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Process Management as an Essential Component of Management in the Maritime Container Terminals: Empirical Evidence using Fuzzy-DEMATEL Approach

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Abstract:

Purpose: *The study aims to determine and evaluate the role of process management within maritime container terminals. The research was conducted on the example of three medium-sized Polish maritime container terminals.*
Methodology: *A few research methods were applied, literature review, questionnaire method, comparative analysis, and fuzzy-DEMATEL method.*
Findings: *Conducted research implies that process management is an essential component of management in maritime container terminals. This area has the greatest impact on other fields of management identified in the maritime container terminal.*
Practical implications: *The results of the study could be considered an interesting source of information for maritime container terminal operators as well as their direct and indirect customers, i.e. container ship operators, maritime freight forwarders, and shippers. Knowledge of the role of process management can be beneficial in the context of improving the service quality.*
Originality: *This research is the first that attempted to find the causal relationship between various management areas of a maritime container terminal.*

Keywords: *Fuzzy-DEMATEL, process management, maritime container terminal, heat map.*

JEL classification: *O31, M16, R49.*

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1. Introduction

Supply chains are complex networks, that meet various stakeholders. Within this network, a crucial role is played by maritime container terminals, which can be perceived as an intermodal transport hub. Moreover, due to their nature and performed logistics functions, they are very susceptible to any disruptions in the logistics supply chain. On the other hand, maritime container terminals are also a source of various kinds of disruption, which can be quickly transferred to the remaining links of the supply chain (Charłampowicz and Grzelakowski, 2022).

Moreover, the role of freight forwarders and shipping lines has changed in last years (Charłampowicz and Mańkowski, 2022; Skiba and Karas, 2022). Therefore, the terminal needs to avoid disruption by performing the efficient service of both container vessels and land means of transport. To ensure a suitable level of efficiency and reliability the proper management system has to be implemented. Moreover, it is crucial to properly manage all processes within the terminal. Therefore, it is important to identify the role of each management area and the causal relationship between them.

Based on the pilot research, performed on one of the Polish maritime container terminal in 2022, it is possible to identify the following areas of management in the maritime container terminal: process management, risk management, strategic and operational management, knowledge and human resources management, customer relations management, environmental management, safety and security management, and change management. In the context of the COVID-19 pandemic, risk management has become an important factor of efficiency in the supply chains (Charłampowicz, 2022; Gaschi-Uciecha, 2021; Szuster and Lotko, 2022). Moreover, knowledge concerning the role of the above-mentioned management area on each other can provide more suitable and proper improvement.

The main purpose of this paper is to evaluate the causal relationship between various areas of management in the maritime container terminal. Therefore, the article is divided into the following sections: section 2 is dedicated to the research methodology, section 3 presents the results of the study performed on the three Polish medium-sized maritime container terminals, and the last section provides discussion and conclusions.

2. Research Methodology

The fuzzy-DEMATEL method is a developed version of the classic DEMATEL method, which has been used for the construction of the cause-effect chain and the analysis of its components. This method is capable of illustrating the overall influence of factors (Wang and Tzeng, 2012), visualizing causal relations *(*Liaw *et al.*, 2011), and analyzing dependent factors (Liou *et al.*, 2008). Although the original method does not always provide precise results, especially along with unreliable human decisions (Muhammad and Cavus, 2017). To solve this problem, some elements of the fuzzy set theory have been implemented (Ertugrul Karsak and Tolga, 2001).

Based on the triangular membership function, it is possible to convert the assigned grades into triangular fuzzy numbers. Triangular fuzzy numbers are intuitive and effective in determining the uncertainty of complex systems through relatively simple operations (Muhammad and Cavus, 2017; Shafiee *et al.*, 2014). The set of triangular fuzzy numbers can be defined as set ***A*** (*a, b, c)*, where *a, b,* and *c* denote the lower, medium, and upper number of fuzzy sets, respectively. The membership function can be defined as follows:

$$u_A(x) = \begin{cases} 0;\ x < a \\ \dfrac{(x-a)}{(b-a)};\ a \le x \le b \\ \dfrac{(x-c)}{(b-c)};\ b \le x \le c \\ 0;\ x > c \end{cases} \tag{1}$$

One of the techniques for defuzzifying the fuzzy numbers into crisp values is Best Non-fuzzy Performance (BNP), which can be expressed as follows:

$$f = \frac{(c-a)+(b-a)}{3} + a \tag{2}$$

To determine the direct relationship between the considered factors can be performed through judgment made by professionals subjectively using a questionnaire design: formed by comparing the criteria of each element pair which is shown by numbers from 0 (no influence) to 4 (very high influence). The obtained results need to be converted to triangular fuzzy numbers (Table 1).

Table 1. *Fuzzy linguistic scale*

Linguistic term	**Influence score**	**Triangular fuzzy number**
Very high influence	4	(0.75, 1, 1)
High influence	3	(0.50, 0.75, 1)
Low influence	2	(0.25, 0.50, 0.75)
Very low influence	1	(0, 0.25, 0.5)
No influence	0	(0, 0, 0.25)

Source: *Muhammad and Cavus, 2017.*

Based on the pairwise comparison it is possible to set up a direct-relation $n \times n$ matrix, figures inside matrix **Z** show the influential extent between the elements. The normalized fuzzy direct-relations matrix and standardized fuzzy direct-relation matrix **X** can be computed using the following formula:

$$\boldsymbol{X} = \boldsymbol{S} \times \boldsymbol{Z}, \tag{3}$$

where:

$\boldsymbol{X}$ – standardized fuzzy matrix of direct relationships,

$$\boldsymbol{S} = \frac{1}{Max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}}, \tag{4}$$

$\boldsymbol{Z}$ – matrix of direct relationships.

Another step is to calculate the total fuzzy impact matrix (direct and indirect) – the following formula is used to determine the matrix:

$$\boldsymbol{T} = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}, \tag{5}$$

where:

$\boldsymbol{T}$ – total fuzzy impact matrix (direct and indirect),
$\boldsymbol{X}$ – standardized fuzzy matrix of direct relationship,
$\boldsymbol{I}$ – unit matrix

Based on the significance indicator and the relation indicator it is possible to draw the causal diagram.

$$\begin{aligned} S_{ij} &= D_{ij} + C_{ij} = \textstyle\sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ij} \text{ (4)}, \\ R_{ij} &= D_{ij} - C_{ij} = \textstyle\sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ij} \text{ (5)}, \end{aligned} \tag{6}$$

where:

S_{ij} – the significance indicator,

R_{ij} – the relation indicator,

D_{ij} – total amount of each row,

C_{ij} – total amount of each column,

t_{ij} – total (direct and indirect) influence from indicator i to indicator j,

n – number of indicators.

The causal diagram uses (D + R, D – R) as ordered pairs. The horizontal axis is dedicated to the significance indicator, while the vertical axis is dedicated to the relation indicator. Elements located above the horizontal axis are the cause, while elements below the horizontal axis are the effect in the cause-effect chart.

Therefore, this method allows presenting the causality of the elements as a simple and clear structure (Shafiee *et al.*, 2014). Although, when there are many factors taken into consideration the cause-effect chart could be illegible. Therefore, the heat map would be a better method to present data.

3. Results

The causal relation between various areas of maritime container management has been made based on eight factors representing each management area (Table 2). The total fuzzy impact matrix is presented in Table 3.

The bolded values are representing the values above the threshold value θ, which can be calculated in various ways – from an average of the element in the matrix $\boldsymbol{T}$ (Sara *et al.*, 2015) to a more complex method based on an entropy concept using the maximum mean de-entropy algorithm (Charlampowicz, 2022; Chung-Wei and Gwo-Hshiung, 2009). The threshold value θ calculated using the MMDE method was 0.7178.

Table 2. *Maritime container terminal management areas*

Factor	**Management area**
f1	Process management
f2	Risk management
f3	Strategic and operational management
f4	Knowledge and human resources management
f5	Customer relations management
f6	Environmental management
f7	Safety and security management
f8	Change management

Source: *Own elaboration based on research examined in 2022*

Table 3. *Total fuzzy impact matrix* ***T***

	f1	**f2**	**f3**	**f4**	**f5**	**f6**	**f7**	**f8**
f1	0.5764	0.6679	**0.7822**	0.7113	0.7013	0.6775	**0.8136**	0.6616
f2	0.6653	0.5158	**0.7345**	0.6598	0.6663	0.6465	**0.7735**	0.6027
f3	0.6707	0.6410	0.6307	0.6852	0.6917	0.6219	**0.7814**	0.6095
f4	0.4218	0.4000	0.5619	0.4006	0.5093	0.4655	0.5740	0.4596
f5	0.4263	0.3665	0.5124	0.4476	0.3769	0.3713	0.5307	0.4045
f6	0.5633	0.5490	0.6315	0.5747	0.6004	0.4548	0.6780	0.5114
f7	0.6309	0.5948	0.6858	0.6138	0.6393	0.6041	0.6106	0.5473
f8	0.5625	0.5370	0.6548	0.5350	0.5842	0.5065	0.6801	0.4359

Source: *Own elaboration based on research examined in 2022*

The analysis of the influence of each management area within the maritime container terminals is presented in Table 4.

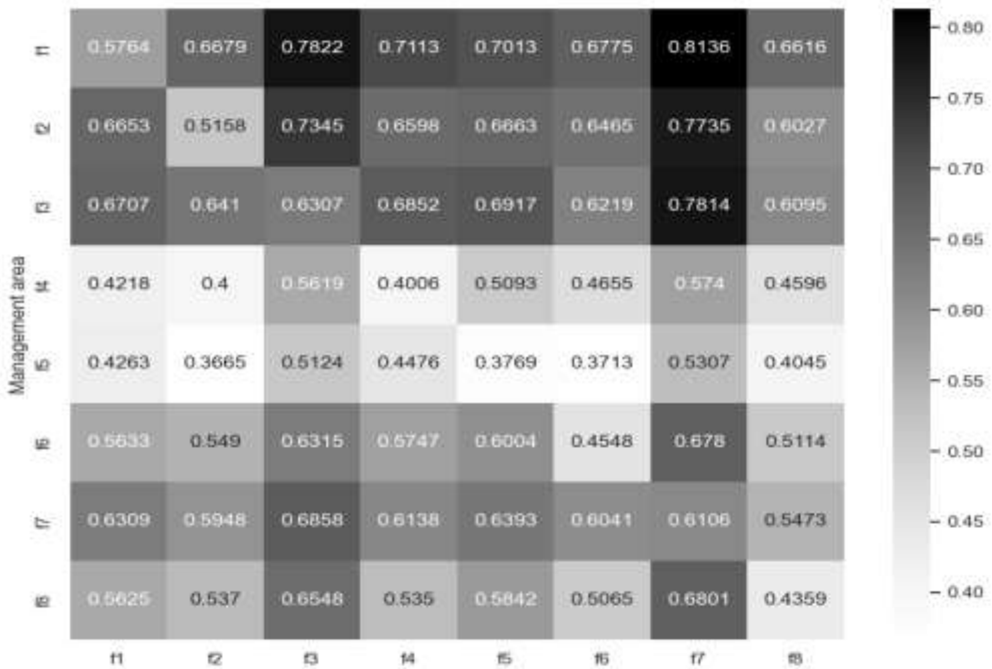
__Table 4.__ The analysis of the influence of each management area within the maritime container terminals

Factor	Management area	Significance indicator	Relation indicator	Causal character
f1	Process management	10.1089	1.0745	Cause
f2	Risk management	9.5364	0.9924	Cause
f3	Strategical and operational management	10.5259	0.1384	Cause
f4	Knowledge and human resources management	8.4209	-0.8354	Effect
f5	Customer relations management	8.2057	-1.3330	Effect
f6	Environmental management	8.9112	0.2151	Cause
f7	Safety and security management	10.3683	-0.5154	Effect
f8	Change management	8.7287	0.2634	Cause

Source: *Own elaboration based on research examined in 2022.*

Based on the results it can be stated that five out of eight factors have causal character. Therefore, these factors should be firstly improved. The heat map (Table 5) presents all relations between management areas of the maritime container terminals. Thus, even very weak relations can be identified.

__Table 5.__ Heat-map of mutual relations between all identified areas of management in maritime container terminal



Source: *Own elaboration using the Python programming language.*

Based on the data presented in Table 5 it can be stated that there is numerous mutual relation between all identified management areas. The highest value of the relation indicator has been achieved by process management. This can be understood as a crucial role and impact of process management on other areas. Similarly, strategic and operational management has achieved the highest result in the significance indicator, which means that this area is the most important in managing maritime container terminals.

4. Discussion and Conclusions

The research results obtained based on the applied methodology indicate that process management is the most important aspect of managing maritime container terminals. The dominant role of this factor is expressed in the influence exerted on other factors, in which the highest value of impact is on safety and security management (0.8136) and strategic and operational management (0.7822).

Even though process management has the lowest values of impact on risk management (influence value 0.6679) and change management (influence value 0.6616) it is still higher than the average of the values in the matrix $\boldsymbol{T}$ (average value 0.5844). In every management area, the highest impact is exerted by process management.

Another interesting aspect of this research is the fact that safety and security management (f7) is susceptible to the influence of other areas. This can be perceived not only as an actual safety and security of load and transport means but also in the context of cyber-security.

Nowadays, when a whole supply chain is integrated, the role of safety and security is increasing. Therefore, all decisions made in other areas of management have an impact on safety and security. Moreover, the crucial role of this component is also confirmed in this study through the second-highest result in the significance indicator.

Another conclusion from this research is that every component has mutual relation and influence on each other – some of them are very weak and less noticeable – e.g., influence of process management on risk management.

This paper is the first that attempted to identify the mutual causal relations between various components of maritime container terminal management. Further research direction is connected to examine similar research on the different maritime terminals to compare the results and empirically verify, whether process management is the most important and influential area of management in other terminals.

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