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Multicriteria Evaluation of Intermodal (Rail/Road) Freight Transport Corridors

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***Abstract* - This paper deals with the multi-criteria evaluation of the intermodal (rail/road) freight corridors as competing transport alternatives. For such a purpose, the methodology has been developed consisting of two main components; i) the analytical models for estimating the indicators and measures of the corridors' physical/spatial or infrastructural, technical/technological, operational, economic, social, and environmental performance; and ii) the MCDM (Multi-Criteria Decision Making) method using the above-mentioned indicators and measures of performance as the evaluation attributes/criteria in ranking and identifying the preferred among the several mutually competing freight transport alternative corridors.**
The proposed methodology has been applied to two Trans-European intermodal rail/road freight transport corridors. As such, it has shown to be of use, in addition to the researchers, also to the other potential DMs (Decision Maker(s)). These could be, for example, the freight shippers/receivers as the users of the already existing intermodal (rail/road) transport services, the transport and intermodal terminal operators and infrastructure providers, and the business and policy makers facing with the problems of allocating the usually limited investments in the social-economic feasible way to the corresponding infrastructure at the local, regional, national, and international scale.

***Key words:* Intermodal (rail/road) freight transport corridors, indicators and measures of performance, multi-criteria evaluation**

I. INTRODUCTION

The EC (European Commission) transport policy has provided an institutional framework for developing the transport sector including its freight transport segment expected to serve the corresponding growing freight transport demand in a sustainable way over the forthcoming decades (CEC, 2001; 2011). This has implied shifting more freight transport demand from the currently dominating road to rail and intermodal (rail/road) transport mode. Specifically, the EC (European Commission) transport policy has contained different objectives related to the freight transport sector in Europe such as: i) increasing the use of non-road transport modes such as railways, inland waterways, and maritime transport; and ii) increasing the efficiency, effectiveness, and safety of all transport modes. Some of the specific measures related to shifting the freight transport demand to rail have been as follows (CEC, 2001; 2011; EC, 2011):

- Creating the rail network dedicated exclusively to the freight transport services;
- Ensuring the technical and regulatory harmonization and interoperability between different railway systems throughout the EU (European Union) Member States, and later in the rest of Europe;
- Eliminating and mitigating the existing and prospective capacity bottlenecks in the railway network;
- Completing the priority routes aimed at handling the freight flows generated by the EU enlargement, particularly those in the frontier regions; and
- Improving accessibility to the outlying areas.

In addition to this introductory, the paper consists of four other sections. Section 2 describes the concept of intermodal freight transport corridors. Section 3 develops the methodology for the multi-criteria evaluation of these corridors as competing alternatives. Section 4 presents an application of the proposed methodology to the two intermodal rail/road corridors spreading from the north-west to the south-east of Europe. The final section summarizes some conclusions.

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II. THE CONCEPT OF INTERMODAL RAIL/ROAD FREIGHT TRANSPORT CORRIDORS

The more specific measure for achieving some of the above-mentioned objectives related to shifting more freight transport demand to rail has been developing the rail and intermodal rail/road freight transport corridors[1] including (CEC, 2001; 2011):

- The ERTMS (European Rail Traffic Management System) corridors with the core task of deploying the European Train Control System and consequently promoting and providing interoperability throughout the European rail network;
- The RNE (Rail Net Europe) corridors aiming at providing an efficient and effective allocation of the rail infrastructure capacity and timetabling; and
- The RFCs (Rail Freight Corridor(s)) aiming at providing the sufficient infrastructure capacity and services to meet the the existing and prospective freight transport demand both quantitatively and qualitatively.

The parts of the above-mentioned RFCs have overlapped with each other and usually been named according to the geographical features and the EU Member State(s) they have passed through. In addition, they have additionally been characterized by the time of implementation: for nine of them, this has expected to be the period 2013-2015 (EC, 2011). As well, the particular corridors have been named in the scope of the EU-funded FMPs (Framework Program(s)). All these corridors contained the rail infrastructure (lines of tracks connecting the freight terminals), marshalling yards, and the major rail and intermodal rail/road/sea/inland waterways terminals where both rail and intermodal rail/road freight transport services have been carried out.

III. A METHODOLOGY FOR THE MULTICRITERIA EVALUATION OF THE INTERMODAL (RAIL/ROAD) FREIGHT TRANSPORT CORRIDORS

This section describes the evaluation methodology including: A) some related research to the intermodal (rail/road) freight transport corridors, B) the research objectives and assumptions introduced in modelling the indicators and measures of performance of the intermodal (rail/road) transport corridors; and C) the basic structure of the proposed (multi-criteria) evaluation method (Janić, 2016).

A. Some Related Research

The previous research directed explicitly to evaluation of the intermodal (rail/road) freight transport corridors has been relatively scarce. Specifically, in Europe, the available research not explicitly containing the multi-criteria evaluation in the present context could be broadly divided into the qualitative and quantitative one.

The qualitative research has dealt with the corridors from the spatial policy and the governance perspective (Priemus and Zonneveld, 2003). The former has generally considered the corridors as the linear spatial structures with a bulk of all kinds of infrastructure and policies integrating the transport, infrastructure, economy, urbanization, and environmental developments (Chapman et al., 2003). The latter has focused on the mega corridors as the large infrastructure axes spreading between the major urban areas requiring an innovative governance at the local, regional, national, and international scale (de Vries and Priemus, 2003; Romein et al., 2003).

The quantitative research described below has primarily dealt with: 1) investigation of the performances of the rail and intermodal rail-based freight transport corridors in Europe; and 2) application of the different evaluation methods to deal with development of the transport infrastructure and services including partially those of the freight transport corridors.

1) Investigation of Performance of the Rail and Intermodal Rail-based Freight Transport Corridors

[1] In addition to the global TEN-T (Trans European Network-Transport) spreading throughout EC Member States, the second Pan-European Transport Conference in Crete (1994) defined ten Pan-European transport corridors as passenger and freight transport routes in Central and Eastern Europe. Some additions were made at the third conference in Helsinki (1997), which is why these corridors were referred to as "Crete corridors" or "Helsinki corridors", respectively. In particular, after the end of the civil war in the former Yugoslavia, the tenth corridor was defined.

This research could be roughly divided into that published in the scientific/academic journals and that published as a part of the EC-funded research and development projects. In the scientific/academic context, this topic has been constantly under focus (Bontekoning et al., 2004; Janic and Reggiani, 2001; Janić, 2006; Janić, 2007, 2008; Janić and Vleugel, 2012). The EC-funded research and development projects have been carried out in the scope of i) topical networks, ii) concerted actions, and iii) integrated projects. Some of these include the COST Transport Actions, Framework Programs, the Marco Polo Program, and the research on "monitoring" and "investigating" liberalization of the rail freight transport markets in particular EU countries (Ludvigsen, 2009; Ludvigsen and Osland, 2009, Warren et al., 2009: Wiegmans and Janić, 2018; http://www.cost.esf.org/;http://www.transport-research.info/web/projects/transport_themes.cfm#Label9/; http://europa.eu.int/comm/transport/marcopolo/projects/).

2) Application of the Evaluation Methods

The various single- and multiple-objective evaluation methods have been applied by both researchers and practitioners in the scope of the given DSS (Decision Support System) while selecting the preferred among several alternatives of supplying the transport infrastructure and services by different transport modes for satisfying the current and prospective demand. The practitioners have most commonly used the EAT (Economic Analysis Technique) or BAU (Business As Usual) method, which has given the outputs exclusively in the monetary terms such as: NPV (Net Present Value), BCR (Benefit-Cost Ratio), and/or IRR (Internal Rate of Return) (Giuliano, 1985; Tabucanon and Mo-Lee, 1995).
Since the complexity of the above-mentioned DM (Decision Making) processes has increased over time, the MCA (Multi Criteria Analysis) or MCDM (Multi-Criteria Decision Making) methods such as the SAW (Simple Additive Weighting), AHP (Analytical Hierarchy Process), and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method have been increasingly used particularly by the academics/researchers (Hwang and Yoon, 1981; Janić, 2014; Sauian, 2010). Specifically, applying these MCDM methods to evaluation of the transport infrastructure projects in combination with the EAT or BAU method has been of the wide academic/research interest (Brucker et al., 2011; Schutte, and Brits, 2012; Vreeker et al., 2002). In addition, some applications of the SAW, TOPSIS, and AHP methods have explicitly considered the aspects/preferences of particular actors/stakeholders involved in i) the transport corridor planning processes (Bethany et. al., 2011), ii) evaluation of the performances of transport corridors (Ding et al., 2008), iii) general logistics systems (Sawicka et al., 2010), iv) the innovative freight bundling networks in Europe (Janić et al., 1999), and v) the HS (High Speed) transport technologies (Janić et al., 2003). Consequently, in Europe, one of the above-mentioned COST Actions (COST 328) has rather strongly recommended use of the MCDM instead or at least in combination with the "pure monetary" EAT or BAU method for evaluation of the transport infrastructure and services[2].

B. Research Objectives and Assumptions

Despite the above-mentioned relatively large body of the academic/research and the consultancy/professional literature dealing with estimation of the performances of RFCs, the systematic academic research on developing the methodology for their multi-criteria evaluation by different MCDMs (Multi-Criteria Decision Making) methods has been rather scarce. Therefore, the main objectives of this paper have been to:

i) Synthesize the convenient multi-criteria evaluation methodology;
ii) Demonstrate application of the proposed methodology to the selected cases of the intermodal rail/road rail freight transport corridors as the competing alternatives[3]; and

[2] The MCA (Multi-Criteria Analysis) was proposed as a convenient method for evaluating the projects in the scope of TENs (Trans-European Transport Network(s)) (EC, 1998).
[3] In the given context, the competition can be considered from two aspects: i) the corridors can offer to their users-intermodal rail/road transport service providers-different capacities of the infrastructure-rail lines, terminals, border crossings, etc.,- and conditions of their use mainly in terms of

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iii) Indicate the potential usefulness of the propped methodology and its application for the particular actors/stakeholders involved while acting as the DMs (Decision maker(s)).

The proposed methodology has consisted of two parts: i) the analytical models of indicators and measures of the corridors' physical/spatial or infrastructural, technical/technological, operational, economic, social, and environmental performance; and ii) the MCDM (Multi-Criteria Decision Making) method(s) for evaluation and ranking the selected alternative corridors by using the above-mentioned indicators and measures of their performances as the evaluation criteria. As such it has been based on the following assumptions:

1) Characterization of a Corridor

- A corridor is considered as a linear spatial layout spreading longitudinally through different regions and countries with transport infrastructure consisting of bi-directional rail tracks/lines connecting a set of sequentially located intermodal (rail/road) freight terminals. Such infrastructure enables operations of the intermodal freight trains providing the bi-directional transport services between particular terminals;
- The freight flows are consolidated into containers of the basic size - TEU (Twenty Foot Equivalent Unit), which could be loaded and unloaded (i.e., transhipped) at the particular rail/road intermodal terminals. Their loading has taken place after being brought from the shippers to the origin (O) terminal(s) and unloading before being delivered from the destination (D) terminal(s) to the receivers. Delivery between the shippers/receivers and the corresponding O-D (Origin-Destination) intermodal terminal(s), respectively, is carried out by trucks. This implies that the TEU flows enter and/or leave the corridor from/to the gravitational areas of these terminal(s), respectively, as their access locations. The gravitational area of the particular terminals could be of the various size and spatial layout in the horizontal plane (circle, square, rectangle, trapezoid, etc.). This shape could influence the average route length of trucks between the shippers/receivers and the corresponding intermodal terminals (Larson and Odoni, 2007); and
- The O-D (Origin-Destination) terminals and the rail tracks connecting them define the route(s) along the corridor reflecting the trip length of the particular TEU flow(s) provided by the related rail services.

physical/spatial (for example, distance), economic (cost/charges), and institutional (i.e., slots for new entrants) accessibility; and ii) different transport services can be offered in different corridors to the current and prospective users-shippers and receivers of freight shipments-by the providers of door-to-door transport services operating the same or different transport modes and their systems.

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Fig. 1 shows a simplified scheme of the considered corridor.

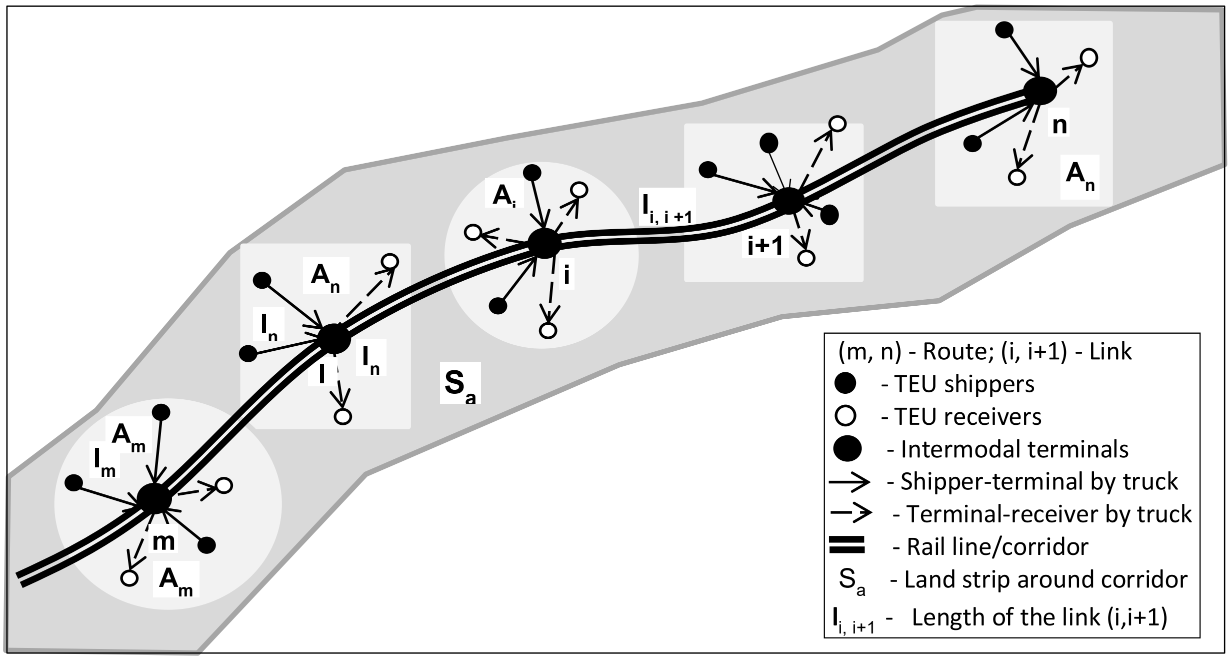

Fig. 1 Scheme of an intermodal rail/road freight transport corridor as a line transport network

2) Operations along a Corridor

- The intermodal rail/road transport services carried out along a given route of a corridor during the specified period of time have the same characteristics. This implies that the road trucks and (intermodal) trains serving the given TEU flows have the same average size/capacity and utilization (i.e., load factor), average speed, operating and external costs, energy consumption, and related emissions of GHG (Green House Gases);
- Shippers and receivers of TEU flows are uniformly distributed in the gravitational area of particular terminals, which implies the same average distances by trucks in collecting and/or delivering TEUs; and
- The quantities of TEU flows on a given route are constant during the specified period of time, which implies considering them as the parameters rather than as the stochastic variables while estimating particular indicators and measures of the corridor's performance.

3) Evaluation Methodology

- The indicators and measures of the corridor's performance are chosen to be as generous as possible and cover a range of their characteristics relevant for the above-mentioned actors/stakeholders involved including convenience to be used as the evaluation attributes/criteria in the different MCDM methods;
- Some indicators and measures of performance are specified in the form of analytical models and some others as the parameters only, which is primarily dependent on the inherent characteristics of the particular performance;
- All indicators and measures of performance are specified and quantified from the selected corridor cases for the given period of time as the constant averages rather than as the stochastic variables regarding the main influencing factors under given conditions; and
- The weights representing the relative importance of particular attributes/criteria are derived from the selected analytical method rather than being provided from the subjective judgments of the above-mentioned particular actors/stakeholders acting as DMs (Decision-Maker(s)).

D. Structure of the Evaluation Methodology

The structure of the proposed multi-criteria evaluation methodology includes definition and the basic analytical structure of the models of particular indicators and measures of the corridor's performance, and the main components of the MCDM process (Janić, 2016).

1) Indicators and Measures of Performance

1) Physical/spatial or infrastructural performance: The indicators and measures of this performance of a given corridor and its specified route are as follows:

- Corridor length is the distance between its start and end intermodal terminal measured along the shortest rail line(s) connecting them. The length reflects the spatial extensiveness of the corridor relevant for the corridor's managers/governors, as well as for the providers of infrastructure and transport services. On the one hand, they are often faced with problems of overcoming the incompatibilities and various pertaining barriers. On the other, they count on the greater number of more spatially concentrated (closer) users and consequently the greater volumes of TEU flows;
- Accessibility is the ratio between the number of intermodal terminals and the length of a corridor. It is particularly relevant for the users, i.e., shippers and receivers of TEUs, since it represents the quality of spatial access to the corridor's transport services;
- Area coverage is the sum of the gravitational areas of the individual terminals along a corridor. As a measure of the spatial availability of services within the entire area around a corridor, this is particularly relevant for the users, i.e., shippers and receivers of TEUs;
- Infrastructure density is the ratio between the length of a corridor and the size of its coverage area. It reflects the extensiveness of a corridor in light of the area it serves. As such, it is relevant for the corridor's managers/governors and the rail transport operators expecting greater demand from the users, i.e., shippers and receivers of TEUs, who can be located either over a wider or concentrated in a narrower area around the corridor;
- Route length is the shortest rail line distance between any two intermodal terminals as the O-Ds of TEUs and related intermodal train services. This reflects the spatial extensiveness of TEU flows, which can be relevant for the rail infrastructure and transport service providers: for the former due to maintaining the longer routes requiring more overall resources; and for the later due to the need for engaging a generally greater train fleet on the longer routes under the given conditions, and vice versa; and
- Maximum axle load is the allowed load per axle of a rail wagon on the particular link(s) of a corridor. It influences the types of wagons used, their utilization, and consequently the composition and utilization of the entire train(s). As such, it is mainly relevant for the rail operators responding to the requirements of their users - shippers and receivers - of TEUs.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE I.

TABLE I
INDICATORS AND MEASURES OF THE *PHYSICAL/SPATIAL OR INFRASTRUCTURAL PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE (JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Corridor length (km)	$L = \sum_{i=1}^{N-1} l_{i,i+1}$ (1a)
• Accessibility (terminals/100km)	$AS = \frac{N}{L}$ (1b)

• Area coverage (km2)	$S_a = \sum_{j=1}^{N} A_j$ (1c)
• Infrastructure density (km/km2)	$ID = \frac{L}{S_a}$ (1d)
• Route length (km)	$L_{nm} = \sum_{i=m}^{n-1} l_{i,i+1}$ (1e)
• Maximum axle load (t/axis)	AXL_{mn} (1f)

where

N	is the number of nodes/terminals in the network/along a corridor;
$N-1$	is the number of links in the network/along a corridor;
L	is the length of a corridor (km);
m, n, i, j	is the index of terminals $(m, n, i, j \in N)$;
$l_{i, i+1}$	is the length of a link connecting the terminals (i) and $(i+1)$ (km);
S_a	is the gravitational area (strip of land) spreading on both sides and along the corridor (km2);
A_j	is the size of gravitational area of the terminal (j), (km2);
l_m, l_n	is the average (road) distance for collecting and distributing TEU flows within the gravitational area of the terminal (m) and (n), respectively (km), and
t	is ton;

2) Technical/technological performance: The indicators and measures of this performance of a given corridor and its specified route are as follows:

- Propulsion system(s) is the number of variously powered engines used for running the intermodal trains along the corridor. Generally, these can be diesel and electric. This appears important if the corridor is not electrified along its entire length. This results in the need for changing the engine usually at the different country border(s), which takes time, and consequently decreases the trains' operating speed and increases the transit and delivery time of TEUs. This is relevant for the rail operators and their users, i.e., shippers and receivers of TEUs;
- Electric propulsion system(s) is an indicator represented by the number of various electric propulsion systems and their corresponding power (kV- Kilovolts) available along the corridor, which is again the country-specific. In case of a lack of the multi-system engines, the impacts for the actors/stakeholders involved can be similar as in the cases of changes between the diesel and electric engines.
- Length/weight, payload capacity, and technical speed of trains are conditioned by the signalling system and the characteristics of rail tracks, respectively, along the particular links of the corridor. The former three are relevant for the rail operators and the latter (fourth) for both rail operators and the users of their services;
- Length/weight, and payload capacity of train wagons characterize their length, gross weight, and payload capacity. These are primarily relevant for the rail operators and generally influence the train length, its gross weight, and payload capacity;
- Number of wagons per train depends on the train's length/weight and is influenced by the volumes of TEU flows, length/weight of individual wagons, and train control, i.e., signalling system along a corridor and its particular route(s). This is again mainly relevant for rail transport service providers;
- Payload capacity of a road-truck is the maximum number of TEUs per truck operating from the shippers to the intermodal terminal at one time, and from the intermodal terminal to the receivers of TEUs on the other end of the given route of a corridor. This is relevant for the road transport operators in planning the type, size, and utilization of their fleets under given conditions;

- Length of rail tracks in terminal(s) reflects the capacity of a terminal expressed by the number of simultaneously accommodated rail wagons. This number is additionally influenced by the above-mentioned wagon length. As such, this is mainly relevant for the terminal and partially for the rail operators;
- Number, service rate, and utilization of the terminal transhipment facilities and equipment reflect the transhipment capacity of terminals under the given operational regime. As such, these are mainly relevant for the terminal operators while offering their services to both (particularly new) road and rail transport operators; and
- Interoperability is the number of different propulsion and electric propulsion systems used along the corridor(s). Usually, these systems are the country-specific. As such, this indicator is mainly relevant for the rail operators while planning deployment of the multi-system engines.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE II.

TABLE II
INDICATORS AND MEASURES OF THE *TECHNICAL/TECHNOLOGICAL PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE (JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Propulsion systems (counts)	k (2a)
• Electric propulsion systems (counts and power) (-; kV)	m, VP_{mn} (2b)
• Length/weight, payload capacity, and technical speed, respectively, of a train (m/t; TEU/train; km/h)	Z_{mn}/W_{mn}, PW_{mn}, V_{mn} (2c)
• Length/weight and payload capacity, respectively of a train wagon (m/t; TEU/wagon)	z_{mn}/w_{mn}, pw_{mn} (2d)
• Number of wagons per train (counts/train)	N_{mn} (2e)
• Payload capacity of road truck (TEU/truck)	$w_{r/mn}$ (2f)
• Length of rail tracks in terminal(s) (m)	L_j (2g)
• Number, service rate, and utilization of the terminal transshipment facilities and equipment (counts, TEU/TU, %)	n_j, θ_j, δ_j (2h)
• Interoperability (counts)	$IOP = (k+m)/NBC$ (2i)

where

TU	is the time unit (hrs., day, week, month, year);
k	is the number of different propulsion systems along a corridor (i.e. diesel and/or electric);
m, VP_{mn}	is the number of different electric propulsion systems and their power along the route *(m, n)* of a corridor (counts; voltage - kV(kilovolt));
Z_{mn}, W_{mn}, PW_{mn}	is the maximum length, gross weight and payload capacity, respectively, of a train on the route *(m, n)* (m; t; t);
V_{mn}	is the maximum technical speed of a train on the route *(m, n)* (km/hrs.);
z_{mn}, w_{mn}, pw_{mn}	is the length, gross weight, and payload capacity, respectively, of a wagon of trains operating along the route *(m, n)* of a corridor (m; tons; TEU/wagon);
N_{mn}	is the number of wagons per train operating on the route *(m, n)* (counts); $(z_{mn} \cdot N_{mn} \le Z_{mn})$;
$w_r/_{mn}$	is the payload capacity of a truck operating in the gravitational area of the terminal *(m)* and *(n)* (TEU/truck);
L_j	is the average length of rail tracks at the terminal *(j)* $(j \in (m, n))$ (m) $(Z_{mn} \le L_j)$;

n_j, θ_j, δ_j is the number, service rate, and utilization of the transhipment facilities and equipment at the terminal *(j)* *(j ∈ (m, n)* (counts; TEU/TU; %) ($\delta_j \le 100\%$); and

NBC_{mn} is the number of border crossings along the route *(m, n)* of a corridor (counts).

The other symbols are analogous to those in Eq. 1.

3) Operational performance: The indicator indicators and measures of this performance of a given corridor and its specified route(s) are as follows:

- Demand density is the ratio between the volumes of TEU flows generated and attracted by the terminals along a corridor and the size of gravitational area of these terminals. This can be useful particularly for the intermodal rail transport operators including the new entrants in assessing the attractiveness of the corridor;
- Traffic and transport capacity is the maximum number of intermodal trains and the volumes of TEUs, respectively, that can be transported and that can pass a fixed point of the given route of a corridor during the specified period of time under conditions of the constant demand for service. The traffic capacity is represented by the maximum frequency of trains that can be dispatched along the route in the same direction as the reciprocal of the minimum time interval between them. This minimum time interval in turn depends on the block signalling system along the particular links of a route. The transport capacity is the product of the train's payload capacity and the traffic capacity. These capacities relevant for the rail infrastructure and transport service providers indicate the overall potential capacity to handle the current and prospective volumes of TEUs. As such they could be an indicator of attractiveness of a corridor/route for the new (rail service) entrants as well as for the prospective users to locate their businesses nearby;
- Traffic and transport concentration are the maximum number of intermodal trains and volumes of TEUs, respectively, simultaneously being on a given route of a corridor operating at the above-mentioned corresponding capacities. As such, they could be primarily relevant for the traffic managers monitoring the current traffic on the route, and the rail transport operators considering the size of train fleet to be engaged;
- Traffic and transport intensity are the maximum number of intermodal trains and volumes of TEUs, respectively, per unit of length of the given route operating at the corresponding (traffic and transport) capacities. Their relevance is similar to that of the "traffic and transport concentration";
- Transport work is defined as the maximum volumes of TEUs transported on the given route operating at the transport capacity. As the basic measure of output, this is relevant for rail infrastructure and transport service providers;
- Productive capacity is the product of transport capacity and the train's operating speed. It incorporates the transport capacity relevant for the transport service providers and the transit speed relevant for the users, i.e., shippers and receivers of TEUs;
- TEU transit speed and time are the average operating speed and the ratio between the length and the corresponding average operating speed including the anticipated delays in the train's services, respectively. They are of high relevance for both users and (rail/road) transport service providers - the former are interested in as high as possible speed and as short as possible time of delivering TEUs, while the later are mainly interested in providing them both just as expected (planned);
- TEU delivery speed and time are the corresponding averages between the doors of shippers and receivers of TEUs located in the gravitational area of the start and the end terminal(s) of the given route of a corridor. They are also preferred to be as high as possible and as short as possible, respectively, for both users and (rail/road) transport service providers under given conditions;
- *Reliability of services* is the ratio between the actually realized and planned/scheduled rail transport services during the specified period of time. This is relevant for both users, i.e., shippers and receivers of TEUs, as well as for providers of transport services along the given route of a corridor;
- Punctuality of services is the ratio between the number of delayed and on-time rail transport services realized during the specified period of time. This is also relevant for both users, i.e., shippers and receivers of TEUs, and transport service providers;

- Train fleet size is the number of train sets of the given (the same) composition operating along the route of a corridor. This is relevant for the providers of rail transport services while planning the train fleet to be engaged under given conditions; and
- Utilization of train fleet (i.e., load factor) is the ratio between the volumes of transported TEUs and the offered payload capacity of a train fleet on the given route of a corridor during the specified period of time. This is particularly relevant for the providers of rail transport services.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE III.

TABLE III
INDICATORS AND MEASURES OF THE *OPERATIONAL PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE (JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Demand density (TEU/km²)	$DD = \sum_{j=1}^{N} \frac{P_j(q_{jg} + q_{ja})}{A_j}$ (3a)
• Capacity[1)] – Traffic (trains/TU) – Transport (TEU/TU)	$TC_{mn} = \min\{f_{\max/mn}; [\min_{i\in(m,n-1)}[\mu_{i,i+1}]; \min_{j\in(m,n)}[\mu_j]]\}$ (3b) where $\mu_{i,i+1} = f_{\max/i,i+1}$ and $f_{\max/i,i+1} = 1/h_{\min/i,i+1}$ and $f_{\max/mn} = 1/h_{\min/mn}$ or $f_{\max/mn} \equiv Q_{\max/mn} / \Lambda_{mn} M_{mn} pw_{mn}$ and $\mu_j = \frac{N_j L_j n_j \theta_j \delta_j}{z\Lambda_{mn} M_{mn}^2 pw_{mn}}$ $TRC_{mn} = \min\{\eta_{\max/mn} [\min_{i\in(m,n-1)}[\eta_{i,i+1}]; \min_{j\in(m,n)}[\eta_j]]\}$ (3c) where $\eta_{i,i+1} = f_{i\,\max/,i+1} \Lambda_{mn} M_{mn} pw_{mn}$ and $\eta_{\max/mn} = TC_{mn} \Lambda_{mn} M_{mn} pw_{mn}$ and $\eta_j = \mu_j \Lambda_{mn} M_{mn} pw_{mn}$
• Concentration – Traffic (trains/route) – Transport (TEU/route)	$TI_{mn} = TC_{mn} \cdot \bar{t}_{mn}$ (3d) $TRI_{mn} = TRC_{mn} \cdot \bar{t}_{mn}$ (3e)
• Intensity – Traffic (trains/km) – Transport (TEU/km)	$TD_{mn} = \frac{TI_{mn}}{L_{mn}}$ (3f) $TRD_{mn} = \frac{TRI_{mn}}{L_{mn}}$ (3g)
• Transport work (TEU-km)	$TW_{mn} = TRC_{mn} \cdot L_{mn}$ (3h)
• Productive capacity (TEU-km/TU)	$TP_{mn} = TRC_{mn} \cdot \bar{V}_{nm}$ (3i)
• TEU transit – Speed (km/h) – Time (TU)	$\bar{V}_{mn} = \frac{\sum_{i=m}^{n-1} v_{i,i+1}(l_{i,i+1})}{(n-1-m)}$ (3j) $\bar{t}_{mn} = \sum_{i=m}^{n-1} [\frac{l_{i,i+1}}{v_{i,i+1}(l_{i,i+1})} + D_{i,i+1}]$ (3k)

• TEU delivery – Speed (km/h)	$V_{mn} = \dfrac{l_m + L_{mn} + l_n}{\left[\dfrac{l_m}{v_m} + \dfrac{1}{2}\tau_m + D_m + \sum_{i=m}^{n-1}\left(\dfrac{l_{i,i+1}}{v_{i,i+1}(l_{i,i+1})} + D_{i,i+1}\right) + \dfrac{1}{2}\tau_n + D_n + \dfrac{l_n}{v_n}\right]}$ (3l) where $\tau_m = \dfrac{Q_{max/mn}}{n_m\theta_m\delta_m}$; $\tau_n = \dfrac{Q_{max/mn}}{n_n\theta_n\delta_n}$; $l_m \approx c_m\sqrt{A_m}$; $l_n \approx c_n\sqrt{A_n}$
– Time (TU)	$t_{mn} = \left[\dfrac{l_m}{v_m} + \dfrac{1}{2}\tau_m + D_m + \sum_{i=m}^{n-1}\left(\dfrac{l_{i,i+1}}{v_{i,i+1}(l_{i,i+1})} + D_{i,i+1}\right) + \dfrac{1}{2}\tau_n + D_n + \dfrac{l_n}{v_n}\right]$ (3m)
• Reliability of services (%)	R_{mn} (3n)
• Punctuality of services (%)	P_{nm} (3o)
• Train fleet size (sets)	$N_{1/mn} = TC_{mn} \cdot \left(\overline{2(\frac{1}{2}\tau_m + \bar{t}_{mn} + \frac{1}{2}\tau_n)}\right)$ (3p)
• Utilization of train fleet (%)	$U_{1/mn} = \dfrac{Q_{max/mn}}{TRC_{nm}} \cdot 100$ (3q)

[1)]The traffic and transport capacity of the route L_{mn} and consisting links are based on the known maximum flow-minimum cut theorem (Ford and Fulkerson, 1962). Thus, the route capacity is determined as the minimum among the corresponding capacities of the nodes and links included. The maximum frequency is inversely proportional to the minimum time interval between dispatching successive trains on the link (route). The capacities of nodes/terminals depend on the number, service rate, and utilization of transshipment facilities there.

where

P_j, A_j	is the population of users (i.e., shippers and receivers of TEUs) and the size of gravitational area, respectively, of the terminal *(j)*, (counts, km^2);
q_{jg}, q_{ja}	is the volume of TEUs generated and/or attracted, respectively, by users (shippers and/or receivers) in the gravitational area of terminal *(j)* $(j \in (m, n)$;
$Q_{max/mn}$	is the maximum volume of TEUs on the route *(m, n)*;
Λ_{mn}	is the average load factor of a train operating on the route *(m, n)* $(\Lambda_{i, i+1} \le 1)$;
λ_{mn}	is the average load factor of a truck operating in the gravitational area of terminal *(m)* and *(n)* $(\lambda_{mn} \le 1)$;
$f_{i,i+1}$, f_{mn}	is the train service frequency on the link *(i,i+1)* and the route *(m, n)*, respectively (trains/TU);
$h_{i,i+1}$, h_{mn}	is the minimum time between successive departures of trains on the link *(i,i+1)* and the route *(m, n)*, respectively (TU/train);
$v_{i,i+1}$, $t_{i,i+1}$	is the average train operating speed and transit time, respectively, on the link *(i,i+1)* (km/hrs.; TU);
$D_{i, i+1}$	is the average train anticipated delay on the link *(i,i+1)* (TU);
R_{mn}, P_{mn}	is the reliability and punctuality, respectively, of the delivery services along the given route *(m, n)* of a corridor (%; %)
τ_m, τ_n	is the average train's service time at the terminals *(m)* and *(n)*, respectively (TU);
D_m, D_n	is the average train's anticipated delay while being served in the terminals *(m)* and *(n)*, respectively (TU); and
v_m, v_n	is the average speed of truck(s) in the gravitational area of terminals *(m)* and *(n)* along the distance l_m and l_n, respectively (km/hrs.).

The other symbols are analogous to those in Eq. 1 and 2.

4) Economic performance: The indicator indicators and measures of this performance of a given corridor and its specified route are as follows:

- Operational cost is the monetary expense of delivering the given volume(s) of TEUs from the shippers to the receivers at both ends of the given route of a corridor. This indicates efficiency of the transport service providers, i.e., intermodal (rail, road, terminal) operators, competing internally among themselves and externally with the other transport mode counterparts. For the users, i.e., shippers and receivers of TEUs, it is relevant due to reflecting the charges (prices) of the offered services;
- External cost is the monetary expense of damages to the society and the environment by delivering TEUs from the shippers to the receivers at both ends of the given route of a corridor. As internalized, this cost is again relevant for the overall efficiency of transport service providers after being included in the charges (prices) of their services as externalities;
- Time cost is the (monetary) value of time of TEUs during their delivery between the shippers and the receivers at both ends of the given route of a corridor. This can be particularly relevant for those shippers and receivers dealing with the time-sensitive (perishable) and/or the high value goods;
- Total cost is the sum of operational, external, and time cost of delivering TEUs along the given route of a corridor under given conditions. As such they are relevant for the managers/governors of a corridor while assessing its competitiveness;
- Investments and subsidies include the expenses for the capital overhauling, i.e., complete refurbishing of the infrastructure and supporting facilities and equipment along the given route of a corridor, acquisition of the rail and road rolling stock, and eventually subsidizing the new intermodal (rail/road) transport services at least initially until they economically stabilize in the given market. On the one hand, this is relevant for the above-mentioned recipients of funds. On the other, it is relevant for the investors and subsidizing institutions/authorities interested in the effects of their invested funds; and
- Contribution to welfare is the monetary contribution of the intermodal rail/road services carried out along the given route of a corridor to the regional and national social welfare, usually expressed as contribution to GDP (Gross Domestic Product). This can be particularly relevant for the local population around the route and a corridor.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE IV.

TABLE IV
INDICATORS AND MEASURES OF THE *ECONOMIC PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE (JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Operational cost[1)] (€/train)	$C_{o/mn} = Q_{\max/mn} \cdot (c_{2o/m} l_m + c_{o/m} + L_{mn} c_{1o/mn} + c_{o/n} + c_{2o/n} l_n)$ (4a)
• External costs[1)] (€/train)	$C_{e/mn} = Q_{\max/mn} \cdot (c_{2e/m} l_m + c_{e/m} + L_{mn} c_{1e/mn} + c_{e/n} + c_{2e/n} l_n)$ (4b)
• Time cost (€/train)	$C_{t/mn} = Q_{\max/mn} \left\{ \left[\frac{l_m}{v_m} + \frac{1}{2} \frac{Q_{\max/mn}}{\beta_m} \right] \alpha_m + \bar{t}_{mn} \alpha_{mn} + \left[\frac{1}{2} \frac{Q_{\max/mn}}{\beta_n} + \frac{l_n}{v_n} \right] \alpha_n \right\}$ (4c)
• Total costs (€/train)	$C_{mn} = C_{o/mn} + C_{e/mn} + C_{t/mn} + C_{i/mn} + C_{w/mn}$ (4d)
• Investments and subsidies (€/train)	$C_{i/mn} = L_{mn} c_{mn} + TW_{mn} c_{s/mn}$ (4e)
• Contribution to the welfare (€/train)	$C_{w/mn} = PR_{mn} \cdot TW_{mn}$ (4f)

[1)] For reasons of simplicity, the unit operational and external costs of particular phases are shown as constant, although they actually decrease more
than proportionally with increasing of both transport distance and volumes of TEUs at both road and rail transport mode, as well as at intermodal terminals. The external costs include the costs of emissions of GHG (Green House Gases), land use, noise, and traffic incidents/accidents (Janic, 2007).

where

$c_{1o/mn}$, $c_{1e/mn}$	is the average unit operational and external cost, respectively, of a train operating on the route *(m, n)* (€/TEU-km);
$c_{2o/m}$, $c_{2e/n}$	is the average unit operational and external cost, respectively, of a truck operating in the gravitational area of terminals *(m)* and *(n)*, respectively (€/TEU-km);
$c_{o/m}$, $c_{o/n}$	is the average unit operational cost of the terminals *(m)* and *(n)*, respectively (€/TEU);
PR_{nm}	is the average unit social-economic benefits from intermodal rail/road services on the route *(m, n)* (€/t-km);
$c_{e/m}$, $c_{e/n}$	is the average unit external cost of the terminals *(m)* and *(n)*, respectively (€/TEU);
α_m, α_{mn}, α_n	is the average unit cost of TEU's time while at the terminal *(m)*, route *(m, n)*, and the terminal *(n)*, respectively (€/TEU-TU);
β_m, β_n	is the average rate of collecting and distributing TEU flows to/from the terminals *(m)* and *(n)*, respectively (TEU/TU), and
c_{mn}, $c_{s/mn}$	is the average unit investment cost and subsidies, respectively, for the (intermodal) rail services, respectively, on the route *(m, n)* (€/km; €/TEU-km).

The other symbols are analogous to those in Eq. 1, 2, and 3.

5) Social performance: The indicator indicators and measures of this performance of a given corridor and its specified route are as follows:

- <u>Noise – cumulative level and spatial intensity</u> is the noise and the noise per unit length of the route, respectively, generated by the trucks and trains during delivering TEUs between their shippers and receivers at both ends of the given route of a corridor. This appears relevant for the local population, which is very likely already exposed to the noise from other sources;
- <u>Congestion</u> is the time loses of cars and other (passenger) trains interacting with the trucks around the (intermodal) terminals and with the intermodal freight trains, respectively, transporting TEUs on the given route of a corridor. This can be relevant for the above-mentioned affected parties; and
- <u>Safety</u> is the risk of traffic incidents and accidents, which could happen just due to transporting TEUs between their shippers and receivers at both ends of the given route of a corridor. This is relevant for all actors/stakeholders involved in operations on the route (and a corridor). It is also relevant for third parties - i.e. the local population, which is exposed to the risk of such incidents and accidents and their consequences – injuries, loss of life, and property damage.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE V.

TABLE V
INDICATORS AND MEASURES SYSTEM OF THE *SOCIAL PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE
(JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Noise[1)] – Cumulative level (dBA) – Spatial intensity (dBA/km)	$L_{eq/mn} = 10\log\sum_{k=1}^{TC_{mn}} 10^{\frac{L_{1/eq}(k)}{10}} + 10\log\sum_{k=1}^{N_{2/mn}} 10^{\frac{L_{2m/eq}(k)+L_{2n/eq}(k)}{10}}$ (5a) where $N_{2/mn} = \frac{Q_{\max/mn}}{\lambda_{mn} w_{mn}}$ (trucks/train)

	$\overline{L}_{eq/mn} = \frac{L_{eq/mn}}{l_m + L_{mn} + l_n}$ (5b)
• Congestion (TU)	D_{mn} (5c)
• Safety (counts/TU)	$TAC_{mn} = TW_{mn}a_{1/mn} + Q_{\max/mn}(l_m + l_n)a_{2/mn}$ (5d)

1) The noise intensity is assumed to be uniformly distributed along the door-to-door distance in line with distribution of the primary sources – vehicles (trucks and trains). The noise due to transshipment of TEUs in the terminals is not taken into account.

where

$L_{1/eq}(k)$	is the noise generated by the *(k)*-th train operating on the route *(m, n)* (dBA);
$L_{2m/eq}(k)$, $L_{2n/eq}(k)$	is the noise generated by the *(k)*-th truck operating in the gravitational area of terminal *(m)* and *(n)*, respectively (dBA);
D_{mn}	is the average delay, i.e., the time losses, as the difference between the actual and planned delivery of TEUs along the route *(m, n)* (TU); and
$a_{1/mn}$, $a_{2/mn}$	is the average rate of traffic incidents/accidents/fatalities of the freight (intermodal) trains and road trucks, respectively, operating on the route *(m, n)* and in the gravitational area of terminals *(m)* and *(n)*, respectively (counts/TEU-km).

The other symbols are analogous to those in Eq. 1, 2, 3, and 4.

6) Environmental performance: The indicators and measures of this performance of a given corridor and its specified route are as follows:

- Energy/fuel consumption and related emissions of GHG are the quantities consumed and emitted, respectively, by transporting TEUs between their shippers and receivers at both ends of the given route of a corridor. They are relevant for all actors/stakeholders directly and/or indirectly involved or affected by operations on the route. Transport service providers intend to maximize the energy/fuel and GHG emissions efficiency by deploying innovative technical/technological and operational measures in order to minimize the local and global impacts of their operations; and
- Land use is the total area of land used for the corridor's infrastructure including the intermodal terminals, road network(s) in their gravitational areas, and the rail links connecting them.

The analytical expressions of the above-mentioned indicators and measures of performance are given in TABLE VI.

TABLE VI
INDICATOR SYSTEM OF THE *ENVIRONMENTAL PERFORMANCE* OF A CORRIDOR AND ITS GIVEN ROUTE
(JANIĆ, 2016)

Indicator/measure	*Equation/Symbol*
• Energy/fuel[1)] consumption (kWh)	$EC_{mn} = TW_{mn}e_{1/mn} + Q_{\max/mn}(l_m e_{2m} + e_m + e_n + l_n e_{2n})$ (6a)
• Emissions of GHG[1)] (tons)	$EM_{mn} = TW_{mn}e_{1/mn}r_{1/mn} + Q_{\max/mn}(l_m e_{2m} r_{2m} + e_m r_m + e_n r_n + l_n e_{2n} r_{2n})$ (6b)
• Land use (km²)	$LU = \sum_{j=1}^{N} A_j + \sum_{i=1}^{N-1}[l_{i,i+1} - d_i - d_{i+1}] \cdot s_{i,i+1}$ (6c)

1) The energy/fuel consumption is directly proportional to the product of the volumes of TEUs and the unit energy/fuel consumption; the latter is assumed to be constant under given conditions. The emissions of GHG expressed in CO_{2e} (CO, CO_2, NO_X, H_2O, particles, etc.) are proportional to the total energy/fuel consumption and the corresponding emission rates of GHG.

where

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e_{2m}, e_{2n}; r_{2m}, r_{2n}	is the average rate of energy/fuel consumption and related emissions of GHG (Green House Gases), respectively, of a truck operating in the gravitational area of terminal *(m)* and *(n)*, respectively (kWh/TEU-km; $kgCO_{2e}$/kWh; alternatively the energy/fuel consumption can be expressed in litres of fuel/100km);
$e_{1/mn}$, $r_{1/mn}$	is the average rate of energy/fuel consumption and related emissions of GHG, respectively, of a train operating on the route *(m, n)* (kWh/TEU-km; $kgCO_{2e}$/kWh);
e_m, e_n; r_m, r_n	is the average rate of energy consumption and related emissions of GHG, respectively, of the terminals *(m)* and *(n)*, respectively (kWh/TEU; $kgCO_{2e}$/kWh),
d_i, d_{i+1}	is the approximate radius of the gravitational area of the terminals constraining the link *(i)* and *(i+1)*, respectively (km); and
$s_{i,i+1}$	is the width of land strip around the link *(i, i+1)* not overlapping with the gravitational area of terminals at both of its ends (km).

The other symbols are analogous to those in Eq. 1, 2, 3, 4, and 5.

2) Components of the MCDM (Multi-Criteria Decision Making) Process

The MCDM (Multi-Criteria Decision Making) process has consisted of the main components: i) choosing the methods/techniques and ii) estimating the evaluation attributes/criteria. Assuming that the alternative corridors are already known and having the above-mentioned indicators and measures of performance as their attributes/criteria ready, one of the MCDM methods - SAW (Simple Additive Weighting) method - has been chosen to evaluate them mainly thanks to some advantages such as: i) relative simplicity, ii) convenience of taking into account all types of attributes/criteria (subjective and objective), iii) easy understandable, and iv) straightforward computational process (Abdullah and Adawiyah, 2014; Olson, 2004; Zanakis et al., 1998). The basic structure of the method including the entropy method for assigning the weights of particular attributes/criteria of the considered alternatives is given in Appendix *(A1)*.

IV. AN APPLICATION OF THE PROPOSED METHODOLOGY

The proposed methodology has been applied by using the inputs from the two trans-European corridor cases, which has enabled estimation of the above-mentioned indicators and measures of their performance as the evaluation attributes/criteria, and the weights as the measures of their relative importance in the given context (Janić, 2016).

A. Inputs

1) Geography of the Corridor Cases

The proposed methodology has been applied to two Trans-European RFCs (Rail Freight Corridors) named in the EU-funded research as RETRACK (REorganization of Transport Networks by Advanced RAil Freight Concepts) and CREAM (Customer-driven Rail-Freight Services on a European Mega-Corridor Based on Advanced Business and Operating Models) (EC, 2008; 2012a).
The RETRACK corridor has connected the North Sea and the Black Sea gateways, i.e., Rotterdam (Netherlands) and Antwerp (Belgium) and Constanta (Romania). This corridor has passed through the Netherlands, Belgium, Germany, Austria, Hungary, Romania, Bulgaria and finally Turkey. Its overall length between the farthest origin(s) and destination(s) of the freight (TEU) flows has exceeded 1,500 km, of which the main route between Cologne (Germany) and Gyor (Hungary) has been 1,220 km. The RETRACK corridor has partially overlapped with the RNE Corridor C02 in its northern part: Rotterdam/Antwerp-Cologne, and RNE Corridor C09, TNT-T Priority axis 22 in its middle and south-eastern part: Budapest – Gyor - Bucureşti – Constanța/Kulata/Svilengrad/Varna/Burgas, and partially with the ERTMS E corridor Dresden - Constanța. The CREAM corridor of the total length of 3,150 km has passed through the Benelux countries (the Netherlands, Belgium), Germany, Austria, Hungary (the main route of 908km), Romania, Bulgaria, Serbia-Montenegro, and Turkey/Greece. It partially

overlapped with the RNE Corridor C11: Munich– Salzburg – Ljubljana - Zagreb - Beograd - Sofia - Istanbul (EC, 2008; http://www.rne.eu/). Fig. 2 shows the simplified layout of both corridors.

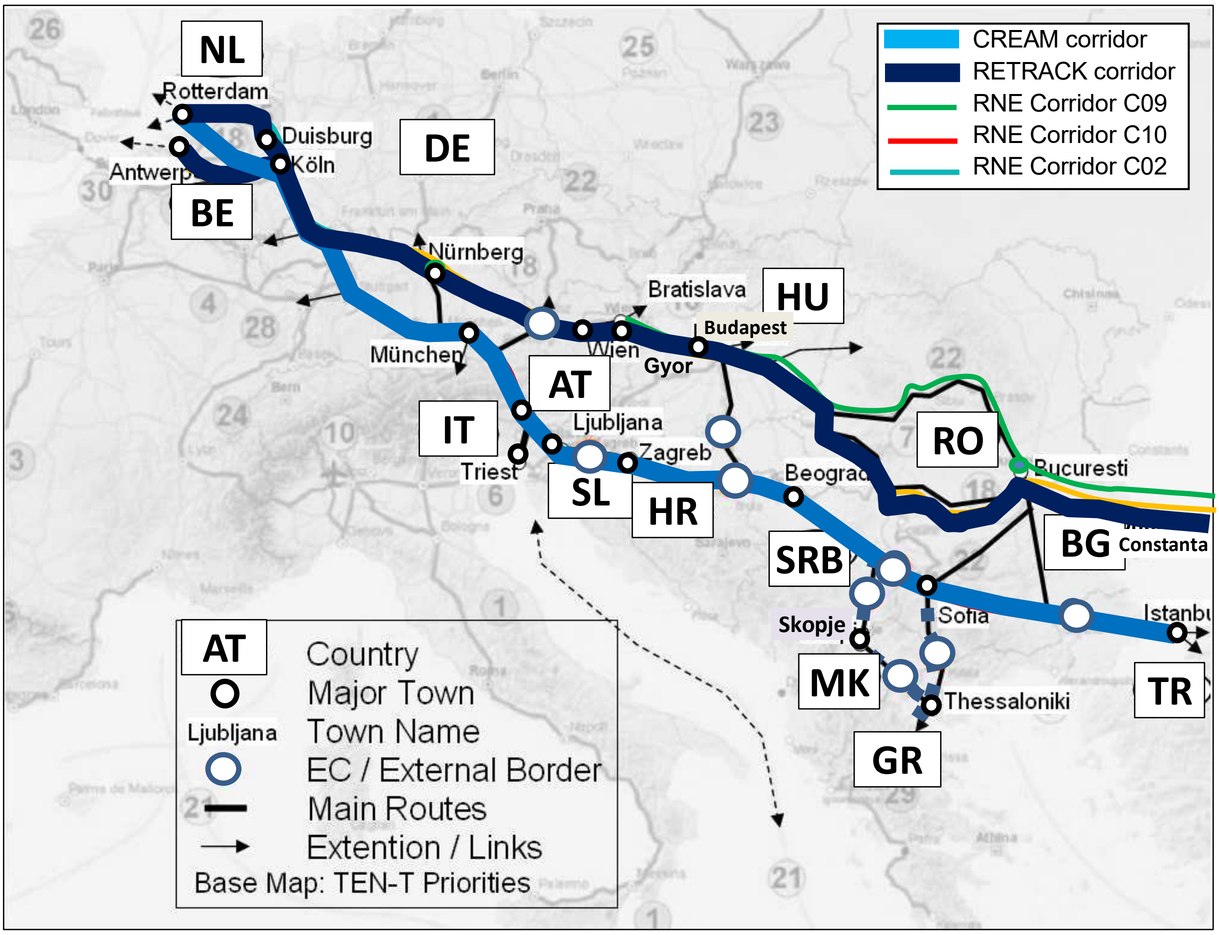

Fig. 2 Simplified layout of the RETRACK and CREAM corridor (EC, 2008)

The rail/road intermodal transport services in the RETRACK corridor have been provided mainly by the private rail operators focused on both containerized and non-containerized freight shipments. In the CREAM corridor, these have been mainly the national rail operators focusing exclusively on the containerized freight shipments. In order to make both corridors comparable for the purposes of their evaluation, the particular indicators and measures of performance have been expressed in tones (t), where necessary.

2) Indicators and Measures of Performance as the Evaluation Attributes/Criteria and Weights of Criteria

The inputs for applying the above-mentioned evaluation methodology have been derived from the demonstration phase of the above-mentioned two EU projects. This relate to the estimated values of the above-mentioned 46 indicators and measures of performance given in the self-explanatory TABLE VII.

TABLE VII
THE INDICATORS AND MEASURES OF PERFORMANCE AS THE ATTRIBUTES/CRITERIA FOR EVALUATION OF TWO ALTERNATIVE INTERMODAL (RAIL/ROAD) FREIGHT TRANSPORT CORRIDORS AND THEIR WEIGHTS, I. E. , RELATIVE IMPORTANCE (JANIĆ, 2016)

Indicator/measure- attribute/criteria	*Alternative*		*Preference*	*Weight of criterion*
	1 RETRACK	*2 CREAM*		
Physical/spatial or infrastructural				
• Corridor length (km)	1800	3150	+	0.0250
• Accessibility (terminals/100km) [1)]	0.5	0.4	+	0.0560
• Area coverage (km^2) [2)]	70650	94200	+	0.0070
• Infrastructure density (km/km^2)	0.025	0.033	+	0.0060
• Route length (km)	1220	908	+	0.0830
• Maximum axle load (t/axis)	20	20	+	-
Technical/technological				
• Propulsion systems (number)	1	2	-	0.0380
• Electric propulsion systems (counts, power) (-; kV)	3	4	-, +	0.0034
• Length/weight, payload capacity, and technical speed of a train (m/t; t/train; km/h)	450/969/100	475/1026/100	+/+/++	0.0005
• Length/weight, and payload capacity of a train wagon (m/t; t/wagon)	25/77/57	25/77/57	+/+/+	0.0005
• (Maximum) number of wagons per train (counts/train)	17	18	+	0.0005
• Payload capacity of a road truck (t/truck)	26	26	+	-
• Length of rail tracks in terminal(s) (-, m)[4)]	525	-	+	-
• Number, service rate, and utilization of terminal transshipment facilities and equipment (counts, t/h, %) [4)]	3/35/80	-	-,+,+	-
• Interoperability (-)	1.70	1.25	+	0.0035
Operational				
• Demand density (t/km^2) [3)]	2.924	18.072		0.1869
• Capacity – Traffic (trains/week) – Transport (t/week)	 4 3876	 5 5130	 + +	 0.0040 0.0060
• Concentration – Traffic (trains/route/week) – Transport (t/route/week)	 0.806 781.0	 0.711 729.6	 + +	 0.01084 0.00415
• Intensity – Traffic (trains/100km) – Transport (t/km)	 0.066 0.640	 0.00078 0.803	 + +	 0.0020 0.0005
• Transport work (million t-km/week)	4728.7	4658.0	+	0.0005
• Productive capacity (t-km/h) [5)]	23256	37962	+	0.0194
• TEU transit – Speed (km/h) – Time (h)	 36.0 33.8	 38.0 23.9	 + -	 0.0022 0.0097
• TEU delivery – Speed (km/h) – Time (h)	 24.0 50.8	 37.0 24.3	 + -	 0.0152 0.0420.
• Reliability of services (%)	83	86	+	0.00045
• Punctuality of services (%)	90	95	+	0.00046
• Train fleet size (sets)	2	2	-	-
• Utilization of train fleet capacity (%)	70	75	+	0.00046

Economic				
• Operational + time cost (thousand €/week) [6]	125.098	158.288	-	
• External costs (thousand €/week) [6]	35.678	41.143	-	
• Total cost (thousand €/week) [6]	160.176	199.924	-	0.00415
• Investments and subsidies (€/week)[4]	-	-	-	-
• Contribution to the welfare (thousand €/week) [7]	699.4	688.9	-	0.00415
Social				
• Noise – Cumulative level (dBA) – Spatial intensity (dBA/km)	 180.94 0.137	 182.14 0.185	 - -	 0.00005 0.00738
• Congestion (hr)[4]	-	-	-	-
• Safety (counts)[8), 9)]	$8.078 *10^{-9}$	$2.510 \cdot 10^{-3}$	-	0.44533
Environmental				
• Energy/fuel consumption (MWh/week)[10]	116.12	110.40	-	0.00023
• Emissions of GHG (t/week)[10]	53.455	50.828	-	0.00622
• Land use (km^2) (thousand)[11]	180	315	-	0.02516

1) Only those located nearby the main cities are considered; [2] The radius of the gravitational area of each intermodal terminal is considered to be 50km; [3] Ratio of the total quantity of freight and the gravitational area of all terminals (RERTRACK - 206590t; CREAM -1702416t); [4] Not taken into evaluation due to the lacking data; [5]Based on the freight delivery speed; [6] Based on Janić (2007); [7] Estimated from EU (2012a); [8] An estimate; [9]Based on the real events; [10] Based on Janić and Vleugel (2012); [11] Estimated as the product of length and radius of the terminals of 50km.

The sign (+) or (-) indicates preference for as high as and as low as possible values of particular indicators and measures of performances, respectively, when using them as the attributes/criteria in the MCDM process. The weights of particular attributes of the corridors' performances as criteria have been estimated by the entropy method (*Appendix A2)***)** and given in TABLE VII as well. As such, these weights reflect the relative preferences of particular criteria from the research perspective. Consequently, the results from the MCDM method can be considered as an illustration of its application to the given cases under given conditions. Such an approach also prospectively enables any other DM to put his/her own weights on the particular criteria and take a look at the outcome means by the given MCDM method (SAW).

B. Analysis of Results

The indicators and measures of performance and their weights in TABLE VII have been used as inputs for the above-mentioned SAW method. Due to their similarity (equality) and/or the lack of relevant data, some attributes/criteria (8) such as the maximum axle load, characteristics of train wagons, truck payload capacity, characteristics of intermodal terminals, train fleet size, investments and subsidies, and congestion have been dropped off from the evaluation procedure. Thus, by taking into account the remaining (36) attributes/criteria, the results have been obtained and given in Table VIII.

TABLE VIII
RESULTS FROM THE SAW METHOD IN THE GIVEN EXAMPLE (JANIĆ, 2016)

Performance	*Alternative 1: RETRACK S_1*	*Alternative 2: CREAM S_2*	*Alternative/ Rank*
• Physical/spatial or infrastructural	0.89019	0.82282	1/1
• Technical/technological	0.99849	0.54794	1/1
• Operational	0.42351	1.00000	1/2
• Economic	1.00000	0.94659	1/1
• Social	1.00000	0.01172	1/1
• Environmental	0.99905	0.57860	1/1
All	0.796	0.436	1/1

As can be seen, the RETRACK corridor has scored as the preferred alternative regarding all 36 attributes/criteria. In addition, TABLE VIII gives evaluation of both corridors regarding the particular performance. In this latter case, the RETARCK corridor has shown as the preferable alternative with respect to all except the operational performance. In particular, regarding the physical/spatial performance, the RETRACK corridor has been the better alternative mainly due to the longer main route and the higher (spatial) accessibility of the intermodal (rail/road) services. These factors have fully compensated its weaknesses reflected in the overall length, total area coverage, and infrastructure density. Regarding its technical/technological performance, the RETRACK corridor has again shown to be the better alternative. This has been mainly due to its greater interoperability, i.e., the smaller number of different (country-specific) propulsion (and electrical propulsion) systems used, and despite operating the shorter and lighter trains. In both corridors, these trains have been composed of the similar types of wagons carrying the similar types of loading units such as ISO and non-ISO containers, swap-bodies, and semi-trailers. The trains have been pulled by the multi-system electric engines, thus diminishing the impacts of differences in the electric propulsion systems along the route(s). In addition, in the CREAM corridor, diesel engines have been also deployed along the non-electrified links of the main route, thus additionally compromising the already lower interoperability of the CREAM trains. Furthermore, the trains/wagons/loads have been monitored and tracked/traced by using different systems. In the RETRACK corridor, an innovative IT system consisting of four components has been used, whereas in the CREAM corridor, an IT system - Software Train Monitor and GPS devices + wireless personal area network(s) have been used.

The CREAM corridor has appeared as the preferable alternative regarding the operational performances. This has mainly mainly been due to carrying out the transport services at much larger scale during the demonstration phase. These have been carried out by the trains with the fixed configuration compared to those of the RETRACK counterpart with a rather flexible configuration. Consequently, almost all directly related indicators and measures of these performances such as the demand concentration, capacity, concentration, intensity, transport work (frequency of the "shuttle" train services operating on the shorter route), and utilization of the train fleet (fixed train composition along the route with the sufficient demand secured at the beginning) have been higher at the CREAM than at the RETRACK corridor. In addition, the transit and delivery speed of freight shipments by the CREAM trains has been higher and consequently the corresponding times substantively shorter. These have mainly been influenced by differences in the length of route(s), the very low but similar commercial speeds, and the long through time of the RETRACK wagons and wagon groups at two hubs (about one third of the total train service time). In addition, the reliability and punctuality of the CREAM transport services have been greater despite being carried out by the longer, heavier, and less interoperable trains on the shorter route.

The RETRACK corridor has been the preferable alternative regarding the economic performance mainly due to the lower operating time, externalities, and consequently the total cost, including also its slightly higher contribution to the overall welfare. The former three cost components have been lower mainly due to carrying out the operations at a much lower scale characterized by the train lower service frequency and the payload capacity. The latest has been due to carrying out the operations on the longer route, which has compensated the lower scale of operations.

Similarly as in the case of the economic performance, the RETRACK corridor has been the preferable alternative regarding the social performance. This has mainly been due to the lower cumulative noise and its spatial density, and the higher level of safety, i.e., a lower risk of traffic incidents/accidents. In addition, the RETRACK corridor has also been preferable alternative regarding the environmental performance mainly due to its lower energy consumption, emissions of GHG, and land use. However, these three categories of performance - economic, social, and environmental – have been lower mainly due to its substantively lower absolute scale of operations compared to the CREAM corridor counterpart.

V. CONCLUSIONS

This paper has developed the methodology for the multi-criteria evaluation of the intermodal (rail/road) freight transport corridors. The methodology consisted of: i) the analytical models of the indicators and measures of the corridors' physical/spatial or infrastructural, technical/technological, operational, economic, social, and environmental performance, ii) the MCDM (Multi-Criteria Decision Making) SAW (Simple Additive Weighting) method using the above-mentioned estimated indictors and measures of performance as the evaluation attributes/criteria; and iii) the entropy method for estimating their weights, i.e., relative importance in the given context. The inputs for estimating particular indicators and measures of performance as the evaluation attributes/criteria have been taken from the demonstration phases in the two RFCs named in the EU-funded projects as the RETRACK and CREAM corridor and from the convenient (representative) secondary data sources. In both cases, the indicators and measures of performance have been expressed in the mixed relative-absolute terms, thus allowing the scale of operations to greatly impact the final evaluation score(s). In any case it would be very easy to apply the proposed methodology if all indicators and measures of performance were expressed exclusively in the relative terms.

The results have indicated the RETRACK corridor as the preferable alternative regarding all performance simultaneously. The CREAM corridor has shown to be the preferable alternative regarding only the operational performance.

The above-mentioned scores have indicated that the proposed methodology could be efficiently applied as:

i) An additional tool for the multi-criteria evaluation of the current and prospective developments in the (intermodal) transport corridors in Europe and elsewhere by the researchers, as well as the particular actors/stakeholders such as the managers/governors of corridors, the mangers/providers of transport infrastructure and services, the advisory groups, and the users of transport services, i.e., shippers and receivers of freight shipments. For example, most generally, this could involve determining independently and/or dependently the priorities of the actors/stakeholders involved in the further development and upgrading of the segments of TEN-T towards Eastern and South-East Europe including different transport modes. Apart from the intermodal rail/road, this could specifically encompass the evaluation of improvements of the existing and setting up the new segments and/or the entire corridors in the Mediterranean and West Coast of Europe including the short-sea shipping, and further improvements of the corridors passing through the high mountains (the Alps and Pyrenees);
ii) An additional tool to the other similar cases worldwide; and
iii) An additional tool for evaluation of the passenger transport corridors, particularly those with the modal competition, for example, between the HSR (High Speed Rail), air passenger transport, and road cars, but after the relevant modifications mainly of the models of particular indicators and measures of performance. This has been an increasing trend in the regions and countries developing and consolidating their HSR networks such as the EU, China, and USA.

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APPENDIX

A1) *<u>The SAW method</u>*

The SAW (<u>S</u>imple <u>A</u>dditive <u>W</u>eighting) method includes quantification of the values of attributes/criteria for each alternative, construction of the Decision-Matrix *A* containing these values, derivation of the normalized Decision-Matrix *R*, assigning the relative importance (weights) to attributes/criteria, and calculation of the overall score for each alternative. The analytical structure of the SAW method for *(N)* alternatives and *(M)* attributes/criteria is as follows (Hwang and Yoon, 1981; Zanakis et all, 1998):

$$S_i = \sum_{j=1}^{M} w_j \cdot r_{ij} \quad \text{for } i = 1,\ 2,..,N \tag{A1}$$

where

- S_i is the overall score of *i*-th alternative;
- r_{ij} is the normalized rating of *i*-th alternative on *j*-th criterion, which computed as: $r_{ij} = x_{ij} / (\max_i x_{ij})$ for the "benefit" and $r_{ij} = (1/x_{ij})/[\max_i (1/x_{ij})]$ for the "cost" criterion represents an element of the normalized matrix *R*;
- x_{ij} is an element of the Decision-Matrix *A*, which represents the "original" value of *j*-th criterion of *i*-th alternative;
- w_j is the relative importance (weight) of *j*-th criterion;
- *M* is the number of criteria; and
- *N* is the number of alternatives.

Then, the alternative with the highest score S_i is selected as the preferable (i.e., the best) one.

A2) *<u>The entropy method</u>*

The relative importance (weight) of the attributes/criteria to be used by the chosen MCDM method(s) can be determined by different methods including the entropy method. Highlighting the importance of particular attributes/criteria with the greater differences in their values it is especially useful when the DM does not have any reason to prefer one attribute/criterion to others (Hwang and Yoon, 1981). When there are *(N)* alternatives each characterized by *(M)* attributes/criteria the weight of attribute/criterion *(j)* of a given alternative can be estimated as follows:

$$w_j = (1 - E_j) / \sum_{j=1}^{N} (1 - E_j),\ j \in M$$

(A21)

The entropy of the attribute/criterion E_j can be expressed as follows:

$$E_j = -[1/\ln(M)] \cdot \sum_{i=1}^{N} p_{ij} \cdot \ln p_{ij},\ j \in M \qquad \text{(A22)}$$

The term $[1/\ln(M)]$ in Eq. A22 guarantees fulfilment of the condition: $0 \le E_j \le 1$. In addition, the probability p_{ij} that the alternative A_i is the "best" per the attribute/criteria x_{ij} can be estimated as follows:

$$p_{ij} = x_{ij} / \sum_{i=1}^{N} x_{ij},\quad i \in N;\ j \in M \qquad \text{(A23)}$$

where all symbols are as in the previous Equations.

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