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Evaluation of Transshipment Technologies in Intermodal Terminals: A Hybrid FSWARA-ADAM Approach

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Abstract: The accelerating process of globalization has led to an increase in freight transport volumes, exacerbated road congestion, and heightened environmental concerns, underscoring the imperative for sustainable and alternative transport solutions. Intermodal transport, which amalgamates the benefits of various modes of transportation, emerges as a paramount solution to these challenges. At the core of intermodal transport lies the intermodal terminal, whose efficiency and efficacy are critically contingent upon the transshipment technology employed. This investigation is dedicated to the evaluation of transshipment technologies within intermodal terminals. It is recognized that the selection of transshipment technology necessitates consideration of diverse criteria, mandating the application of appropriate multi-criteria decision-making methodologies. To address this complexity, a novel hybrid model, integrating Fuzzy Step-Wise Weight Assessment Ratio Analysis (FSWARA) with Axial-Distance-Based Aggregated Measurement (ADAM), is proposed. The efficacy of this model is demonstrated through its application in assessing various transshipment technologies, with an emphasis on optimizing the decision-making process in the selection of the most appropriate technology. This study contributes to the body of knowledge by providing a comprehensive framework for the evaluation of transshipment technologies in intermodal terminals, facilitating enhanced decision-making in the context of sustainable and efficient intermodal transport systems.

Keywords: Intermodal transport; Intermodal terminal; Transshipment technology; Fuzzy Step-Wise Weight Assessment Ratio Analysis (FSWARA); Axial Distance-Based Aggregated Measurement (ADAM)

1. Introduction

The globalization of the world market has precipitated an escalation in freight transport volumes alongside fluctuating demands within supply chain management, thereby presenting significant challenges to the transportation sector. There is a demand for achieving economically efficient transport that must simultaneously be safe and environmentally sustainable, with individual modes of transport not providing adequate solutions (Krstić et al., 2023). Enhancing the use of intermodal transport can help integrate various modes of transport, which is one way to potentially accomplish this goal. This reduces the negative effects of a single mode of transport by substituting it with one that uses fewer resources, benefiting the economy and the environment (Liu & Wang, 2023). Intermodal transport is defined as the concept of using two or more modes of transportation in combination to form an integrated transport chain to achieve efficient and economical delivery of goods in an environmentally sustainable manner from their origin to the final destination. Utilizing the best features of each mode of transport is the essence of intermodal transport (Lowe, 2006).

According to the definition of the European Conference of Ministers of Transport (ECMT, 2022), intermodal transport involves the movement of goods in the same unit or vehicle for loading while utilizing successive modes of transport as long as the goods are not handled during the mode change (ESCAP, 2004). This definition restricts intermodal transport to unitized transport, avoiding the handling of cargo between vehicles and intermodal transport units (ITUs). Consolidation of cargo into such units is crucial as it allows for faster handling by packing multiple smaller units into a larger one, enabling the loading of a larger number of smaller units in a single operation. In line with this, it is essential to emphasize that one of the significant subsystems of intermodal transport involves the subsystem of ITUs. Within this subsystem, a vital aspect involves standardization, which plays a key role in changing modes of transport. The primary requirement is that the ITU be adapted to both transshipment technology at different intermodal terminals and the cargo space of various modes of transport. The main goal is to ensure that the efficiency of door-to-door transport is not compromised by time losses during the transition from one mode of transport to another.

Since transshipment of transport units is inevitable in intermodal transport, it is necessary to provide a place that will facilitate this transshipment, known as an intermodal terminal. An intermodal terminal is one of the fundamental subsystems of intermodal transport that provides space, equipment, and a working environment for the transshipment and storage of transport units, mode switching, and the collection and storage of goods (Ramaekers et al., 2012). It can be said that an intermodal terminal represents a node in the intermodal transport network, as every freight transport flow begins, ends, or transits through it. To enable the efficient implementation of intermodal transport, the presence of subsystems of terminal networks and traffic infrastructure is necessary, as they are essential parts of the transport system. The subsystem of terminal networks involves a system of interconnected terminals with the unique goal of ensuring continuous connectivity between different modes of transport on a micro, meso, and macro technological level. Such connectivity would not be possible without the traffic infrastructure subsystem, which connects transport hubs such as intermodal terminals with starting or final destinations.

Considering that one of the primary functions of an intermodal terminal is handling ITUs, it is clear that its efficiency and effectiveness largely depend on the applied transshipment technology. Accordingly, the selection of suitable transshipment technology emerges as a specific problem that requires a detailed technical and comparative analysis of ITUs and transshipment technologies as the foundation of intermodal transport. This study aims to evaluate transshipment technologies in an intermodal terminal depending on the applied ITUs, the modes of transport to which the terminals are connected, and the distances covered by the dominant mode of transport.

The structure of the paper is as follows: An overview of the relevant literature is provided in Section 2. Section 3 provides an explanation of how to apply the suggested hybrid model to solve the specified problem. In Section 4, the problem that serves as the foundation for both the model demonstration and the applicability of the method is described. The outcomes of using the suggested hybrid model to assess transshipment technologies at the intermodal terminal are given in the same section. Section 5 presents a discussion of the findings. Concluding remarks regarding this study are given in the final section.

2. Literature Review

According to the European Green Deal, rail and inland waterways are to replace a significant portion of the current 75% of inland freight transported by road. In practical terms, this means using intermodal transport, in which only the first and last miles are traveled on public roads and the majority of the trip is completed by rail or water. This calls for effective transshipment facilities and technologies that enable quick and economical transshipping of loading units between the modes (ECMT, 2022). In light of this, the present section centers on the identification and description of transshipment technologies and standardized ITUs, which are essential for enhancing sustainability, streamlining the transportation network, and realizing the objectives of European programs like the European Green Deal.

An ITU refers to a unit containing unitized cargo, i.e., several identical or different smaller units, with no changes during transport. The ITU enables the consolidation of cargo into larger units, facilitating stacking, the application of handling equipment, and transshipping between various transport modes. These units must comply with standards regarding dimensions and construction, but they must also be equipped with devices allowing transshipment between various modes of transport using standardized transshipment technologies. The most commonly used ITUs include containers, swap bodies, semitrailers, and complete road vehicles, which are described below.

According to the definition of the International Organization for Standardization (ISO), a container is a rectangular prism that is watertight and designed for the transportation and storage of a certain number of cargo units, parcels, or bulk cargo. It protects its contents from damage and loss, can be detached from the transport vehicle, manipulated as a single loading unit, and can be transshipped without simultaneously transshipping the cargo. Cargo containers can take the form of standardized ISO containers for maritime transport and containers intended for continental transport (ECMT, 2022).

The European Intermodal Transport Unit (EITU) is a European intermodal unit designed for land transport in Europe. This unit has been defined by the European Committee for Standardization (CEN/TC 119) (ECMT, 2022).

Semi-trailers are trailers with one or more axles at the back that are pulled by a tractor unit. The semi-trailer and the tractor unit are connected by a kingpin on the semi-trailer and a coupling mechanism on the tractor unit known as the "fifth wheel" (ECMT, 2022).

Road vehicles, which include motor vehicles and are therefore self-propelled vehicles that can be transported on specialized transport means (e.g., "Rollende Landstraße"), are distinct from containers, ITUs, and semi-trailers that were previously discussed. Individual vehicles and combination vehicles are the two categories into which road vehicles can be separated (ECMT, 2022).

According to the Combined Transport Report for Europe in 2020, the use of ISO containers demonstrates a strong trend, constituting almost two-thirds (62%) of the total market. Within ISO containers, 20' containers make up 30%, while 40' containers constitute 43% of the total number of ISO containers (UIR, 2020). Therefore, for further analysis, only 20' and 40' ISO containers will be considered.

On the other hand, transshipment technology can be defined as the method of implementing a specific technological requirement, in this case, the requirement for transshipping an ITU from one mode of transport to another. In this context, it is necessary for the transshipment technology to be compatible with different types of intermodal units and transport vehicles and to enable simple, fast, flexible, reliable, and safe transshipment (Woxenius, 1998b). Today, various transshipment technologies are applied, involving vehicles of different transport modes using the same ITU to ensure that the entire transport process is carried out in the most efficient manner possible.

The two main categories of transshipment technologies are horizontal and vertical functions (transshipment type or movement). In a vertical transshipment process, using a lifting system, containers are raised and transferred from one mode of transportation to another, then stacked for interim storage. Since practically all ITUs can be turned vertically, this kind of handling is standard equipment in many terminals and has proven to be effective. Some of these technologies include: Gantry Crane, Reach Stacker, Mobile Harbour Crane, Hydraulic Material Handling Crane, Crane Ship, Nicht-kranbare Sattelauflieger (NiKraSa), Mobiler, Innovativer Sattelanhänger Umschlag (ISU), etc. (Bhoyar et al., 2021; Klemenčič & Burg, 2018; Shejwal et al., 2017). When the transshipment is horizontal, it means that ITU is oriented either lengthwise, diagonally, or across the transport carrier. For non-craneable ITUs, horizontal transshipment is mostly utilized and works well for transshipment between trucks and trains. Some of these technologies include: CarConTrain, Metrocargo, Sidelifter, CargoBeamer, CargoSpeed, Flexiwaggon, ContainerMover, BOXmover, Helrom,Roll-on/Roll-off, RoRo double stacking cassettes, Rollende Landstraße (RoLa), Megaswing, etc. (Bochynek et al., 2020; Cempírek et al., 2020; Nelldal, 2014; Rail Baltica, 2018; Široký, 2012; Woxenius, 1998a).

Vertical transshipment technologies account for 60-80% of the transshipment capacity in the EU (ECMT, 2022). Therefore, the further analysis will include vertical transshipment technologies that are commonly used, such as the Reach Stacker, Gantry Crane, and Mobile Harbour Crane.

3. Methodology

For the evaluation of transshipment technologies, which represents the goal of this paper, it is necessary to take into account a large number of criteria, meaning it is a complex Multi-Criteria Decision-Making (MCDM) problem that requires the application of appropriate methods. The presence of conflicting criteria in solving the problem of choosing transshipment technology in an intermodal terminal excludes the possibility of finding a unique solution that could simultaneously satisfy all criteria. For this reason, MCDM methods are applied to differentiate possible solutions based on the expressed preferences of decision-makers. The three basic steps that form the foundation of all MCDM methods are as follows: first, selecting sets of alternatives and criteria for their assessment; second, allocating numerical values to criteria to indicate their relative importance; and third, assigning numerical values to alternatives in relation to the criteria being considered to arrive at a final ranking of alternatives and the selection of the best among the set of potentials (Aruldoss et al., 2013; Odu, 2019).

This paper uses a hybrid model of multi-criteria decision-making based on the combination of the FSWARA for criterion weight assessment and the ADAM for obtaining alternative assessments, final ranking, and selection of the most favorable alternative concerning the considered criteria. The following explains the steps of applying a hybrid model, and the general view of the proposed model is shown in Figure 1.

Table 1. Linguistic terms and corresponding fuzzy values

Linguistic Term	Abbreviations	Fuzzy Scale
"None"	"N"	(1, 1, 2)
"Very low"	"VL"	(1, 2, 3)
"Low"	"L"	(2, 3, 4)
"Fairly low"	"FL"	(3, 4, 5)
"Medium"	"M"	(4, 5, 6)
"Fairly high"	"FH"	(5, 6, 7)
"High"	"H"	(6, 7, 8)
"Very high"	"VH"	(7, 8, 9)

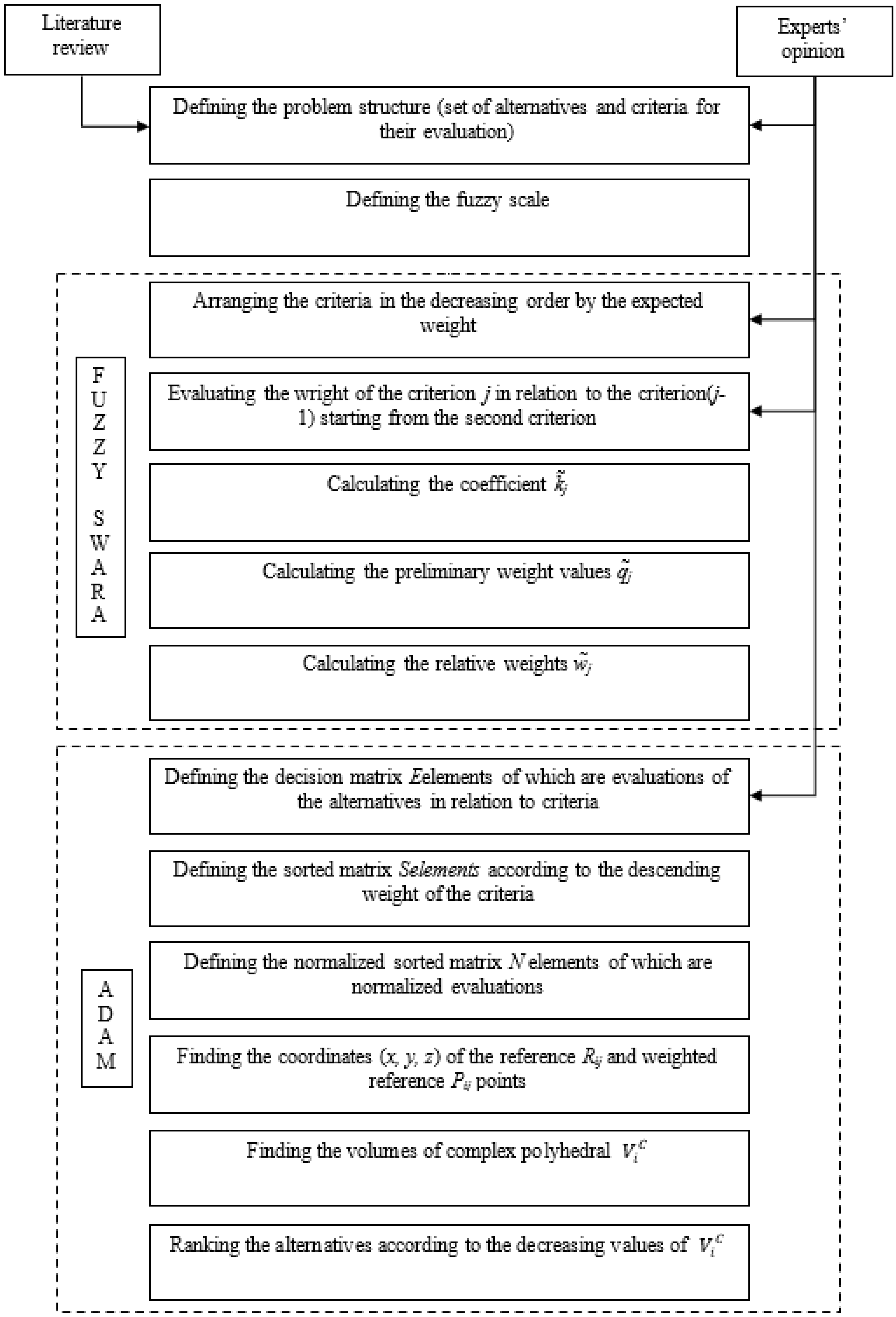

Figure 1. The general view of the hybrid FSWARA-ADAM model (Krstić et al., 2019; Krstić et al., 2023)

Step 1: Define the problem structure, i.e., forming a set of alternatives and a set of criteria for evaluating alternatives.

Step 2: Define the evaluation scale (Table 1).

Step 3: Obtain criterion weights using the FSWARA method. The steps of the method (3.1 - 3.5) are explained below (Krstić et al., 2019):

Step 3.1: Arrange criteria in a decreasing order.

Step 3.2: Obtain the relative weight of the criterion j in relation to the criterion (j-1) starting from the second criterion $\tilde{S}_j$, where $\tilde{S}_j=(l_j, m_j, u_j)$, $j=1,\dots,m$ is a triangular fuzzy number that corresponds to the linguistic terms given in Table 1.

Step 3.3: Calculate the coefficient $\tilde{k}_j$:

$$\tilde{k}_j = \begin{cases} (1,1,1), j = 1 \\ \left(\frac{l_j}{\max_j u}, \frac{m_j}{\max_j u}, \frac{u_j}{\max_j u}\right) + (1,1,1), j > 1, \dots, m \end{cases} \quad (1)$$

Step 3.4: Calculate the preliminary values of criterion weights $\tilde{q}_j$:

$$\tilde{q}_j = \begin{cases} (1,1,1), j = 1 \\ \frac{\tilde{q}_{j-1}}{\tilde{k}_j}, j > 1, \dots, m \end{cases} \quad (2)$$

Step 3.5: Calculate the relative weight of the criterion $\tilde{w}_j$:

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_j \tilde{q}_j} \quad (3)$$

Step 4: Evaluate and rank the alternatives using the ADAM method (Krstić et al., 2023):

Step 4.1: Define the decision matrix E elements, which are evaluations e_{ij} of the alternatives i in relation to criteria j:

$$E = [e_{ij}]_{m \times n} \quad (4)$$

where, m is the total number of alternatives, and n is the total number of criteria.

Step 4.2: Define the sorted decision matrix:

$$S = [s_{ij}]_{m \times n} \quad (5)$$

Step 4.3: Define the normalized sorted matrix N elements, which are obtained as:

$$n_{ij} = \begin{cases} \frac{s_{ij}}{\max_i s_{ij}}, & for j \in B \\ \frac{\min_i s_{ij}}{s_{ij}}, & for j \in C \end{cases} \quad (6)$$

where, B is the set of benefits, and C is the set of cost criteria.

Step 4.4: Find the coordinates (x, y, z) of the reference R_{ij} and weighted reference P_{ij} points:

$$x_{ij} = n_{ij} \times \sin \alpha_j, \forall j = 1, \dots, n; \ \forall i = 1, \dots, m \quad (7)$$

$$y_{ij} = n_{ij} \times \cos \alpha_j, \forall j = 1, \dots, n; \ \forall i = 1, \dots, m \quad (8)$$

$$z_{ij} = \begin{cases} 0, for R_{ij} \\ w_j, for P_{ij} \end{cases}, \forall j = 1, \dots, n; \ \forall i = 1, \dots, m \quad (9)$$

where, α_j is the angle that determines the direction of the vector that defines the value of the alternative:

$$\alpha_j = (j-1)\frac{90°}{n-1}, \forall j = 1, \dots, n \quad (10)$$

Step 4.5: Find the volumes of complex polyhedra V_i^C:

$$V_i^C = \sum_{k=1}^{n-1} V_k, \forall i = 1, \dots, m \quad (11)$$

where, V_k is the volume of the pyramid obtained by applying the following equation:

$$V_k = \frac{1}{3} B_k \times h_k, \forall k = 1, \dots, n-1 \tag{12}$$

where, B_k is the surface of the base of the pyramid:

$$B_k = c_k \times a_k + \frac{a_k \times (b_k - c_k)}{2} \tag{13}$$

where, a_k is the Euclidean distance between the reference points of two consecutive criteria:

$$a_k = \sqrt{\left(x_{j+1} - x_j\right)^2 + \left(y_{j+1} - y_j\right)^2} \tag{14}$$

b_k and c_k are the magnitudes of the vectors corresponding to the weights of two consecutive criteria, that is:

$$b_k = z_j \tag{15}$$

$$c_k = z_{j+1} \tag{16}$$

h_k is the height of the pyramid from the defined base to the top of the pyramid located at the coordinate origin *(O)*:

$$h_k = \frac{2\sqrt{s_k(s_k - a_k)(s_k - d_k)(s_k - e_k)}}{a_k} \tag{17}$$

where, S_k is the semi circumference of the triangle defined by the *x* and *y* coordinates of two consecutive criteria and the coordinate origin:

$$s_k = \frac{a_k + d_k + e_k}{2} \tag{18}$$

where, d_k and e_k are the Euclidean distances of the reference points of two consecutive criteria from the coordinate origin:

$$d_k = \sqrt{x_j^2 + y_j^2} \tag{19}$$

$$e_k = \sqrt{x_{j+1}^2 + y_{j+1}^2} \tag{20}$$

Step 4.6: Rank the alternatives according to the decreasing values of the volumes of complex polyhedra V_i^C (i=1, …, m).

4. The Ranking of Transshipment Technologies

The ranking of the transshipment technologies begins with a thorough understanding of the problem at hand. Then, lists of alternatives and criteria are carefully crafted. By following the steps outlined in the hybrid model, the process leads to the ultimate results.

4.1 Problem Description

The baseline for solving the problem of choosing an appropriate transshipment technology for an intermodal terminal, concerning ITUs that it can serve and in relation to the available modes of transport, involves the identification and formation of a list of alternatives that will be considered, as well as a list of criteria based on which the alternatives are evaluated using appropriate methods. Before defining potential solutions, it is necessary to understand the problem being addressed so that the alternatives can be developed appropriately.

When it comes to the loading process, it involves unloading an ITU (e.g., various types of containers, ITUs, semi-trailers, complete road vehicles) from one transport vehicle (e.g., railway freight wagon, ship, barge, road vehicle) and loading it onto another transport vehicle (Filina-Dawidowicz & Kostrzewski, 2022). By switching from one mode to another, efficient cargo movement is facilitated throughout the entire chain, optimizing factors such as costs, speed, and availability by combining the advantages of different modes. Such a process also requires the existence of a transfer point where various handling activities related to cargo take place, which is referred to as an intermodal terminal. An intermodal terminal serves as a node in the intermodal transport network when combining two or more modes of transport, and its role lies in changing modes and means of transport (Pyza & Jachimowski, 2019). Adequate infrastructure and equipment are necessary for the realization of the transshipment process within an intermodal terminal, enabling the handling of ITUs and related transshipment technology. In this context, an alternative is considered as a combination of transshipment technology, ITUs, the dominant transport mode in the chain, and the distances covered (Table 2).

Table 2. List of alternatives

Alternative	Transshipment Technology	ITU	Dominant Transport Mode	Distance
A1	Reach Stacker	Container 20’	Rail	600 km
A2	Reach Stacker	Container 40’	Rail	600 km
A3	Reach Stacker	Container 20’	Inland waterway	600 km
A4	Reach Stacker	Container 40’	Inland waterway	600 km
A5	Gantry Crane	Container 20’	Rail	600 km
A6	Gantry Crane	Container 40’	Rail	600 km
A7	Gantry Crane	Container 20’	Inland waterway	600 km
A8	Gantry Crane	Container 40’	Inland waterway	600 km
A9	Mobile Harbour Crane	Container 20’	Rail	600 km
A10	Mobile Harbour Crane	Container 40’	Rail	600 km
A11	Mobile Harbour Crane	Container 20’	Inland waterway	600 km
A12	Mobile Harbour Crane	Container 40’	Inland waterway	600 km

After forming the list of potential solutions, the next step involves identifying criteria that serve to assist in making the final decision, i.e., selecting the best from the potentially available alternatives. Criteria can be defined as tools for assessing and comparing alternatives in terms of the consequences of their selection (Taherdoost & Madanchian, 2023). For the purpose of evaluating the defined alternatives, the criteria taken into account are presented in Table 3. With the formation of this list, the formulation of the problem of selecting transshipment technology for an intermodal terminal, to which the proposed hybrid model will be applied, is complete.

Table 3. List of criteria

Criteria	Name	Type	Description
C1	Transportation costs	min	The transportation costs of one unit of cargo include costs for two road legs, each covering 75 km by road transport, costs for the main leg of 450 km, costs for two transshipment processes, costs for the ITU, as well as costs for the intermodal organization itself. These cost elements are selected to enable comparisons between different transshipment technologies and combinations of ITUs, as well as between different modes of transport over a total distance of 600 km.
C2	Delivery time	min	The duration of transportation for one unit of cargo includes the time for two road legs, each covering 75 km by road transport, the duration of two transshipment processes, and the duration of transportation for the main leg of 450 km.
C3	Availability	max	Availability of the terminal for a specific technology and ITU.
C4	Network coverage	max	Current network coverage of the technology and ITU.
C5	Productivity	max	Productivity is a parameter that expresses the number of movements that could be done per hour.
C6	Energy consumption	min	The energy consumption in kilograms of oil equivalent per container.

4.2 Results

In this section, the results obtained by combining the baseline defined in Section 4.1 and the hybrid model defined in Section 3 are presented. As previously described, it was primarily necessary to apply the fuzzy SWARA method to obtain criterion weights. The results of the application are shown in Table 4, where the criteria are ranked according to their importance, from most important to least important.

Table 4. The obtained weights of the criteria through the application of the FSWARA method

Criteria	Linguistic Term	$\tilde{S}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$	Final Weight
W	-	-	(1, 1, 1)	(1, 1, 1)	(0.311, 0.377, 0.441)	0.376
C2	"L"	(2, 3, 4)	(1.4, 1.6, 1.8)	(0.556, 0.625, 0.714)	(0.173, 0.235, 0.315)	0.238
C3	"VL"	(1, 2, 3)	(1.2, 1.4, 1.6)	(0.347, 0.446, 0.595)	(0.108, 0.168, 0.262)	0.174
C4	"FL"	(3, 4, 5)	(1.6, 1.8, 2)	(0.174, 0.248, 0.372)	(0.054, 0.093, 0.164)	0.099
C5	"N"	(1, 1, 2)	(1.2, 1.2, 1.4)	(0.124, 0.207, 0.310)	(0.039, 0.078, 0.137)	0.081
C6	"L"	(2, 3, 4)	(1.4, 1.6, 1.8)	(0.069, 0.129, 0.221)	(0.021, 0.049, 0.098)	0.052

Once the criteria weights are calculated, it is necessary to evaluate the alternatives in relation to these criteria (Table 5). The evaluations of alternatives according to criteria C1 and C2 are based on data from fact sheets of transshipment technologies in the literature (ECMT, 2022). Evaluations according to criteria C2 and C3 were assessed qualitatively based on data from the literature (ECMT, 2022), where grade 1 represents the lowest and grade 9 the highest. Ratings according to criterion C5 are obtained by applying the following equation:

$$P = \frac{60}{t_{l/u}}\left[\frac{moves}{h}\right] \tag{21}$$

where, P is productivity [moves/h], and $t_{l/u}$ is the time for loading/unloading one container [min/cont.], which is obtained as:

$$t_{l/u} = \frac{T_{l/u}}{N}\left[\frac{min}{cont.}\right] \tag{22}$$

where, $T_{l/u}$ is the total time for loading/unloading one train/barge [min/cont.], and N is the maximum number of ITUs on full trains (740 m, 2000 t)/barges (110 m) assuming 20 t loaded weight per ITU. These data were obtained based on fact sheets of transshipment technologies from literature (ECMT, 2022).

Evaluations according to criterion C6 are obtained by applying the following equation (Stoilova & Martinov, 2019):

$$EC = PH \times FC \times 0.83 \times 1.01\left[\frac{kgoe}{cont.}\right] \tag{23}$$

where, EC is the energy consumption [kgoe/cont.], 0.83 is the weight of one liter of diesel fuel [kg/l], 1.01 is the energy content of 1 kg of diesel fuel [kgoe/kg], and PH is the average period for handling of one container in the intermodal terminal [h/cont.], obtained by applying the following equation:

$$PH = \frac{60}{t_{l/u}}\left[\frac{h}{cont.}\right] \tag{24}$$

FC is the average fuel consumption of one handling equipment per hour [l/h], obtained by applying the following equation:

$$FC = P \times DC\left[\frac{l}{h}\right] \tag{25}$$

where, DC is diesel consumption per move [l/move] also obtained based on fact sheets of transshipment technologies from literature (ECMT, 2022).

To ensure that all alternatives are evaluated on the same scale, every evaluation must be normalized. Normalized evaluations of alternatives are shown in Table 6. This table, along with Table 4, serves as input data for launching the ADAM software package.

Based on the results of the ADAM method shown in Table 7, the values and the final ranking of alternatives are presented. Some alternatives have the same value; hence, a better rank is assigned to alternatives with a lower index. According to the results, it can be concluded that the best alternative is the A5 – Gantry Crane – for transferring 20' containers – for the main leg covered by rail transport.

In Figure 2, complex polyhedra obtained through the application of the ADAM method for evaluating alternatives according to defined criteria are presented.

Table 5. Evaluations of alternatives in relation to criteria

Evaluations	C1 [€]	C2 [h]	C3	C4	C5 [moves/h]	C6 [kgoe/h]
A1	488.76	22.84	9	9	17	0.72
A2	557.07	21.96	9	9	17	0.73
A3	688.70	62.37	1	3	8	0.27
A4	705.46	56.50	1	3	8	0.27
A5	441.40	19.24	9	9	35	0.82
A6	492.10	19.10	9	9	34	0.83
A7	515.11	48.10	3	8	17	0.81
A8	534.24	45.17	3	8	17	0.81
A9	579.18	28.30	1	3	10	0.66
A10	679.80	27.76	1	3	8	0.64
A11	620.82	55.50	2	5	11	0.95
A12	638.98	51.10	2	5	11	0.95

Table 6. Normalized evaluations of alternatives in relation to criteria

Evaluations	C1 [€]	C2 [h]	C3	C4	C5 [moves/h]	C6 [kgoe/h]
A1	0.90	0.84	1.00	1.00	0.49	0.38
A2	0.79	0.87	1.00	1.00	0.49	0.37
A3	0.64	0.31	0.11	0.33	0.23	1.00
A4	0.63	0.34	0.11	0.33	0.23	1.00
A5	1.00	0.99	1.00	1.00	1.00	0.33
A6	0.90	1.00	1.00	1.00	0.97	0.33
A7	0.86	0.40	0.33	0.89	0.49	0.33
A8	0.83	0.42	0.33	0.89	0.49	0.33
A9	0.76	0.67	0.11	0.33	0.29	0.41
A10	0.65	0.69	0.11	0.33	0.23	0.42
A11	0.71	0.34	0.22	0.56	0.31	0.28
A12	0.69	0.37	0.22	0.56	0.31	0.28

Table 7. The obtained values and the ranking of alternatives using the ADAM method

Alternative	Value	Rank
A1	0.062	3
A2	0.060	4
A3	0.010	11
A4	0.010	12
A5	0.078	1
A6	0.075	2
A7	0.023	5
A8	0.023	6
A9	0.020	7
A10	0.018	8
A11	0.013	10
A12	0.014	9

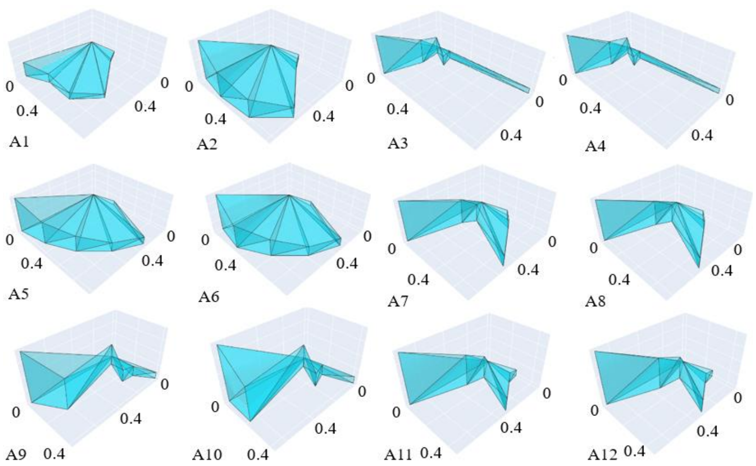

Figure 2. Complex polyhedra for the defined alternatives

5. Discussion

Due to its many benefits, including compatibility with common crane able loading units, fast transshipment rate, ease of automation and digitalization implementation, coverage of a large working area that is used very efficiently, efficient technology for consumption and transshipment speed, low life cycle costs, long service life, etc., Gantry Crane transshipment technology achieves the lowest transportation costs (especially for 20' containers) and delivery times when compared to other technologies.

Comparisons between rail and inland water ways can also be influenced by the higher load capacity of barges compared to trains. Specifically, when it comes to 20' containers, a barge offers slightly less than twice the ITU capacity compared to the train due to weight restrictions. This could be one reason why rail transport is less expensive in this instance. However, on the other hand, when looking at 40' containers, the barge has twice the ITU capacity of the train, thus reducing the cost difference for Gantry Crane for both modes of transport and 40' containers compared to 20' containers. Another effect becomes apparent when comparing the cost differences for 20' and 40' containers for the Mobile Harbour Crane technology across various modes of transport. This effect results from the technology's limited reach, which means that loading and unloading a long train requires more frequent relocation than loading and unloading a compact barge, which is much shorter in length. Because of the longer loading length, it can handle fewer 40' containers in a relocation cycle than 20' containers. Consequently, for longer ITUs, relocation affects the overall transshipment times and costs more per unit. Due to the previously mentioned effect, this technology shows lower transportation costs for transshipping 40' containers on inland waterways compared to rail transport, even though there are higher transportation costs for transshipping 20' containers in inland waterway transport (ECMT, 2022).

When delivery times and ratings are examined using this criterion, the biggest variations are found between modes of transport. It is anticipated that rail technology and ITU combinations will typically be faster than those on inland waterways due to the higher average transport speed of rail over inland waterways. The quantity of ITUs on the train or barge can also affect how long it takes to deliver something because more ITUs mean longer loading times, which in turn mean longer delivery times overall (ECMT, 2022).

For availability and network coverage criteria, Reach Stacker and Gantry Crane technologies transhipping 20' and 40' containers achieve the highest scores per rail transport. The identical technologies have a higher rating for railways than for IWW because the majority of the identified terminals have access to railways. This is a reasonable assumption since there are fewer geographical requirements for railways than there are for IWW terminals, which need access to navigable rivers. Compared to the Mobile Harbour Crane, these technologies have been around for far longer, are dominating the market, and as a result, there are many times more terminals available (ECMT, 2022).

As for the criteria for productivity, Gantry Crane technology transhipping 20' and 40' containers also achieve the highest scores per rail transport because it enables fast and efficient cargo handling. Gantry Crane technology is equipped for high-speed handling, meaning it can efficiently manipulate containers and transfer them onto or off of trains faster than other technologies. This speed allows for reduced loading and unloading times, resulting in greater operational efficiency.

Higher energy consumption can negatively impact the economic efficiency of operations and can also have a negative impact on environmental factors, such as greenhouse gas emissions and other harmful effects on the environment. It is the only criterion by which Gantry Crane technology is not rated the highest, but it is negligible given that this criterion has been assigned the least importance. This can be explained by the fact that technology that is highly productive may require higher energy consumption to maintain a high level of efficiency and speed of operation. However, this is not always the case. Gantry Crane technology often requires powerful motors, has larger dimensions and weight compared to other technologies, and has more complex systems for handling and manipulating cargo, which require a greater amount of energy.

6. Conclusions

The goal of this paper was to evaluate transshipment technologies in the intermodal terminal. The evaluation was carried out concerning ITUs in use, the type of transport connecting the terminals, and the distances covered by the dominant mode of transport. To achieve this goal, it was necessary to start by identifying ITUs widely applied in intermodal transport. The ITUs described in this work are containers, swap bodies, semi-trailers, and road vehicles.

The role of ITUs is to facilitate transshipping during a change in transport mode, reducing the time and effort needed for loading and unloading cargo at different points in the supply chain. Their main purpose is to simplify and improve the efficiency of transporting goods between different modes of transport and geographical regions. These units are standardized in terms of dimensions, strength, and handling methods, significantly simplifying the processes of loading, unloading, securing, and transporting goods, making them compatible with all modes of transport. Their construction provides a high level of security for transported goods by preventing theft, manipulation, and damage during transport while also protecting them from various factors such as weather conditions, vibrations, etc.

It is concluded that among the mentioned units, ISO containers of 20’ and 40’ have the widest application, and for this reason, they were further analyzed. In general, the use of ITUs has led to the development of complex intermodal networks or terminal networks where different modes of transport intersect to facilitate cargo overloading. In improving the overall efficiency, reliability, and flexibility of such networks, overload technology plays a key role, involving different infrastructure, equipment, and processes that enable the continuous transport chain.

In this paper, numerous transshipment technologies were identified. Reach Stacker, Gantry Crane, and Mobile Harbour Crane were included in further analysis due to their wide application in intermodal transport, characterized by specific capabilities, adaptability, and efficiency in handling containers.

After identifying ITUs and transshipment technologies, alternatives and criteria were defined as the baseline for solving the problem. Twelve potential solutions were defined, and to choose the best solution, they were analyzed concerning six criteria: transportation costs, delivery time, availability, network coverage, productivity, and energy consumption, reflecting the logistics chain’s performance. The hybrid FSWARA-ADAM model was proposed in this work for multi-criteria decision-making, and its applicability was demonstrated by solving the problem of choosing transshipment technology in an intermodal terminal. After solving the problem, it can be concluded that the proposed model represents an adequate tool for multi-criteria decision-making, providing a simple and quick solution to the defined problem. It can also be concluded that alternatives better adapted to use in intermodal terminals are those where main leg transport is covered by rail transport, as well as those using 20’ ISO containers. Among the most commonly used technologies, the alternative A5 - Gantry Crane for transshipping 20’ containers for main leg transport by rail is highlighted as the most suitable solution for the defined problem due to its most favorable ratings according to the specified criteria.

Data Availability

The experimental data used to support the findings of this study are available from the author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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