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A MULTI-CRITERIA EVALUATION OF CONTAINER TERMINAL TECHNOLOGIES APPLYING THE COPRAS-G METHOD

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Abstract. Over the recent years, the usage of containers has dramatically increased; subsequently, port container terminals annually serve more and more intensive flows, which leads to the necessity to find the ways of increasing terminal performance in order to achieve that a growing number of containers would be expeditiously served. The minimization of container handling duration in a terminal would reduce the total transportation time and create preconditions for an increase in the efficiency of the transport chain. The article deals with the above introduced problem on the basis of research on container handling operations applying different technologies when the objective function is the optimization of the container handling cycle that includes assessing the parameters of terminal technical systems and determining the most rational container handling technology. For this purpose, the system of the factors directly influencing the container handling cycle and expert assessment estimating the weight of each factor of the overall handling duration have been determined. With reference to the obtained results and adapted multi-attribute assessment method COPRAS-G, the evaluation of traditional terminal technologies was performed thus determining the most efficient technology under supposed conditions.

Keywords: intermodal transport, container terminal, handling technology, multi-criteria evaluation, decision-making.

1. Introduction

The transport sector faces serious problems having economic and social impact due to high congestion on roads. Traditional methods for developing separate transport modes fail to resolve increasing problems of the transport system. The integration of transport modes based on the shift of freight from road transport to alternative transport modes has been considered as the main solution to the existing problem (European Commission 2001, 2011).

Recently, the importance of intermodal transport is strongly emphasized supporting, promoting and allocating various political and financial tools beneficial not only for the participants of the freight transportation chain but also for the whole society. Collective advantages of intermodal transport are a reduction in infrastructural costs that occur through a reduction in the road traffic volume and external costs that appear through a reduction in noise, air pollution, the consumption of energy sources and climatic changes.

However, intermodal transport is a complex transportation form of the transport system, including a variety of transport modes, different actors and business models. Close interoperability in terminals is necessary for the smooth integration of transport modes.

Along with larger ships and rapid growth in container flows (UNCTAD 2010), container terminals at ports have become very important transport network nodes that serve as the interface between maritime and land transport and ensure continuous flows of freight traffic (Murty *et al.* 2005). Container terminals as well as serving ships fast and qualitatively determine port competitiveness in the region. In order to maintain or strengthen their position in the competitive market, stevedoring companies are forced to look for ways to improve the performance of a terminal. This means an increase in the efficiency of container handling, improvement on flexibility in management and a reduction in cost through adequate facilities (Parola, Sciomachen 2005). For this reason, new activity planning strategies are developed and investments in advanced information technologies and automated guided vehicle systems are made. However, hasty investments may not always be successful in solving problems, especially if terminal infrastructure is not adapted to modern technologies. Therefore, it is necessary to select suitable technology for container handling as terminal processes are an integral part of the whole transport process and directly affect the overall freight shipment time. The minimization of container handling duration in a terminal would reduce the total transportation time and create preconditions for an increase in the efficiency of the transport chain.

The main purpose of the article is to perform the evaluation of the most popular container handling technologies by assessing the parameters of technical systems and to determine the most efficient technology ensuring the shortest container handling duration in the terminal. The structure of the paper is as follows: Section 2 covers the analysis of works on the efficiency of the performance of container terminals and studies the factors of effective functioning; a description of multi-criteria evaluation and the application of a decision-making method are presented in Section 3; Section 4 is dedicated to determining the system of factors directly influencing the duration of container handling; Section 5 performs a multi-criteria evaluation of traditional terminal technologies; finally, conclusions are given in Section 6.

2. Factors Determining the Efficiency of a Container Terminal

There is a great variety of intermodal terminals of different types (Roso *et al.* 2009; Woxenius 2007), sizes and layouts (Lee, Kim 2010; Golbabaie *et al.* 2012) providing a number of value-added services. The independency of this main objective of all terminals is general and designed to support the intermodal transportation of cargo and at the same time to achieve the minimization of the total transportation cost, the elimination of traffic congestion on the roadway network and a reduction in environmental pollution and deterioration (Nathanail 2007).

Meanwhile, a container terminal at a port is the place where container ships are docked on berths, inbound containers are unloaded and outbound containers are loaded (Murty *et al.* 2005). Accordingly, the container terminal must ensure the smooth transfer of freight and thus continuous flows between sea and land transport modes.

The scholars claim that the efficiency of a container port is an important factor for the international competitiveness of the country. For this reason, intensive studies have been carried out in order to determine port performance across all the regions of the world. Cullinane and Wang (2006) used the DEA (*Data Envelopment Analysis*) approach to measure the efficiency of 69 container terminals in Europe with an annual throughput over 10000 TEUs. The findings of the study include significant inefficiency that generally pervades most of the terminals. Le-Griffin and Murphy (2008) assessed the productivity of Los Angeles and Long Beach ports and compared these measurements with those of other major container ports situated in the U.S. and overseas. The drawn comparisons suggest that the ports of Los Angeles and Long Beach are underperforming relative to other leading container ports. Turner *et al.* (2004) used DEA for measuring the growth of seaport infrastructure productivity in North America from 1984 to 1997 and explored several causal relationships between infrastructure productivity and industry structure and conduct. The authors stated that during the study period gross infrastructure productivity rose on average for North American container ports. By applying the DEA model, So *et al.* (2007) attempted to measure the operational efficiency of 19 major container ports in Northeast Asia. According to the obtained results, the conclusion that 8 container ports were operated efficiently was made; Honkong was ranked top as the most efficient port in Northeast Asia. Liu *et al.* (2008) used DEA models and Malmquist TFP approach for determining the efficiency of 47 terminals in China with an annual throughput over 10000 TEUs. The empirical results uncover that the majority of efficient terminals are lying in the largest ports such as Shanghai and Szenzhen, indicating that large ports may have a positive effect on the technical efficiency of their terminals for the closeness to the shipping market. The study by Munisamy and Sigh (2011) employed the DEA technique to benchmark and evaluate the operating performance of 69 major Asian container ports and generate efficiency ranking. The received results indicated that the average technical efficiency of Asian container pots was 48.8% due to pure technical inefficiency. DEA analysis also was used for providing an efficiency measurement of 4 Australian and 12 other international container ports (Tongzon 2001). The ports of Melbourne, Rotterdam, Yokohama and Osaka are found to be the most inefficient ports mainly due to enormous slack in their container berths, terminal area and labour inputs. The efficiency of 22 seaports of the Middle East and African region were evaluated by Al-Eraqi *et al.* (2008). Analysis was performed employing the DEA method. The results indicated that small ports were efficient, whereas the big ones were not. Wu and Goh (2010) evaluated the efficiency of operations performed in the emerging markets of container ports with more advanced markets using the DEA approach based on import and export cargo volumes. The achieved results suggest that none of the ports in the advanced markets are role models for the field.

Few studies have investigated the relationship between ownership structure and port efficiency. The results based on the experience of container terminals around the world have shown that private sector participation in port industry to some extent can improve port operation efficiency, which in turns increases port competitiveness (Tongzon, Heng 2005; Cullinane *et al.* 2005a). According to Cheon *et al.* (2010), the government sector should focus primarily on policy-making regarding environmental, safety and custom regulations, whereas public parties should focus on long-term planning, financing infrastructure and creating a market structure to reduce monopolistic characters.

The analysis of scientific literature suggests that the productivity of a container port mainly depends on the efficient use of labour, land and capital. Labour inputs include the number of terminal workers (Barros, Athanassiou 2004; González, Trujillo 2008) and other labour expenditures (Matinez-Budria *et al.* 1999). In terms of land inputs, the terminal area has often been noticed as a variable (Cheon *et al.* 2010; González, Trujillo 2008; Le-Griffin, Murphy 2006), the total length of the terminal (Cullinane *et al.* 2006; Cullinane, Wang 2006; Cullinane *et al.* 2005b) and the total length of the quay (Liu *et al.* 2008; So *et al.* 2007) or the yard area (Al-Eraqi *et al.* 2008; Lin, Tseng 2005). Capital inputs include berths, docks, roads and the number of various handling equipment such as quay cranes (Munisamy, Singh 2011; Liu *et al.* 2008), tugs (Tongzon 2001), yard cranes and straddle carriers (Cullinane, Wang 2006; Cullianne *et al.* 2005b). It can be concluded that the key elements of the effective functioning of the container terminal at a port are adequate terminal space and correctly chosen container handling technology.

Scientists emphasize the role of technical equipment in terminal operations, as terminals are faced with more and more containers to be handled in short time; consequently, they are forced to enlarge handling capacities and strive for achieving gains in productivity. Accurately selected handling technology could solve the capacity problems of terminals.

3. Application of the Decision-Making Method

Multi-criteria evaluation is a decision-making tool developed for complex problems that include qualitative and/or quantitative aspects of the problem in the decision-making process and is often called multi-criteria decision making (MCDM) or multi-criteria decision analysis (MCDA).

There are a number of diverse multi-criteria decision-making methods used worldwide. The common purpose of those is the ability to evaluate selected alternatives based on multiple criteria using systematic analysis and to determine the best one. The result of some approaches is ranking alternatives, whereas the others determine a single optimal alternative or the differentiation of acceptable or unacceptable alternatives.

The planning process of decision-making is shown in Fig. 1 where rectangles show the stages of the planning process and the bubbles present the stages of multi-criteria evaluation.

Literature contains various ways of classifying decision-making methods. The common distribution of the methods divides them into quantitative and qualitative approaches according to available information. Quantitative methods evaluate each alternative and obtain numerical superiority between them. Quantitative approaches include such methods as SAW, TOPSIS, VIKOR, MOORA, COPRAS and the new method ARAS.

For achieving a solution to the problem under consideration, the COPRAS-G (*COmplex PRoportional ASsessment of alternatives with Grey relations*) decision-making method was selected. This method allows determining the priority of each considered alternative and

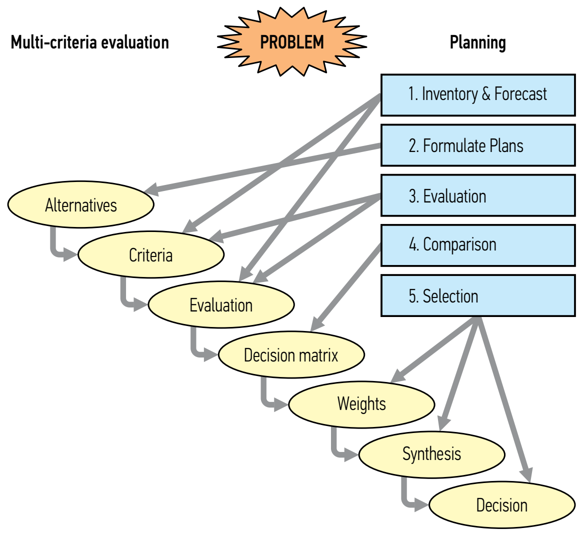


Fig. 1. The process of decision-making (Linkov *et al.* 2005)

calculating the utility degree, which facilitates a visual assessment of alternative efficiency.

Most of multi-criteria decision-making problems cannot be determined accepting the exact criteria values; instead, fuzzy values or values in some intervals are taken. The idea of the COPRAS-G method comes from applying the theory of grey systems when criteria values are expressed in intervals, which corresponds the real conditions of decision making (Zavadskas *et al.* 2009, 2010). For the past 25 years, both the theory and practical application of grey systems have achieved splendid results and many academics are still widely applying the grey system theory in decision-making of various scientific areas. In sequence, the theory of grey systems has been recognized as a powerful tool for qualitative and quantitative system analysis (Lin *et al.* 2004).

The process of multi-criteria evaluation using the COPRAS-G method includes the following steps:

1. Selecting the system of criteria describing the alternatives.
2. Determining the weights of the selected criteria.
3. Preparing the grey decision-making matrix:

$$\otimes X = \begin{bmatrix} [w_{11};b_{11}] & [w_{12};b_{12}] & \dots & [w_{1m};b_{1m}] \\ [w_{21};b_{21}] & [w_{22};b_{22}] & \dots & [w_{2m};w_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [w_{n1};b_{n1}] & [w_{n2};b_{n2}] & \dots & [w_{nm};b_{nm}] \end{bmatrix}, \quad (1)$$

where: w_{ji} – a lower value of criterion j in alternative i; b_{ji} – an upper value of criterion j in alternative i; n – the number of criteria; m – the number of alternatives.

4. Preparing the normalized decision-making matrix. The normalized values of the matrix are calculated using the formulas:

$$\bar{w}_{ji} = \frac{w_{ji}}{\frac{1}{2}\left(\sum_{i=1}^{m} w_{ji} + \sum_{i=1}^{m} b_{ji}\right)} = \frac{2w_{ji}}{\sum_{i=1}^{m} w_{ji} + \sum_{i=1}^{m} b_{ji}}; \quad (2)$$

$$\bar{b}_{ji} = \frac{b_{ji}}{\frac{1}{2}\left(\sum_{i=1}^{m} w_{ji} + \sum_{i=1}^{m} b_{ji}\right)} = \frac{2b_{ji}}{\sum_{i=1}^{m}\left(w_{ji} + b_{ji}\right)}. \quad (3)$$

5. Calculating the weighted normalized decision-making matrix. The weighted normalized values of the matrix are calculated by the formulas:

$$\hat{w}_{ji} = \bar{w}_{ji} \cdot q_j; \quad (4)$$

$$\hat{b}_{ji} = \bar{b}_{ji} \cdot q_j, \quad (5)$$

where: q_j – the weight of criterion *j*.

6. Calculating the sum of the criteria of the weighted normalized decision-making matrix in which larger values are more preferable for alternatives, i.e. optimization direction is maximization:

$$P_i = \frac{1}{2}\sum_{j=1}^{k}\left(\hat{w}_{ji} + \hat{b}_{ji}\right), \quad (6)$$

where: k – the number of the criteria the values of which must be maximised.

7. Calculating the sum of the criteria of the weighted normalized decision-making matrix the smaller values of which are more preferable for alternatives, i.e. optimization direction is minimization:

$$R_i = \frac{1}{2}\sum_{j=k+1}^{n}\left(\hat{w}_{ji} + \hat{b}_{ji}\right), \quad (7)$$

where: $(n - k)$ – the number of the criteria the values of which must be minimised.

8. Determining a minimal value of R_i:

$$R_{\min} = \min_i R_i. \quad (8)$$

9. Calculating the relative weight of each alternative:

$$Q_i = P_i + \frac{R_{\min}\sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{m} \frac{R_{\min}}{R_i}}. \quad (9)$$

Relative weight is based on the positive and negative characteristics of the alternatives and determines the significance of each alternative.

10. Determining the optimality criterion:

$$L = \max_i Q_i. \quad (10)$$

11. Determining the priority of the alternatives. Greater relative weight indicates a higher rank of the alternative.

12. Calculating the utility degree of each alternative:

$$N_i = \frac{Q_i}{L} \cdot 100\ \%. \quad (11)$$

The utility degree is determined by comparing each alternative with the alternative contained in the highest relative weigh.

The COPRAS-G method has been applied to reaching a solution to various problems encountered in construction, economics, property management, civil engineering and management on numerous occasions before (Turskis *et al.* 2009; Zavadskas *et al.* 2007, 2008; Zolfani *et al.* 2012). The article adapts the COPRAS-G method to evaluate traditional container handling technologies and to determine the most efficient technology for applying it in the terminal. Relative weight indicates the performance degree of the analyzed technologies; in the case of Q_{max}, it means that the performance degree is the highest and implies that container handling duration in the terminal is the shortest. The utility degree indicates how much one container handling technology is better or worse than the other in percentage expression.

4. Determination of the Criteria System and Estimation of Factor Weights

In order to evaluate container handling technologies, a system of the criteria describing alternatives must be developed. For this purpose, the container handling process in the terminal has been investigated seeking to ascertain factors influencing the container handling cycle.

The container handling cycle is considered as the duration of container movement in a terminal starting from container pickup by a quay crane off a ship to export by client truck through terminal gates. This means that the container is performed by a wide number of handling operations, including:

T1 – transhipment between a ship and a quay using a quay crane;

T2 – transportation between the quay and a storage yard using a quay terminal vehicle;

T3 – transhipment between the quay terminal vehicle and a storage place using yard equipment;

T4 – storage;

T5 – transhipment between the storage place and a customer's vehicle using yard equipment;

T6 – transportation from the terminal using the customer's vehicle;

T7 – the inspection of documents and container condition at the exit gates.

The equivalents of every above mentioned operation separate the stage of the container handling cycle (Fig. 2).

Container handling operations disclosed that the cycle of container handling was directly influenced considering 36 factors itemized in Table 1. All these factors depend on such aspects as the specification of terminal activity, terminal size and storage yard layout, the type of operating handling equipment and the human factor.

The significance of the factors was assessed by 10 experts who participated in the survey on purpose to identify the significance of determined factors influencing the duration of container handling. The experts were given the task to estimate the importance of each factor considering the overall container handling time in the terminal. The results of the expert survey have been processed to substantiate the reliability of assessment.

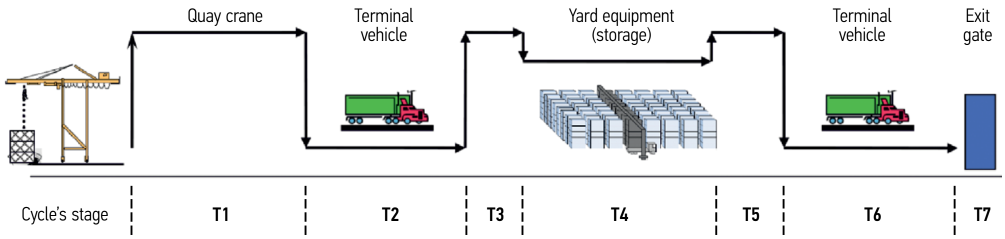


Fig. 2. The stages of the container handling cycle

Table 1. The results of assessing factor weight

Cycle stage	Factor	Optimization direction	Weight
T1: Transshipment between a ship and quay	1.1. Spreader position fixing above the container and its lock time	min	0.0250
	1.2. Container lifting height	min	0.0300
	1.3. Container lifting speed	max	0.0329
	1.4. Container lowering height	min	0.0272
	1.5. Container lowering speed	max	0.0315
	1.6. Container transfer distance in a horizontal direction	min	0.0264
	1.7. Container transfer speed in a horizontal direction	max	0.0300
	1.8. Container overlapping*	min	0.0300
	1.9. Container position fixing above a landing place and its unlock time	min	0.0257
	1.10. Actuate and disengage time of crane mechanisms	min	0.0179
T2: Transportation to the storage yard	2.1. Container transportation distance from a quay to a storage sector	min	0.0264
	2.2. Vehicle movement speed	max	0.0279
T3: Transshipment between the terminal vehicle and storage place	3.1. Spreader position fixing above the container and its lock time	min	0.0257
	3.2. Container lifting height	min	0.0293
	3.3. Container lifting speed	max	0.0315
	3.4. Container lowering height	min	0.0286
	3.5. Container lowering speed	max	0.0322
	3.6. Container transfer distance in a horizontal direction	min	0.0257
	3.7. Container transfer speed in a horizontal direction	max	0.0279
	3.8. Operation overlapping*	min	0.0307
	3.9. Container position fixing above a storage place and its unlock time	min	0.0272
	3.10. Actuate and disengage time of equipment mechanisms	min	0.0172
T4: Storage	–	–	–
T5: Transshipment between the storage place and customer's vehicle	5.1. Container rearrangement	min	0.0243
	5.2. Spreader position fixing above the container and its lock time	min	0.0243
	5.3. Container lifting height	min	0.0307
	5.4. Container lifting speed	max	0.0329
	5.5. Container lowering height	min	0.0293
	5.6. Container lowering speed	max	0.0322
	5.7. Container transfer distance in a horizontal direction	min	0.0272
	5.8. Container transfer speed in a horizontal direction	max	0.0293
	5.9. Operation overlapping*	min	0.0300
	5.10. Container position fixing above the vehicle and its unlock time	min	0.0279
	5.11. Actuate and disengage time of equipment mechanisms	min	0.0179
T6: Transportation from the terminal	6.1. Container transportation distance from the storage sector to the exit gate	min	0.0257
	6.2. Vehicle movement speed	max	0.0279
T7: Inspection	7.1. Inspection time of documents and container condition	min	0.0336

Notes: * Operation overlapping – when more than one operation can be carried out at the same time; ** Storage stage in a container cycle is not estimated since it does not depend on technology used.

The method capable to identify inconsistent evaluation was first proposed by Kendall (1970) that defined dispersive concordance coefficient (Pukėnas 2009):

$$W = \left(\frac{F}{e(n-1)} \right) \left(\frac{e^2 n(n^2-1)/12}{e^2 n(n^2-1)/12 - e\sum T/12} \right), \quad (12)$$

where: F – Friedman's χ^2 statistic; e – the number of experts; n – the number of criteria; T – the rate of related rankings calculated by the formula:

$$\sum T = \sum_{i=1}^{e} \sum_{j=1}^{k} (t^3 - t), \quad (13)$$

where: t – the number of criteria with related rankings through all investigation.

The concordance coefficient varies between 0 and 1. In case the expert opinion is consistent, the value of concordance coefficient W is approximate 1; in case the expert opinion strongly differs, the value of concordance coefficient W is close to 0.

If the number of judging objects is considerable enough ($n > 7$), the significance of the concordance coefficient is determined by criterion χ^2 (Podvezko 2005). Friedman's χ^2 statistic is defined by the formula (Pukėnas 2009):

$$\chi^2 = \frac{\left(12/en(n+1)\right)\sum_{j}^{n} C_j^2 - 3e(n+1)}{1 - \sum T/en(n^2-1)}, \quad (14)$$

where: C_j – the sum of criterion j (j = 1, 2, …, n) ranks.

If the calculated value of χ^2 is higher than critical value χ^2_{cr} derived from the table with evaluated freedom degree ($f = n - 1$) and significance level α, it suggests that the expert opinion is consistent and the results of the expert survey are reliable.

In that case, the concordance coefficient of the expert survey was estimated W = 0.294. Equally, the value of χ^2 was estimated χ^2 = 125.38 and defined it exceeded critical value $\chi^2_{cr} = 49.76$ with significance level α = 0.05 and freedom degree f = 35, which substantiates that the expert opinion is consistent and the significance of the criteria evaluated by the experts can be used determining the weight of factors.

First, the average value of criteria significance has been determined by formula (Viteikienė 2006):

$$\bar{t}_j = \frac{\sum_{r=1}^{n} t_{jr}}{e}, \quad (15)$$

where: t_{jr} – the significance of criterion j by expert r; e – the number of experts.

Consequently, the weight of each criterion has been determined by the formula (Viteikienė 2006):

$$q_j = \frac{\bar{t}_j}{\sum_{j=1}^{n} \sum_{r=1}^{e} t_{jr}}. \quad (16)$$

The weight of each factor influencing the container handling cycle has been estimated identifying that documents, container condition inspection time at the exit gates, container lifting and lowering speed at every stage of container's transfer have the greatest impact on the duration of container handling. The detailed list of factor weights is inscribed in Table 1.

5. Evaluation of Container Handling Technologies

Different types of material handling are involved in container handling during quay and yard operations. Most of the terminals using the manned equipment like gantry cranes (RTG and RMG), straddle carriers, reach stackers, terminal trucks and container handling systems can be categorized considering the combination of this equipment (Huang, Chu 2004).

For multi-criteria evaluation, five alternatives of the most popular below considered container handling systems were accepted.

The concept of a multi-trailer system (1) consists of a number of trailers capable of carrying two TEU or one FEU and coupled behind each other to form a trailer train pulled by a terminal truck (Table 2). The system is designated for multiple container transportation and storage on the appointed trailer. The main weakness of this system is a large area required for container storage where they can be slot entirely by one level. The multi-trailer system can accommodate only up to 250 TEUs/ha of the storage yard.

In the system of gantry cranes, containers from the quay to storage yard are transported by terminal trucks. The stacking process in the storage yard is done employing gantry cranes. The system of gantry cranes is divided into two types – rubber tyred gantry (RTG) crane system (2a) and rail mounted gantry (RMG) crane system (2b). The storage capacity of these systems is quite high as gantry cranes can accommodate up to 1000 TEUs/ha and much more when the containers are stacked in 4-high.

Table 2. The results of multi-criteria assessment

Container handling system	1	2a	2b	3	4	5
The sum of criteria with maximizing optimization direction, P_i	0.02295	0.06430	0.06956	0.04570	0.05802	0.07566
The sum of criteria with minimizing optimization direction, R_i	0.04497	0.12279	0.12345	0.12423	0.12201	0.12646
Relative weight, Q_i	0.2587	0.1506	0.1554	0.1310	0.1449	0.1595
Rank	1	4	3	6	5	2
Utility degree, N_i	100.00	58.23	60.09	50.66	56.02	61.66

In the reach stacker system (3), the containers from the quay to storage yard are transported by terminal trucks. They are accommodated by the reach stackers in the storage yard. This is one of the most flexible handling solutions, however, the utilization of the terminal area is quite low as it is necessary to maintain wide space for the free movement of equipment. The storage capacity of the reach stacker system is up to 500 TEU/ha when the containers are stacked in 3-high.

The straddle carrier system is divided into two different systems – a straddle carrier direct system (4) and a straddle carrier relay system (5). In the direct system, straddle carriers transport containers directly between the quay crane and the stacking area where containers are removed in stacks. In this case, straddle carriers perform both transportation and transhipment operations. In the relay system, containers are transferred between the quay and storage area by terminal trucks and straddle carriers pick up containers and moves along the rows to stack them. The systems of straddle carriers can accommodate up to 750 TEUs/ha of the storage yard when the containers are stacked in 3-high.

The comprehensive results of multi-criteria evaluation applying the COPRAS-G method for container handling technologies are given in Table 2. The outcome indicates that the multi-trailer system reaches the highest utility degree and therefore is the most efficient technology. The utility degree of the rest of the systems is rather low and varies between 50÷62% comparing to the multi-trailer system.

According to the storage capacity of the multi-trailer system, a conclusion that a particular system can operate only in the terminal with low volumes of container flows can be made. Therefore, this technology is not suitable for the use in the conventional terminal with medium or high workload where generally intensive container flows are handled.

Taking into account the practical storage capacity (Stahlbock, Voβ 2008) of every system, additional evaluation was conducted. The results of computation are given in Fig. 3.

The outcome has showed that if container handling requires storing up to 500 TEUs/ha, gantry cranes, reach stackers and straddle carrier systems in the terminal can be applied. It has been found that the most efficient technology is the system of straddle carrier relay. In this case, the utility degree of the rest of technologies include the RTG crane system – 96.22%, RMG crane system – 98.4%, reach stacker system – 86.69% and straddle carrier direct system – 94.24%.

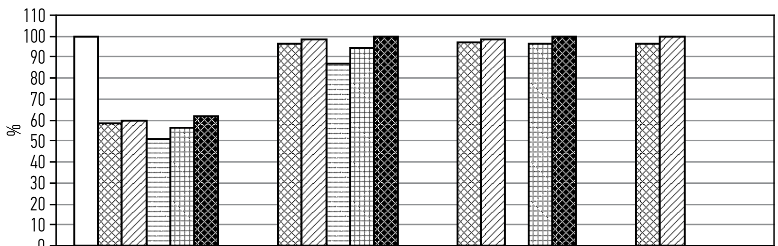
If container handling requires storing up to 750 TEUs/ha, gantry cranes and straddle carrier systems can be employed in the terminal. It has also been revealed that the most efficient technology in this case is the system of straddle carrier relay. The utility degree of the RTG crane system is 96.76%, RMG crane system – 98.62%, straddle carrier direct system – 96.12%, straddle carrier direct system – 96.12%.

In the case where container flows are concentrated and the required storage capacity is up to 1000 TEUs/ha and more, only gantry crane systems can be used in the terminal. The RMG crane system is more efficient technology than the RTG crane system, the performance degree of which makes 96.17%.

Fig. 3 presents the visual efficiency of the compared container handling's technologies assessed systems' technical parameters and the possibilities of applying them according to practical storage capacity.

6. Conclusions

1. The theoretical study has showed that the key elements of the efficient functioning of a container terminal at a port are an adequate terminal area and correctly chosen container handling technology. Rational container handling technology could solve the capacity problem of the terminal with minimal costs of container handling time and financial investment.
2. The paper has developed the system of factors directly influencing the container handling cycle and estimated that time for inspecting documents and container condition, container lifting speed and container low-



	250 TEUs/ha	500 TEUs/ha	750 TEUs/ha	1000 TEUs/ha
1 alternative	100	–	–	–
2a alternative	58,23	96,22	96,76	96,17
2b alternative	60,09	98,4	98,62	100
3 alternative	50,66	86,69	–	–
4 alternative	56,02	94,24	96,12	–
5 alternative	61,66	100	100	–

Fig. 3. The utility degree of the compared technologies and the possibilities of application according to storage capacity

ering speed at each stage of container transfer have the greatest impact on container handling duration.

3. The conducted multi-criteria evaluation has showed that the multi-trailer system reaches the highest utility degree and therefore is the most efficient technology. However, it has been ascertained that the application of technology in the terminal is restricted by its practical storage capacity.
4. If container handling requires storing up to 500 TEUs or up to 750 TEUs per hectare, the most efficient technology is the straddle carrier relay system. If container handling requires storing up to 1000 TEUs per hectare, the most efficient technology is the rail mounted gantry crane system.

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