carried and placed in the supermatrix and further calculations are made to obtain the best transportation plan alternative using the ANP methodology. The calculations of the supermatrix can be easily solved by using the professional software named "Super Decisions".

An overview of the proposed evaluation process is also given in Fig. 3.

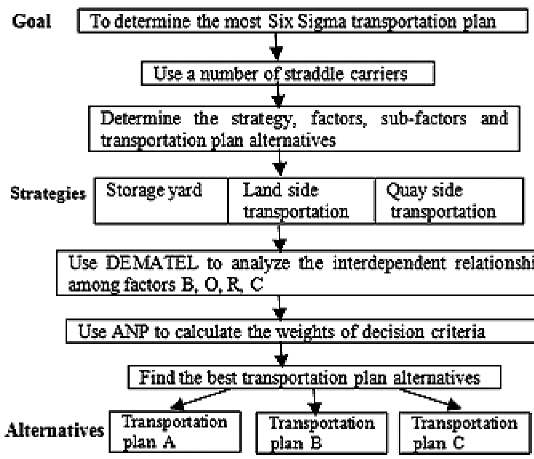


Figure 3: Proposed evaluation framework for Six Sigma transportation plan selection

5.1. Application of DEMATEL

After defining the decision strategies, factors and sub-factors, pairwise comparisons are made to the 4-leveled scale of DEMATEL. Firstly, the inner dependence among strategies composed of storage of containers in the yard, land side transportation and the quay side transportation is calculated.

Following the previously presented steps of DEMATEL, the initial direct-relation matrix for strategies (see Table 1) is produced. Based on the direct-relation matrix, the normalized direct-relation matrix for strategies is obtained by using formulas (4) and (5) (See Table 2): Utilizing the formula (6), the total-relation matrix for strategies is constituted (See Table 3). Then, using formulas (7)-(9) the impact-diagraph map for strategies is acquired by mapping the dataset of (*D+R, D–R*) given in Fig. 4.

Table 1: The initial direct-relation matrix for strategies.

	SY	LS	QS
SY	0	2	4
LS	3	0	3
QS	2	4	0

Source: Authors

Table 2. The normalized direct-relation matrix for strategies.

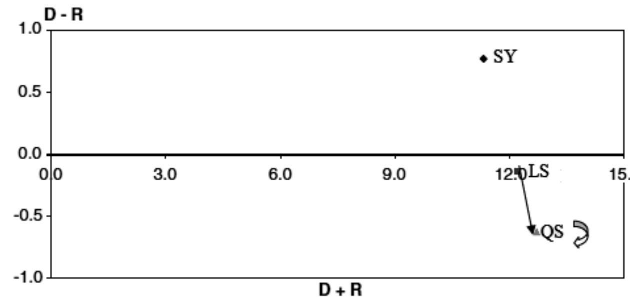
	SY	LS	QS
SY	0	0.286	0.572
LS	0.429	0	0.429
QS	0.286	0.572	0

Source: Authors

Table 3. The total-relation matrix for strategies.

	SY	LS	QS	*D*	*D + R*	*D – R*
SY	1.577	2.094	2.372	6.042	11.317	0.768
LS	1.884	1.856	2.303	6.042	12.224	–0.140
QS	1.814	2.232	1.996	6.042	12.712	–0.628
R	5.275	6.182	6.670			

Source: Authors



Source: Authors

Figure 4: The impact-diagraph-map of total relation for strategies.

The assigned threshold value for strategies is accepted to be 1.85. The value under the threshold value gains too many factors and complex relationships in the system. It is seen that the storage of containers in the yard is the dispatcher and land side and quay side transportation are the receivers. According to the graph, storage of containers in the yard has a high impact on land side transportation and quay side transportation in Six Sigma strategy. Obviously, the convergence of *D+R* values of strategies' elements shows the degree of relation and proves strong inner dependence.

Secondly, the inner dependency between factors is measured.

Based on the pairwise comparisons made for process excellence, customer satisfaction, financial performance and learning and growth sub-factors, the initial direct-relation matrix for benefits (See Table 4) is produced. Derived from the direct-relation matrix, the normalized direct-relation matrix for benefits is obtained by using formulas (4) and (5) (See Table 5).

Utilizing the formula (6), the total-relation matrix for benefits is constituted (See Table 6). Then, using formulas (7)-(9) the impact diagraph map for benefits is acquired by mapping the dataset of (*D+R, D–R*) given in Fig. 5. The assigned threshold value for benefits is accepted to be 0.5.

Table 4: The initial direct-relation matrix for benefits.

	PE	CS	FP	LG
PE	0	2	3	2
CS	0	0	4	1
FP	3	2	0	3
LG	4	2	3	0

Source: Authors

Table 5: The normalized direct-relation matrix for benefits.

	PE	CS	FP	LG
PE	0	0.2	0.3	0.2
CS	0	0	0.4	0.1
FP	0.3	0.2	0	0.3
LG	0.4	0.2	0.3	0

Source: Authors

Table 6: The total-relation matrix for benefits.

	PE	CS	FP	LG	D	*D + R*	*D – R*
PE	0.519	0.607	0.888	0.631	2.645	5.346	–0.056
CS	0.423	0.336	0.798	0.458	2.014	4.328	–0.300
FP	0.822	0.662	0.737	0.752	2.972	6.431	–0.487
LG	0.938	0.709	1.036	0.569	3.252	5.662	0.843
R	2.701	2.314	3.459	2.409			

Source: Authors

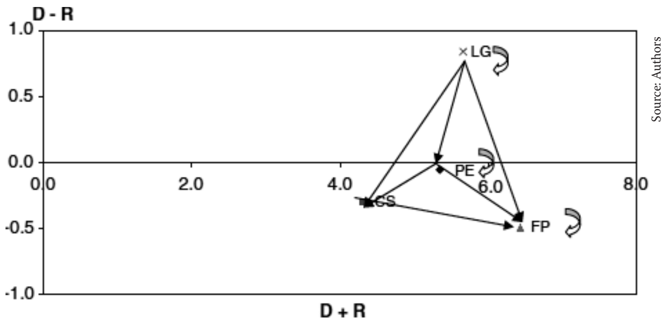


Figure 5: The impact-diagraph-map of total relation for benefits.

It can be analyzed that under the factor of benefits, learning and growth has a higher impact than customer satisfaction and process excellence in applying the Six Sigma application. Learning and growth is the dispatcher whereas process excellence, customer satisfaction and financial performance are the receivers. Additionally, the close $D+R$ values of benefit sub-factors confirm strong inner dependency between each other. Orderly, the inner dependency between the other factors opportunities, risks and costs are measured by applying exactly the same transaction processes given above. Based on the pairwise comparisons made for sub-factors of opportunities, the direct-relation matrix (see Table 7), the normalized direct-relation matrix (see Table 8) and the total-relation matrix (see Table 9) are formed. The assigned threshold value for opportunities is accepted to be 0.45. Placing the numerical values on the impact-diagraph-map for opportunities helps to visualize the inner dependencies clearer (see Fig. 6).

The following factor risks, is examined in three sub-factors budget overrun, dwell time and transportation plan related risks.

Table 7: The initial direct-relation matrix for opportunities.

	OE	MS	CL	EC
OE	0	3	2	2
MS	2	0	3	1
CL	2	4	0	1
EC	4	3	3	0

Source: Authors

Table 8: The normalized-relation matrix for opportunities.

	OE	MS	CL	EC
OE	0	0.3	0.2	0.2
MS	0.2	0	0.3	0.1
CL	0.2	0.4	0	0.1
EC	0.4	0.3	0.3	0

Source: Authors

Table 9: The total-relation matrix for opportunities.

	OE	MS	CL	EC	***D***	***D + R***	***D − R***
OE	0.492	0.861	0.693	0.454	2.500	5.163	−0.162
MS	0.583	0.550	0.684	0.340	2.157	5.548	−1.235
CL	0.628	0.900	0.505	0.366	2.399	5.215	−0.417
EC	0.960	1.080	0.934	0.393	3.367	4.920	1.814
R	2.663	3.391	2.816	1.553			

Source: Authors

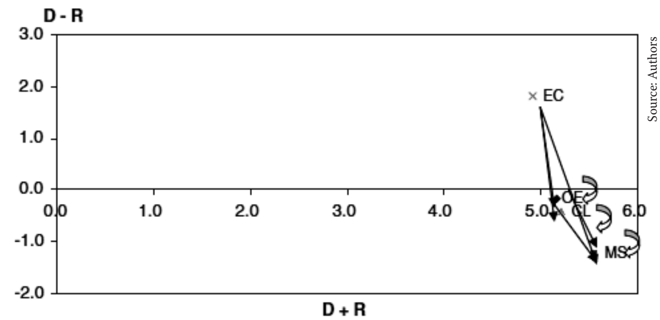


Figure 6: The impact-diagraph-map of total relation for opportunities.

Table 10: The initial direct-relation matrix for risks.

	BO	TD	PJ
BO	0	4	3
TD	4	0	2
PJ	3	3	0

Source: Authors

Table 11: The normalized direct-relation matrix for risks.

	BO	TD	PJ
BO	0	0.572	0.429
TD	0.572	0	0.286
PJ	0.429	0.429	0

Source: Authors

After running the similar operations step by step given formerly, derived from the pairwise comparisons made the direct-relation matrix (see Table 10), the normalized direct-relation matrix (see Table 11) and the total-relation matrix (see Table 12) for risks factor are obtained.

Table 12: The total-relation matrix for risks.

	BO	TD	PJ	***D***	***D + R***	***D − R***
BO	3.602	3.966	3.109	10.677	21.461	−0.107
TD	3.644	3.280	2.788	9.712	20.496	−1.072
PJ	3.538	3.538	2.529	9.605	18.031	1.179
R	10.784	10.784	8.426			

Source: Authors

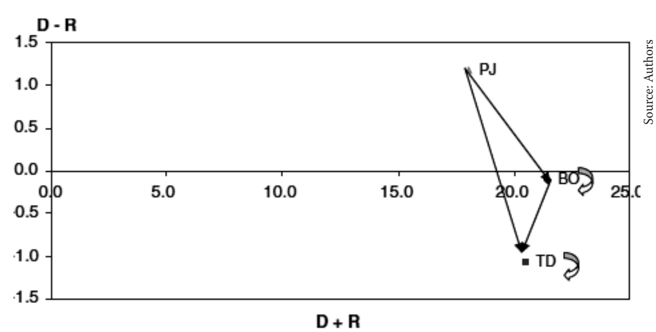


Figure 7: The impact-diagraph-map of total relation for risks.

Table 13: The initial direct-relation matrix for costs.

	CI	CT	HR
CI	0	0	0
CT	1	0	0
HR	0	0	0

Source: Authors

Table 14: The normalized direct-relation matrix for costs.

	CI	CT	HR
CI	0	0	0
CT	1	0	0
HR	0	0	0

Source: Authors

Table 15: The total-relation matrix for costs.

	CI	CT	HR	*D*	*D+R*	*D−R*
CI	0	0	0	0	1	−1
CT	1	0	0	1	1	1
HR	0	0	0	0	0	0
R	1	0	0			

Source: Authors

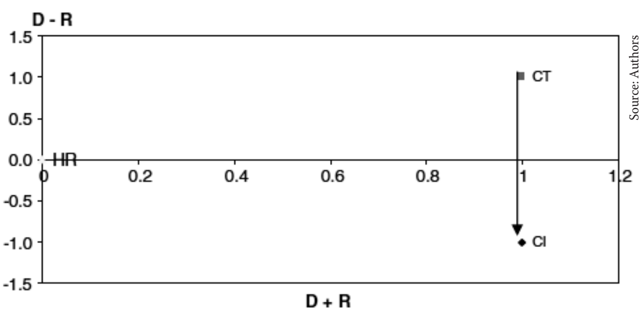


Figure 8: The impact-diagraph-map of total relation for costs.

The assigned threshold value for risks is agreed to be 2.8. Placing the numerical values on the impact-diagraph-map for risks (see Fig. 7) assists to envision the inner dependencies.

It can be observed that under the factor of risks, transportation plan related risks sub-factor has a higher impact than budget overrun and dwell time in applying Six Sigma. Transportation plan related risks prove to be the dispatcher; budget overrun and dwell time are the receivers. Moreover, the close *D+R* values for risks sub-factors verify the high inner dependency between each other.

The final factor costs, is also analyzed in three sub-factors given as cost of implementation, cost of training and cost of human resources. Operating the formulas (4)-(9) on the pairwise comparisons made for costs factor, the direct-relation matrix (see Table 13), the normalized direct-relation matrix (see Table 14) and the total-relation matrix (see Table 15) are formed.

Table 16: Inner dependence matrix for strategies.

	BE	RG	PR
BE	0.299	0.339	0.356
RG	0.357	0.300	0.345
PR	0.344	0.361	0.299

Source: Authors

Table 17: Inner dependence matrix for benefits

	PE	CS	FP	LG
PE	0.192	0.263	0.257	0.262
CS	0.156	0.145	0.231	0.190
FP	0.304	0.286	0.213	0.312
LG	0.347	0.306	0.299	0.236

Source: Authors

Table 18: Inner dependence matrix for opportunities

	OE	MS	CL	EC
OE	0.185	0.254	0.246	0.292
MS	0.219	0.162	0.243	0.219
CL	0.236	0.265	0.179	0.236
EC	0.361	0.318	0.332	0.253

Source: Authors

The assigned threshold value for costs is approved to be 1. The relationship between the sub-factors of costs is investigated considering the positioning of values on the impact-diagraph-map for costs (see Fig. 8). As seen on the diagraph-map of costs, the discrete *D+R* values of costs' sub-factors prove to have no inner dependency on each other. Cost of training seems to have a priority considering deployment of the Six Sigma transportation plans. It is observed to be the dispatcher and the other sub-factors cost of implementation and cost of human resources are the receivers.

After analyzing the relationships between factors and sub-factors by DEMATEL technique we can now regenerate and finalize our evaluation model for Six Sigma transportation plan selection. According to the results obtained, it is found out those strategies and the factors benefits, opportunities and risks show strong inner dependency as given in Fig. 9.

As a further step in the proposed decision making model, to combine ANP and DEMATEL we obtained the inner dependence matrix by normalizing the total-relation matrix which prove to have inner dependency.

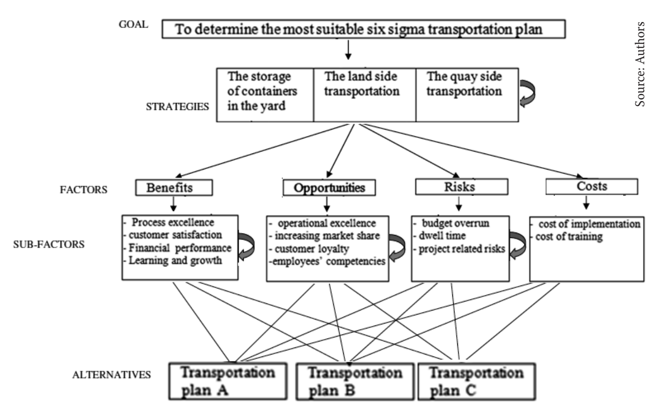


Figure 9: Final Six Sigma transportation plan evaluation model.

Table 19: Inner dependence matrix for risks.

	BO	TD	PJ
BO	0.0.334	0.368	0.369
TD	0.338	0.304	0.331
PJ	0.328	0.328	0.300

Source: Authors

Table 20: Pairwise comparison of strategy with respect to the goal.

Goal	BE	RG	PR	Weights
BE	1	1/2	3	0.300
RG	2	1	6	0.600
PR	1/3	1/6	1	0.100
CR				0.00013

Source: Authors

Table 21: Pairwise comparison of strategy with respect to revenue growth.

RG	BE	PR	Weights
BE	1	2	0.667
PR	1/2	1	0.333
CR			0

Source: Authors

According to the results and the given diagraph- maps of total relation matrix, strategies and the factors benefits, opportunities and risks have inner dependency. The normalized inner dependency matrix for strategies (see Table 16), benefits (see Table 17), opportunities (see Table 18) and risks (see Table 19) are directly utilized in unweighted supermatrix during ANP application.

5.2. Application of ANP

After determining the relationship structure with DEMATEL methodology, the ANP method is applied to calculate the weight of each criterion. Here again, the series of pairwise comparisons are evaluated with Saaty's 1-9 scale where 1 represents equal importance, while 9 represents extreme importance that favours one element over another. If the element has a weaker impact than its comparison element the scale ranges from 1 to 1/9 indicating indifference. This ANP model is solved using the Super Decisions software.

The consistency ratio (CR) values of obtained results are all acceptable and the eigenvectors displayed are ready to enter into the supermatrix. Such an example, the pairwise comparison of strategies with respect to the goal is given in Table 20, and in Table 21 the pairwise comparison of strategies with respect to revenue growth is given.

All pairwise comparison matrices are computed and given in the form of unweighted supermatrix as shown in Table 22. A weighted supermatrix is transformed first to be stochastic as shown in Table 23. After entering the normalized values into the supermatrix and completing the column stochastic, the supermatrix is then increased to sufficient large power until convergence occurs. Table 24 provides a final limit matrix. This limit matrix is column stochastic and represents the final eigenvector. According to obtained results, Transportation plan C, optimizing inventory, is the most effective Six Sigma transportation plan alternative. The second transportation plan alternative is improving the Transportation processes.

Table 22: The unweighted supermatrix.

	Goal	SY	LS	QS	B	O	R	C	PE	CS	FP	LG	OE	MS	CL	EC	BO	TD	PJ	CI	CT	HR	PA	PB	PC
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SY	0.300	0.299	0.339	0.356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LS	0.600	0.357	0.300	0.345	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QS	0.100	0.344	0.361	0.299	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE	0	0	0	0	0.195	0	0	0	0.192	0.263	0.257	0.262	0	0	0	0	0	0	0	0	0	0	0	0	0
CS	0	0	0	0	0.231	0	0	0	0.156	0.145	0.231	0.190	0	0	0	0	0	0	0	0	0	0	0	0	0
FP	0	0	0	0	0.426	0	0	0	0.304	0.286	0.213	0.312	0	0	0	0	0	0	0	0	0	0	0	0	0
LG	0	0	0	0	0.148	0	0	0	0.347	0.306	0.299	0.236	0	0	0	0	0	0	0	0	0	0	0	0	0
OE	0	0	0	0	0	0.185	0	0	0	0	0	0	0.185	0.254	0.246	0.292	0	0	0	0	0	0	0	0	0
MS	0	0	0	0	0	0.370	0	0	0	0	0	0	0.219	0.162	0.243	0.219	0	0	0	0	0	0	0	0	0
CL	0	0	0	0	0	0.345	0	0	0	0	0	0	0.236	0.265	0.179	0.236	0	0	0	0	0	0	0	0	0
EC	0	0	0	0	0	0.100	0	0	0	0	0	0	0.361	0.318	0.332	0.253	0	0	0	0	0	0	0	0	0
BO	0	0	0	0	0	0	0.500	0	0	0	0	0	0	0	0	0	0.334	0.368	0.369	0	0	0	0	0	0
TD	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0.338	0.304	0.331	0	0	0	0	0	0
PJ	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0.328	0.328	0.300	0	0	0	0	0	0
CI	0	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CT	0	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HR	0	0	0	0	0	0	0	0.500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0.400	0.250	0.297	0.400	0.500	0.297	0.250	0.400	0.216	0.286	0.400	0.286	0.433	0.300	0	0	0
PB	0	0	0	0	0	0	0	0	0.200	0.500	0.163	0.200	0.250	0.163	0.500	0.200	0.102	0.143	0.200	0.143	0.101	0.100	0	0	0
PC	0	0	0	0	0	0	0	0	0.400	0.250	0.540	0.400	0.250	0.540	0.250	0.400	0.682	0.572	0.400	0.571	0.466	0.600	0	0	0

Table 23: The weighted supermatrix.

	Goal	SY	LS	QS	B	O	R	C	PE	CS	FP	LG	OE	MS	CL	EC	BO	TD	PJ	CI	CT	HR	PA	PB	PC
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SY	0.300	0.058	0.065	0.069	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LS	0.100	0.069	0.058	0.066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QS	0.600	0.069	0.069	0.058	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0.282	0.282	0.282	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0.103	0.103	0.103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0	0.160	0.160	0.160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0.263	0.263	0.263	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE	0	0	0	0	0.195	0	0	0	0.096	0.132	0.129	0.131	0	0	0	0	0	0	0	0	0	0	0	0	0
CS	0	0	0	0	0.231	0	0	0	0.078	0.073	0.116	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0
FP	0	0	0	0	0.426	0	0	0	0.152	0.143	0.106	0.156	0	0	0	0	0	0	0	0	0	0	0	0	0
LG	0	0	0	0	0.148	0	0	0	0.174	0.153	0.150	0.118	0	0	0	0	0	0	0	0	0	0	0	0	0
OE	0	0	0	0	0	0.185	0	0	0	0	0	0	0.092	0.127	0.123	0.146	0	0	0	0	0	0	0	0	0
MS	0	0	0	0	0	0.370	0	0	0	0	0	0	0.109	0.081	0.122	0.110	0	0	0	0	0	0	0	0	0
CL	0	0	0	0	0	0.345	0	0	0	0	0	0	0.118	0.133	0.090	0.118	0	0	0	0	0	0	0	0	0
EC	0	0	0	0	0	0.100	0	0	0	0	0	0	0.180	0.159	0.166	0.127	0	0	0	0	0	0	0	0	0
BO	0	0	0	0	0	0	0.500	0	0	0	0	0	0	0	0	0	0.167	0.184	0.185	0	0	0	0	0	0
TD	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0.169	0.152	0.166	0	0	0	0	0	0
PJ	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0.164	0.164	0.150	0	0	0	0	0	0
CI	0	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CT	0	0	0	0	0	0	0	0.250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HR	0	0	0	0	0		0	0.500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0.200	0.125	0.148	0.200	0.250	0.148	0.125	0.200	0.108	0.143	0.200	0.286	0.433	0.300	0	0	0
PB	0	0	0	0	0	0	0	0	0.100	0.250	0.082	0.100	0.125	0.082	0.250	0.100	0.051	0.071	0.100	0.143	0.101	0.100	0	0	0
PC	0	0	0	0	0	0	0	0	0.200	0.125	0.270	0.200	0.124	0.270	0.125	0.200	0.341	0.286	0.200	0.571	0.466	0.600	0	0	0

Table 24: The limit supermatrix.

	Goal	SY	LS	QS	B	O	R	C	PE	CS	FP	LG	OE	MS	CL	EC	BO	TD	PJ	CI	CT	HR	PA	PB	PC
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE	0.063	0.063	0.063	0.063	0.122	0	0	0	0.122	0.122	0.122	0.122	0	0	0	0	0	0	0	0	0	0	0	0	0
CS	0.048	0.048	0.048	0.048	0.092	0	0	0	0.092	0.092	0.092	0.092	0	0	0	0	0	0	0	0	0	0	0	0	0
FP	0.072	0.072	0.072	0.072	0.139	0	0	0	0.139	0.139	0.139	0.139	0	0	0	0	0	0	0	0	0	0	0	0	0
LG	0.076	0.076	0.076	0.076	0.147	0	0	0	0.147	0.147	0.147	0.147	0	0	0	0	0	0	0	0	0	0	0	0	0
OE	0.023	0.023	0.023	0.023	0	0.123	0	0	0	0	0	0	0.123	0.123	0.123	0.123	0	0	0	0	0	0	0	0	0
MS	0.020	0.020	0.020	0.020	0	0.106	0	0	0	0	0	0	0.106	0.106	0.106	0.106	0	0	0	0	0	0	0	0	0
CL	0.022	0.022	0.022	0.022	0	0.115	0	0	0	0	0	0	0.115	0.115	0.115	0.115	0	0	0	0	0	0	0	0	0
EC	0.029	0.029	0.029	0.029	0	0.156	0	0	0	0	0	0	0.156	0.156	0.156	0.156	0	0	0	0	0	0	0	0	0
BO	0.052	0.052	0.052	0.052	0	0	0.178	0	0	0	0	0	0	0	0	0	0.178	0.178	0.178	0	0	0	0	0	0
TD	0.048	0.048	0.048	0.048	0	0	0.162	0	0	0	0	0	0	0	0	0	0.162	0.162	0.162	0	0	0	0	0	0
PJ	0.047	0.047	0.047	0.047	0	0	0.160	0	0	0	0	0	0	0	0	0	0.160	0.160	0.160	0	0	0	0	0	0
CI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PA	0.167	0.167	0.167	0.167	0.172	0.184	0.149	0	0.172	0.172	0.172	0.172	0.184	0.184	0.184	0.184	0.149	0.149	0.149	0	0	0	0	0	0
PB	0.111	0.111	0.111	0.111	0.123	0.137	0.073	0	0.123	0.123	0.123	0.123	0.137	0.137	0.137	0.137	0.073	0.073	0.073	0	0	0	0	0	0
PC	0.222	0.222	0.222	0.222	0.206	0.179	0.278	0	0.206	0.206	0.206	0.206	0.179	0.179	0.179	0.179	0.278	0.278	0.278	0	0	0	0	0	0

6. Conclusions

Container terminals continuously seek ways to improve the quality of transportation processes and products and differentiate themselves from their competitors to raise customer satisfaction and revenues. Six Sigma is one of the methodologies utilized in the companies. This study aimed to combine two multi-criteria decision making methods, DEMATEL and ANP to effectively identify the most appropriate transportation plan alternative especially in container terminals.

Transportation scheme selection is a complex decision making system composed of goals and sun-systems to better judge differences and interactions which can be referred to a typical multiple decision making criteria application. DEMATEL and ANP techniques are both in conjunction to systematically construct an evaluation model for transportation plan selection. Utilizing only one of the techniques could be satisfactory in choosing the optimum plan; but integrating these two techniques as a combined MCDM approach is a wise option which can be regarded as a consolidated new tool considering inner dependency and weights of criteria. There might be some limitations in combining these two analytical approaches such as different assessment scales; but this non-unification can be improved.

As a result, it is worth to investigate cases and practices responsive to this combined approach.

After making a detailed literature survey and examining Six Sigma appliers' real life experiences, the criteria to be considered in Six Sigma transportation plan selection were determined, and an evaluation model was developed. To support and investigate the effectiveness of the proposed approach an empirical case study from logistics industry was used. It should be noted that an effective transportation plan selection method helps to ensure optimal resource utilization toward container terminal's missions and goals.

For future study, knowledge based or an expert system can be integrated to help decision-makers both make pair wise calculations more concisely, and interpret the results in each step of the DEMATEL and ANP.

Appendix. Pairwise comparison matrices

See tables A1-A19.

Table A1: Strategies with respect to goal.

Goal	SY	LS	QS	Weights
SY	1	1/2	3	0.300
LS	2	1	6	0.600
QS	1/3	1/6	1	0.100

Source: Authors

Table A2. Benefits' sub-factors with respect to benefits

B	PE	CS	FP	LG	Weights
PE	1	1	1/2	1	0.195
CS	1	1	1/2	2	0.231
FP	2	2	1	3	0.426
LG	1	1/2	1/3	1	0.148

Source: Authors

Table A3: Opportunities' sub-factors with respect to opportunities.

O	OE	MS	CL	EC	Weights
OE	1	1/2	1	2	0.185
MS	2	1	1	4	0.370
CL	2	1	1	3	0.345
EC	1/2	1/4	1/3	1	0.100

Source: Authors

Table A4: Risks' sub-factors with respect to risks.

R	BO	TD	PJ	Weights
BO	1	2	2	0.500
TD	1/2	1	1	0.250
PJ	1/2	1	1	0.250

Source: Authors

Table A5: Costs' sub-factors with respect to costs.

C	CI	CT	HR	Weights
CI	1	1	1/2	0.250
CT	1	1	1/2	0.250
HR	2	2	1	0.500

Source: Authors

Table A6: Transportation plan alternatives with respect to process excellence.

PE	A1	A2	A3	Weights
A1	1	2	1	0.400
A2	1/2	1	1/2	0.200
A3	1	2	1	0.400

Source: Authors.

Table A7: Transportation plan alternatives with respect to customer satisfaction.

CS	A1	A2	A3	Weights
A1	1	1/2	1	0.250
A2	2	1	2	0.500
A3	1	1/2	1	0.250

Source: Authors

Table A8. Transportation plan alternatives with respect to financial performance.

FP	A1	A2	A3	Weights
A1	1	2	1/2	0.297
A2	1/2	1	1/3	0.163
A3	2	3	1	0.540

Source: Authors

Table A9: Transportation plan alternatives with respect to learning and growth.

LG	A1	A2	A3	Weights
A1	1	2	1	0.400
A2	1/2	1	1/2	0.200
A3	1	2	1	0.400

Source: Authors

Table A10: Transportation plan alternatives with respect to operational excellence.

OE	A1	A2	A3	Weights
A1	1	2	2	0.500
A2	1/2	1	1	0.250
A3	1/2	1	1	0.250

Source: Authors

Table A11: Transportation plan alternatives with respect to market share.

MS	A1	A2	A3	Weights
A1	1	2	1/2	0.297
A2	1/2	1	1/3	0.163
A3	2	3	1	0.540

Source: Authors

Table A12: Transportation plan alternatives with respect to customer loyalty.

CL	A1	A2	A3	Weights
A1	1	1/2	1	0.250
A2	2	1	2	0.500
A3	1	1/2	1	0.250

Source: Authors

Table A13: Transportation plan alternatives with respect to employees' competencies.

EC	A1	A2	A3	Weights
A1	1	2	1	0.400
A2	1/2	1	1/2	0.200
A3	1	2	1	0.400

Source: Authors

Table A14: Transportation plan alternatives with respect to budget overrun.

BO	A1	A2	A3	Weights
A1	1	2	1/3	0.216
A2	1/2	1	1/7	0.102
A3	3	7	1	0.682

Source: Authors

Table A15: Transportation plan alternatives with respect to dwell time.

TD	A1	A2	A3	Weights
A1	1	2	1/2	0.286
A2	1/2	1	1/4	0.143
A3	2	4	1	0.572

Source: Authors

Table A16: Transportation plan alternatives with respect to transportation plan related.

PJ	A1	A2	A3	Weights
A1	1	2	1	0.400
A2	1/2	1	1/2	0.200
A3	1	2	1	0.400

Source: Authors

Table A17: Transportation plan alternatives with respect to cost of implementation.

CI	A1	A2	A3	Weights
A1	1	2	1/2	0.286
A2	1/2	1	1/4	0.143
A3	2	4	1	0.571

Source: Authors

Table A18: Transportation plan alternatives with respect to cost of training.

CT	A1	A2	A3	Weights
A1	1	4	1	0.433
A2	¼	1	1/5	0.101
A3	1	5	1	0.466

Source: Authors

Table A19: Transportation plan alternatives with respect to cost of human resources.

HR	A1	A2	A3	Weights
A1	1	3	1/2	0.300
A2	1/3	1	1/6	0.100
A3	2	6	1	0.600

Source: Authors

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