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Bi-objective optimization for multi-modal transportation routing problem: the case of the Belt and Road Initiative.

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1. Introduction

Designed by China, the Belt and Road Initiative (BRI) was announced by President Xi Jinping in 2013 under the name ‘One Belt, One Road’ (OBOR) to boost Chinese economy. It was later renamed the “Belt and Road Initiative” in 2017. In 2019 - only 6 years after the launch – 131 countries and 30 international organisations had already adhered to this initiative. (Tohry, 2019; Zhu, 2019) In the BRI, the ‘Belt’ represents the inland transportation route called the ‘Silk Road Economic Belt’, while the ‘Road’ refers to maritime portion called the 21st Century Maritime Silk Road.

In 2017, about 200,000 TEUs (twenty-foot equivalent unit container) were imported from China to Europe by rail via Russia. It rose gradually from 44,200 TEUs in 2014 to 81,100 TEUs in 2015 and 153,000 TEUs in 2016. Rail transport represented 4% of overall EU-China trade in 2016 and more than two third of trains run from China to Europe. At the same time, on another scale the import from China to Europe by sea reached 10 million TEUs in 2016. (Jakóbowski et al., 2018) Around 80 per cent of global trade by volume and over 70 per cent of global trade by value are transported by vessels (UNCTAD, 2018); Rail is the second most used transportation mode, followed by road and air.

Given the scale of the project and its increasing popularity and importance, it is very interesting to analyse the BRI. The magnitude of the importance of the import from China to Europe has very recently become more concrete for a lot of economic actors with the crisis situation that brought COVID19. As the pandemic started in China, the importation process from China to Europe has been dramatically hindered and many actors found themselves unprepared to cope with this situation.

The purpose of this paper is neither to create a new model, nor to extensively study the relationships between different concepts. This paper aims to analyse the BRI in a routing planning perspective using a model suitable for real-life interpretation. This paper tries to answer the following questions:

- How does the cost-time trade-off affect the routing planning decisions regarding the BRI?
- How can the current BRI-related topics affect those decisions in a cost-time perspective?

The approach chosen in this paper to study the BRI is an intermodal routing planning problem that is addressed with a bi-objective optimization model which objectives are minimizing the total cost and the total time to move a consignment of goods from one point to another. The mathematical model in question is developed by Y. Sun and Lang (2015). A Multimodal Transportation Operator (MTO) is assumed. This paper can support routing planning decisions at a tactical level. It can help a decision-maker understanding the trade-off between cost and time minimization and how to cope with that trade-off. This paper explains how to build a set of solutions and how to evaluate and select them in terms of customers' preferences and needs regarding cost and time.

An intermodal freight transportation (IFT) problem is addressed because it falls within the scope of the new and current global society issues. In a society where the market has become worldwide, transportation planning is more and more complex. In order to optimize international freight transportation, intermodal solutions have to be used. As soon as door-to-door delivery in an international context is concerned, intermodal solutions have to be implemented in an international context because trucks are not sufficiently economically efficient. Moreover, there is an ecological incentive to study IFT because those solutions are often more sustainable. Finally, there is an economic incentive because the idea behind intermodal solutions is combining the advantages of different transportation modes.

Studying IFT means studying different transportation modes. In this paper, road, rail and maritime transports are considered as most BRI projects aim at improving railways, highways and ports infrastructure. Besides, according to Mostert et al. (2018) it is important to consider more than two transportation modes to have a more realistic model.

In order to address the intermodal routing planning issue both from a cost and time perspective, this paper examines a Multi-Objective Optimization (MOO). The MOO is solved using the concept of Pareto optimality. Methods to build a Pareto set of solutions and to select the solution fit to one's preferences are reviewed and applied to BRI case.

The BRI routes from China to the European Union are analysed via a simulation network. A new network and dataset are built for that purpose and are derived from both primary and secondary data. First, that network is studied through the construction of a Pareto set and though sensitivity analyses. Then, the observations and their implications are compared with reality.

The advantages of a simulation such as this one is that it allows to model international flows and to help understanding the impact of variations in factors such as subsidies, quality of infrastructure, customs regulations, etc. It gives realistic measures of the total cost and time of travel considering aspects such as change of gauge, transhipment, waiting time, etc. Even if those measures may be realistic, they can however be inexact. Indeed, that kind of simulation and network analysis has also limitations. It is important to remember that a simulation network is a simplified version of reality. The results greatly depend on the data quality. A number of factors are not taken into account such as schedules, passenger lines, climate, etc. The BRI projects also touch aspects that are hard to quantify such as customs efficiency.

The contribution of this paper to the literature is plural. Firstly, it gives an up-to-date literature review of the intermodal freight transportation and multi-objective optimisation research fields. Secondly, the BRI is a relatively new research field as the project was only launched in 2013 so there are few existing case studies. Moreover, our paper focuses on a new case, linked to current BRI topic such as the reduction of the train subsidies. Thirdly, the dataset used in this paper brings new data to the literature. Fourthly, the analysis of the network takes into account aspects - via the dataset - that are usually neglected such as border crossing procedures and change of gauge. Finally, the paper supports the decision making process related to routing planning problems in an international and intermodal context by analysing a concrete case study of the BRI in light of the Pareto optimality and by providing insights on the relationship between transportation modes and routes, and the travel total cost and time.

This paper is organized as follows. In section 2, the relevant literature is reviewed. In section 3, the bi-objective optimisation is modelled. In section 4, the model is applied to the case of the BRI. In section 5, conclusions are drawn.

2. Relevant Literature

In this section, the existing literature is reviewed with three focuses: intermodal freight transportation (IFT), Multi-Objective Optimization (MOO), and finally the relevance with our research.

2.1 Intermodal freight transportation

2.1.1 Definitions and concepts

First and foremost, multimodal or intermodal freight transportation (IFT) is defined as the movement of a consignment of goods from its origin to destination, applying at least two transportation modes such as air, ocean, rail, and road, without change of container for the goods (Cho et al., 2012; Daham et al., 2017; Macharis & Bontekoning, 2004; Y. Sun & Lang, 2015; UN/ECE, 2001). Some authors, however, draw the distinction between multimodal and intermodal transportation. Rodrigue et al. (2017) makes a slight difference between intermodal and multimodal where multimodal transportation requires a higher level of integration between the actors involved.

Another concept worth introducing is the Multimodal Transportation Operator (MTO). In general, in papers written on this topic, the problem of multiple stakeholders is simplified by assuming that there is a single organizer – usually the MTO – who is in charge of controlling and managing the whole operation – that implies several transportation modes - by selecting and coordinating carriers. (Tokcaer & Özpeynirci, 2018)

If IFT research was an emerging field in the beginning of the century (Macharis & Bontekoning, 2004), it is now paid great attention in the research field (Mathisen & Sandberg Hanssen, 2014; Y. Sun & Lang, 2015; Tokcaer & Özpeynirci, 2018).

2.1.2 Support to decisions

The purpose of an important part of the research on IFT is to provide a relevant support to decision-makers, in opposition to papers such as Herrera Rodriguez et al. (2018) which aims at highlighting the conflict between the carrier and the final customer interests and not at supporting the decision-making process.

Decisions related to IFT involve all decision levels. In particular, Caris et al. (2008) conducts a review on planning decisions in IFT in the scientific literature. It classifies planning problems according to the decision level - strategic, tactic and operational – and the type of decision makers: drayage, terminal, network and intermodal operators. Strategic planning problems involve long-term investments in infrastructure and major revisions in the route network, while tactical problems encompass medium-term decisions related to using the existing infrastructure and allocation of existing resources, such as route choice and type of service to operate. As regards operational planning problems, they include short-term decisions such as scheduling-related problems and local management in a dynamic environment. (Crainic

& Laporte, 1997) The papers dealing with routing planning problems (defined in section 2.1.5) – like this one - are usually considered as operating at a tactical level (Herrera Rodriguez et al., 2018; Prakash et al., 2016; Y. Sun & Lang, 2015). However, some authors mitigate that assumption. Cho et al. (2012) which also builds a model to solve a routing planning problem, considers the generation phase of the Pareto set as a tactical phase and the selection phase as an operational phase. Tokcaer and Özpeynirci (2018), considering transportation planning as well, categorizes its paper at a strategic level as intermodal contracts are usually annual agreements.

One decision that has to be made in IFT is the choice of transportation modes. Cullinane and Toy (2000) has studied factors influencing the shippers' choice of intermodal transport modes and highlighted five most frequent factor categories: cost/price rate, speed, transit time, reliability, and characteristics of the product. Danielis et al. (2005) has revealed a strong preference for quality attributes (time, reliability, and safety) over cost. In the empirical analysis of Shinghal and Fowkes (2002), frequency of service, reliability, and service time appear to be the main factors influencing the choice of rail transport as an intermodal transportation mode. It can be concluded that cost cannot be considered as the only factor influencing the transportation modes selection. Therefore, intermodal problems are frequently considered as Multi-Criteria Decision-Making (MCDM) problems. MCDM approaches are then frequently applied in the literature such as mathematical modelling, decomposition, goal programming, Analytical Hierarchy Process, artificial neural network and fuzzy analytic network process (Tokcaer & Özpeynirci, 2018). That is why Multi-Objectives Optimization (MOO) methods are considered in a following section (2.2).

2.1.3 Relevance of studying IFT

IFT is a popular current research field because it falls within the scope of the new and current global society issues.

First, Daham et al. (2017) reports that truck transportation - as most used last-mile delivery means - is more and more complex and difficult to manage. Trucks are not as economically efficient as other transportation modes. Macharis and Bontekoning (2004) argues that 25-40% of the total transport costs result from truck transportation, while Notteboom and Rodrigue (2005) increase that percentage to 40-80%. This significant cost implies that optimizing inland routes is an important question to address to avoid an inefficient use of road transport that would unnecessarily increase costs, traffic and emissions. The IFT could be a solution to optimize inland routes.

Then, intermodal solutions are more sustainable (Tokcaer & Özpeynirci, 2018) and are less energy intensive than freight transport by road (Woodburn et al., 2007). Those solutions are promoted by the European Union (EU) as potential assets to reduce the environment impact of the European transport sector and improve its sustainability (European Commission, 2011).

Finally, intermodal solutions are said to improve economic performance when the convenient transportation mode is chosen for each transport arc (Flodén, 2007; Rodrigue et al., 2017). The purpose of using intermodal transportation is combining the strengths of different transportation modes in an integrated transport chain (Flodén, 2007). For instance, maritime transportation is used when cargoes volumes are large, the delivery date is adaptable, and low costs are needed, while air transport is used when the product needs fast delivery, regardless of the costs (Cho et al., 2012). Moreover, because they move large quantities, intermodal solutions can benefit from economies of scale that can be achieved at different levels of the transport chain (Mostert et al., 2018).

However, even though IFT has become more and more popular in recent years (Y. Sun & Lang, 2015; Tokcaer & Özpeynirci, 2018), Janic (2007) argues that its market share has not increased as positively as expected given the advantageous economic and ecologic performance stated previously. Unlike Janic, Y. Sun and Lang (2015) argues that its market share increases steadily. What could hinder its popularity is the operational complexity resulting from the modal change, which can act as a barrier to change for the decision-maker. Moreover, Vilko and Hallikas (2012) points out that a larger number of handling operations means a bigger risk of delays or damages.

2.1.4 Transportation modes

Studying IFT means studying different transportation modes. Cho et al. (2012) has analysed which transportation modes were considered in the literature related to IFT and has concluded that most of the literature focused on inland transportation modes. All papers cited in Cho et al. (2012) consider trucks as a transportation mode. Two-thirds of the papers cited in Cho et al. (2012) consider trains as a transportation mode, two-thirds as well consider ships and half of them consider airlines.

Therefore, Cho et al. (2012) considers international intermodal transportation modes first, especially the ship, the train, and the airline. As inland transportation schedule is more flexible, it makes sense to consider first international intermodal transportation that is harder to adapt (Cho et al., 2012). Others such as Herrera Rodriguez et al. (2018) considers liner ships and trains as an extension of the former, Mostert et al. (2018) trucks, trains and inland waterways, and Y. Sun and Lang (2015) trucks, trains and ships. According to Mostert et al. (2018) it is important to consider more than two transportation modes to have a more realistic model. Mathisen and Sandberg Hanssen (2014) highlights that waterway transport is the most frequently studied transportation mode in intermodal freight related literature, followed closely by highway, railway, and finally airway which is far less frequent.

2.1.5 Routing planning

One way to address an IFT problem is via a routing planning problem, which is then called the International Intermodal Freight Routing Problem (IIFRP). Routing planning is part of the network design problems which can be defined as "a set of combinatorially complex network analysis problems where routes across (or flows through) the network must be determined" (Curtin, 2009). Mostert et al. (2018) points out different methodologies to address network design problems: agent-based models, GIS-based models and mathematical programming models. Only the latter is covered in this paper.

Y. Sun and Lang (2015) divides the literature addressing the IIFRP in two categories: the empirical analyses using empirical data to calculate the studied criteria for each route without building a model, and the optimization models building a framework to solve the problem. This paper focuses on the second category of literature.

Cho et al. (2012) highlights that there are three important complications in an IIFRP: the multiple objectives, two or more transportation modes, and additional constraints related to capacity, cost, time, etc. Addressing a multi-modal problem is more complex also because it is hard to access a broad consistent knowledge of the ports, stations, fares, time, etc. -and then collect data - for different transportation modes.

2.2 Multi-Objective Optimization

2.2.1 Definitions and concepts

As stated in a previous section concerning the factors influencing the transportation modes selection, intermodal transportation planning problem is considered as a Multi-criteria decision-making (MCDM) problem, especially as a multi-objective problem.

Among MCDM, Drobne and Lisec (2009) explains the distinction between multi-objective decision making (MODM) - or Multi-Objective Optimization (MOO) - and multi-attribute decision making (MADM). It depends on the classification of evaluation criteria into attributes or objectives. “An attribute is a concrete descriptive value, a measurable characteristic of an entity, including inter-entity relationships” while “An objective is a more abstract variable with a specification of a relative desirability of the levels of that variable”. (Drobne & Lisec, 2009) As an objective is usually derived from an attribute that aims to be optimized, MODM derives from MADM. That is why intermodal transportation planning problems are called multi-objective problems in this paper.

2.2.2 Multiple objectives

Who says multi-objective problem, says multiple aspects to evaluate. Cheaitou and Cariou (2019) conducts a literature survey dealing with the MOO problems related to transportation. They divide the literature into two categories: the authors who have used a bi-objective optimization model and the ones who have used a single-objective model to solve a multi-objective problem. In the first one, Zhen and Chang (2012) minimizes costs and maximizes schedule robustness in berth allocation; Demir et al. (2014) minimizes driving time and fuel consumption to determine the optimal number of vehicles and their speed to serve a set of customers; Siddiqui and Verma (2015) minimizes operating costs and transport risk in a scheduling problem for oil tankers; X. Sun et al. (2020) minimizes cost and risk to solve a problem of portfolio management; and Guo et al. (2018) minimizes cost and emissions in a scheduling problem. That category can also include Y. Sun and Lang (2015), Prakash et al. (2016) and Cho et al. (2012) that minimize cost and time in a routing planning problem, Mostert et al. (2018) that minimizes cost and CO2 emissions in a location-allocation optimization model, and Tokcaer and Özpeynirci (2018) that minimizes the total cost and the number of handling operations in a transportation planning problem. In the second category, Boros et al.

(2008) solves the conflict between the interest of two parties by maximising the joint profit, and Herrera Rodriguez et al. (2018) solves a cost-time trade-off by estimating the cost of time and minimizing the total cost.

Minimizing the total cost and total time are some of the most frequently chosen objectives. The choice of minimizing total time can be explained by the following reasons.

First, time is an important criterion for strategic decision in supply chain management, e.g. choosing modes and routes in a transport chain. Supply chain is by definition related to the geographical dispersion of various locations and the distances between them (Stock et al., 2000). One of the main concerns of the supply chain decision-makers is the time of transport along the chain and its cost, i.e. the time needed to cover those distances. Moreover, time is an important factor in logistics of the globalized production because any delay can affect bottlenecks and hinder the arrival of the products on their markets. (Herrera Rodriguez et al., 2018)

Then, time can be considered to improve transport efficiency. Panayides (2006) leads to the conclusion that the demand for a transportation mode does not only depend on the necessity to get the product but also on how the product is delivered. Therefore, time acts as a trade barrier affecting dimensions, such as JIT (Just In Time), lead and time variability, which influence inventories, economic competitiveness and user experience. (Herrera Rodriguez et al., 2018; Y. Sun & Lang, 2015)

Finally, it is interesting to study the cost -time trade-off, especially in an intermodal context. For instance, maritime transport is cheaper than railway transport but slower. Herrera Rodriguez et al. (2018) highlights the conflict between minimizing the total time of transport and the total operations costs. “The lower the time involved in shipping the reference number of TEUs [twenty-foot equivalent units], the higher the operating costs are. On the other hand, the only way to reduce total operating costs consists in accepting that the containers stay longer on the way.”

2.2.3 Solving MOO

The methods to solve MOO generally convert the problem into single-objective optimization problems. The MOO is usually solved by determining a set of Pareto optimal solutions, which is further defined in the following. (Prakash et al., 2016; Y. Sun & Lang, 2015)

The Pareto optimal solutions set can also be called a set of dominant alternatives. A solution is dominant if at least one objective is better than all the other solutions and if all other objectives in that solution are at least equal to the objectives of the other solutions. (Helff et al., 2016; Prakash et al., 2016)

To choose a solution from a Pareto set, there are different methods - also called scoring functions or MCDM methods - that help setting importance to the different objectives to compare the solutions. The alternatives of a Pareto set will always be optimal for at least one scoring function. (Lindley, 1982) Those methods can also be used to find a Pareto set by altering their parameters. Cheaitou and Cariou (2019) advises using more than one method because using only one does not ensure finding all the Pareto optimal solutions. Several methods are proposed and used in the literature (Cheaitou & Cariou, 2019; Cho et al., 2012; Helff et al., 2016; Prakash et al., 2016; Y. Sun & Lang, 2015; Tokcaer & Özpeynirci, 2018).

The Weighted Sum Method (WSM) combines the different objectives linearly to create a single score for each combination. This method is most commonly used in MOO problems. (Helff et al., 2016).

The lexicographic goal programming method is probably the simplest and most used scoring function to solve MOO problems (Ben-Tal, 1980). Via this method, the objectives are ordered in a list, tuple, or vector for instance, and prioritized. The solution with the highest or lowest value for the prioritized objective is selected. If there are more than one solution, the algorithm is repeated on the second objective in the priority list, and so on. Using this method, Prakash and Aggarwal (1992) have solved a cost-time trade-off routing network problem at a tactical level by minimizing the total cost as a primary objective and minimizing the total time of transport as a secondary objective (as cited in Prakash et al., 2016). In a subsequent work, Prakash et al. (2016) have attempted to solve the same type of problem by using the concept of lexicographic minimization of ordered pairs for finding the set of Pareto optimal solutions without objectives being prioritized.

The Normalized Weighted Sum Algorithm (NWSA) is based on the WSM. A problem of the WSM is that apples and oranges cannot be summed. The NWSA solves that problem by normalizing the different objectives with for instance a user-defined value (Helff et al., 2016; Kim & Weck, 2006). The Weighted Linear Combination (WLC), or Simple Additive Weighting, follows the same logic and standardizes the values (Drobne & Lisec, 2009). As a reminder, standardizing means obtaining a mean of zero and standard deviation of 1, and normalizing means scaling the values between 0 and 1. Talking about normalization, the Weighted Comprehensive Criterion Method (WCCM) is also a normalization technique where each sub-problem is normalized using the optimal value of an objective and then summed into the objective function (Cheaitou & Cariou, 2019). It is used in Cheaitou and Cariou (2019) to study the economic and environmental trade-off in maritime transportation. Cho et al. (2012) also uses normalization techniques. In their bi-objective optimization model, they draw at first a graph where each axis is related to an objective and set an ideal solution point on that graph consisting of the minimal (as they minimize the objectives) value for each objective (see Figure 1). Once normalized, Cho et al. (2012) selects a solution from their Pareto set by calculating the closest solution to that ideal point, also called Utopia point (Kim & Weck, 2006), in terms of distance on the graph. As an alternative selection, it uses a weighted sum method on those normalized values. Another way to select a solution from the Pareto set is by calculating the furthest solution from the pseudo Nadir point, which is - in a bi-objective optimization model - the worst value of an objective given the optimal value of the other one (see Figure 1) (Kim & Weck, 2006).

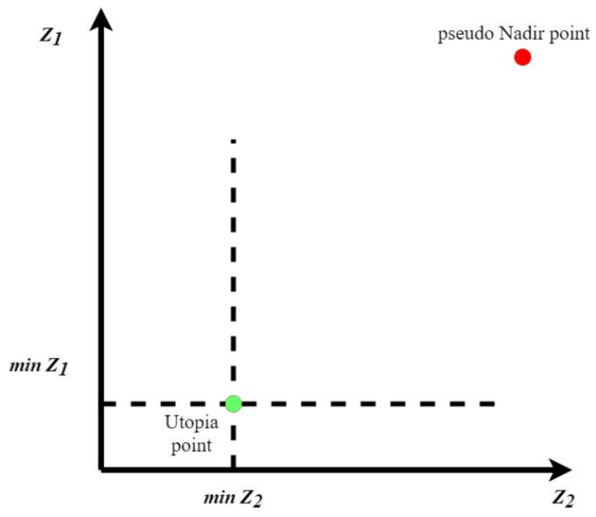


Figure 1: Utopia and pseudo Nadir points

In the ε-constraint method (ECM), one objective is chosen to be optimized and the other objectives are considered as constraints with an upper bound (Cheaitou & Cariou, 2019). This method is used in Cheaitou and Cariou (2019) along with the WCCM, and in Tokcaer and Özpeynirci (2018) to understand the trade-off between cost and operational difficulties involved in changing the mode of transport.

Y. Sun and Lang (2015) claims to solve a MOO problem with the Pareto frontier using the Normalized Normal Constraint method (see Figure 2) so that the decision-maker can choose a suitable convenient solution on the Pareto frontier with regard to their objectives and likings. The Pareto frontier contains an arbitrary prescribed number of solution points, the same number of points as the Utopia Line. For instance, the corresponding Utopia Line Point *a* in the Pareto Point *b* (see Figure 1).

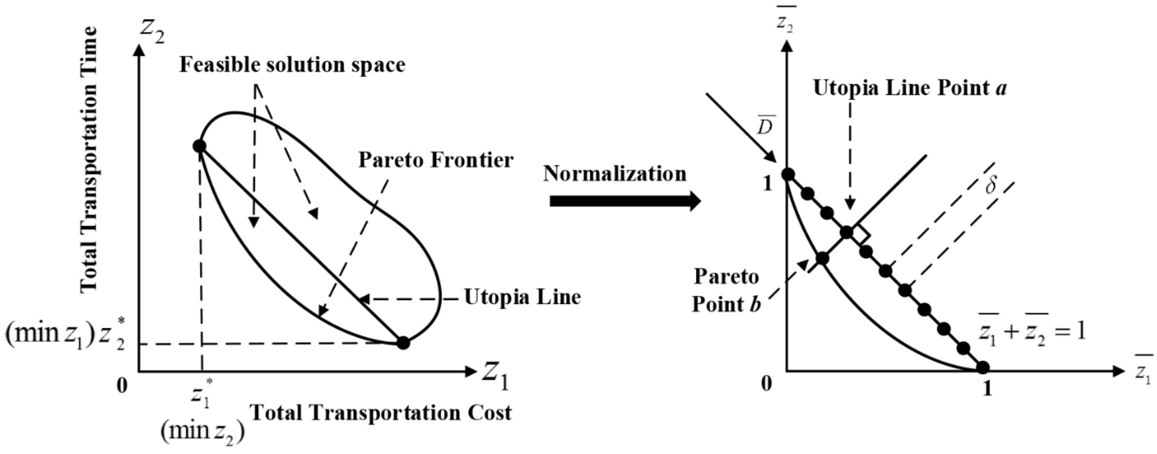


Figure 2: Normalized Normal Constraint method where the two objectives are denoted z_1 and z_2. (Y. Sun & Lang, 2015)

In this paper, the focus is on solving a time-constraint multi-modal transportation routing planning.

Y. Sun and Lang (2015) conducts a literature review on the way authors have addressed the time-constraint multi-modal transportation routing planning problem. Some of them have added the maximum transit period of the consignment of goods to the constraints. Based on that, some studies minimize an optimization objective consisting of the WLC of total transportation cost and total transportation time, considering cost and time as attributes or criteria as the method is part of the MADM, while others solve a single-objective optimization model with time windows. The problem of the first method is that the optimal result depends on the weight put on each objective, which can be biased by the subjective experience of the researcher, while the second method does not take time enough into account. (Y. Sun & Lang, 2015)

Other authors have solved the MOO problem via the WSM that combines the different objectives linearly, the lexicographic goal programming method that grants the objectives different priorities or without the objectives being prioritized (Prakash et al., 2016), or via an evenly distributed optimal solution set called “Pareto frontier” (Y. Sun & Lang, 2015).

2.3 Related work

Our research paper is primarily based on the papers of Y. Sun and Lang (2015), Cho et al. (2012), Tokcaer and Özpeynirci (2018) and Herrera Rodriguez et al. (2018). Like Y. Sun and Lang (2015), Cho et al. (2012) and Tokcaer and Özpeynirci (2018), we focus on bi-objective intermodal routing planning problem and Pareto optimality, while Herrera Rodriguez et al. (2018) presents a bi-criterion intermodal routing planning problem. Moreover, just like Y. Sun and Lang (2015) and Cho et al. (2012), we consider minimizing the total cost and the total time of travel, whereas Herrera Rodriguez et al. (2018) considers minimizing the sum of the total cost of travel and the opportunity cost of transit time, and Tokcaer and Özpeynirci (2018) considers the total cost and the number of handling operations as an indicator for operational difficulty. Like Y. Sun and Lang (2015) and Tokcaer and Özpeynirci (2018), we also deal with road, railway and maritime transportation, while Herrera Rodriguez et al. (2018) takes only into account railway and maritime transportation, and Cho et al. (2012) considers air instead of road transportation.

Y. Sun and Lang (2015) concludes that their proposed model and Pareto optimality have good performance in dealing with the bi-objective optimization and promotes their method for further practice. The advantage of using their model is that it is easy to understand and interpret. On the other hand, it has limitations. The optimization object of the model consists simply of a single consignment of goods but there may be multiple consignments that need to be delivered in different locations from different origins at different periods. (Y. Sun & Lang, 2015) Nevertheless, those limitations are neglectable for the purpose of this paper contrary to others, such as the estimation of several parameters differing from one arc to another solely from the distance as Y. Sun and Lang (2015) assumes that the speed of the transportation modes is constant.

In conclusion, the relevant literature has laid a solid foundation for our research. While section 2 depicts an overview of the existing literature, including the model that is used for the following case study, the following section describes and defines the model borrowed from Y. Sun and Lang (2015).

3. Modelling of the Bi-objective Optimization

3.1 Problem Description

The multi-modal transportation routing planning aims at determining the optimal route through a multi-modal transportation network to move a consignment of goods from its known origin to its determined destination, taking into account the volume of the consignment and the required transit period, while optimizing the following two objectives:

1. Minimizing the total cost of moving a consignment of goods from its origin to its destination.
2. Minimizing the total time needed to move a consignment of goods from its origin to its destination.

The routing planning problem has also to follow the five following rules:

- To travel between two nodes, the consignment can only travel on one arc with one transportation mode.
- There can be only one transhipment per node if needed.
- The consignment of goods cannot stop more than once at the same node.
- The total time needed for the journey cannot exceed the required transit period.
- The number of TEUs needed to move the consignment of goods must be lower than the transportation capacity of the selected nodes and arcs.

3.2 Notation

In this study, the notation of Y. Sun and Lang (2015) is used. $G = (N, A, M)$ denotes a multi-modal transportation network, where N, A, and M represent the transportation node set, the transportation arc set and the transportation mode set, respectively. Let o, d and Tr denote the origin node, destination node and candidate transhipping node set of the consignment of goods, then there is $N = Tr \cup \{o, d\}$. The parameters and decision variables in the model are defined as follows.

n: Number of containers (measured by TEU) carrying the consignment of goods.

h, i and j: Indexes of the nodes in the multi-modal transportation network.

k, l and m: Indexes of the transportation modes in the multi-modal transportation network.

I: Conjoint node set of node i and $I \subseteq N$.

M_I: Set of the transportation modes linking node i and its conjoint nodes and $M_I \subseteq N$.

M_{ij}: Transportation mode set of arc (i, j), $M_{ij} \subseteq M_I$, $i \in N$, $j \in N$ and $(i, j) \in A$.

C_{ij}^m: Transportation cost of transportation mode m on arc (i, j) and $m \in M_{ij}$.

d_{ij}^m: Transportation distance of transportation mode m on arc (i, j).

v_{ij}^m: Transportation speed of transportation mode m on arc (i, j).

n_{ij}^m: Transportation capacity of arc (i, j) by transportation mode m.

C_i^{kl}: Transhipping cost at node i from transportation mode k to transportation mode l, $i \in Tr$, $k \in M_I$, $l \in M_I$.

T_i^{kl}: Transhipping time at node i from transportation mode k to transportation mode l.

n_i^{tk}: Transhipping capacity node i from transportation mode k to transportation mode l.

T: Transit period of goods.

x_{ij}^m: 0-1 decision variable. If the consignment of goods is transported across arc (i,j) by transportation mode m, $x_{ij}^m = 1$; otherwise, $x_{ij}^m = 0$.

y_i^{kl}: 0-1 decision variable. If the consignment of goods is transhipped from transportation mode k to transportation mode l at node i, $y_i^{kl} = 1$; otherwise, $y_i^{kl} = 0$.

3.3 Bi-objective Optimization Model

OBJ 1:

$$\min z_1 = \min \sum_{(i,j)\in A} \sum_{m \in M_{ij}} C_{ij}^m \cdot x_{ij}^m + \sum_{i\in Tr} \sum_{k\in M_I} \sum_{l \in M_I} C_i^{kl} \cdot y_i^{kl} \qquad (1)$$

OBJ 2:

$$\min z_2 = \min \sum_{(i,j)\in A} \sum_{m \in M_{ij}} \frac{d_{ij}^m}{v_{ij}^m} \cdot x_{ij}^m + \sum_{i\in Tr} \sum_{k\in M_I} \sum_{l \in M_I} T_i^{kl} \cdot y_i^{kl} \qquad (2)$$

Subject to:

$$\sum_{h\in I} \sum_{l\in M_{ij}} x_{hi}^l - \sum_{j\in I} \sum_{m\in M_{ij}} x_{ij}^m = \begin{cases} 1 \; i = d \\ 0 \; \forall i \in Tr \; \forall i \in N \\ -1 \; i = o \end{cases} \qquad (3)$$

$$\sum_{m\in M_{ij}} x_{ij}^m \le 1 \; \forall (i,j) \in A \qquad (4)$$

$$\sum_{k\in M_I}\sum_{l\in M_I} y_i^{kl} \le 1 \ \ \forall i \in Tr \tag{5}$$

$$\sum_{k\in M_I} y_i^{kl} = \sum_{j\in I} x_{ij}^{l} \ \ \forall i \in Tr \ \forall l \in M_I \tag{6}$$

$$\sum_{h\in I} x_{hi}^{k} = \sum_{l\in M_I} y_i^{kl} \ \ \forall i \in Tr \ \forall k \in M_I \tag{7}$$

$$\sum_{(i,j)\in A}\sum_{m\,\in M_{ij}} \frac{d_{ij}^{m}}{v_{ij}^{m}} \cdot x_{ij}^{m} + \sum_{i\in Tr}\sum_{k\in M_I}\sum_{l\,\in M_I} T_i^{kl} \cdot y_i^{kl} \le T \tag{8}$$

$$x_{ij}^{m} \cdot n \le n_{ij}^{m} \ \forall (i,j) \in A \ \forall m \in M_{ij} \tag{9}$$

$$y_i^{kl} \cdot n \le n_i^{kl} \ \forall i \in Tr \ \forall k \in M_I \ \forall l \in M_I \tag{10}$$

$$x_{ij}^{m} = \begin{cases} 0 \\ 1 \end{cases} \forall (i,j) \in A \ \forall m \in M_{ij} \tag{11}$$

$$y_i^{kl} = \begin{cases} 0 \\ 1 \end{cases} \forall i \in Tr \ \ \forall k \in M_I \ \forall l \in M_I \tag{12}$$

$$y_i^{kl} = 0 \ \ \forall i \in \{o, d\} \ \forall k \in M_I \ \forall l \in M_I \tag{13}$$

“In Equation (1), the first part is the transportation cost on route, and the second part is the transhipping cost at the nodes. Their summation is the total transportation cost of the consignment of goods. In Equation (2), the first part is the transportation time on route, and the second part is the transhipping time at the nodes. Their summation is the total transportation time of the consignment of goods.

Constraint (3) is the flow equilibrium constraint for each node. Constraint (4) ensures the consignment of goods will not be transported by splitting into several sub consignments. Constraint (5) ensures the transhipping times at a node will not exceed once. Constraint (5) means the times that the consignment of goods is transported across a node should not exceed once. Constraints (6, 7) indicate the relationship between the two decision variables: if there is a transhipping at a node, two arcs linking it and its conjoint nodes must be covered in the transportation route; otherwise, these two arcs should not be covered. Constraint (8) means the total transportation time should not exceed the transit period of goods. Constraints (9, 10) ensure the volume of the consignment of goods will not exceed the transportation capacity of the selected arcs and the transhipping capacity of the selected nodes, respectively. Constraints (11, 12) represent the variable domain constraints. Constraint (13) means there is no transhipping at the origin node and destination node." (Y. Sun & Lang, 2015)

3.4 Resolution: Pareto Optimality

3.4.1 Building the Pareto set

More than one scoring functions are used to build a Pareto set to ensure that it is as complete as possible. First, each objective is optimized independently. Based on those results, the Utopia and the pseudo Nadir points are identified (see Figure 1). They are used in the normalization of the NWSA. Then, a set weighing factors is chosen depending on the intended depth of analysis. (Kim & Weck, 2006) In a second phase, the ECM enriches the Pareto set. Given a number of solutions, the gap between the Utopia and pseudo Nadir points is divided into the intervals accordingly. Those will be used as constraints.

Then duplicates are gotten rid of and the Pareto set is done.

One way to select a solution from the Pareto set is to minimize or maximize the Euclidian distance from a referential point, such as the Utopia or pseudo Nadir point.

3.4.2 Mathematical translation

The NWSA, ECM and Euclidian distance to Utopia and pseudo Nadir points are translated with equations borrowed from Kim and Weck (2006) adapted to a bi-objective problem.

Step 1**:** find the Utopia point and the pseudo Nadir point.

When J_i is the ith objective function (i=1, 2) and x^{i*} the optimal solution vector for the single objective optimization of the ith objective function J_i, the Utopia point $\boldsymbol{J}^{Utopia}$ is defined as

$$\boldsymbol{J}^{Utopia} = [J_1(x^{1*})\ \ J_2(x^{2*})] \tag{14}$$

and the pseudo Nadir point $\boldsymbol{J}^{Nadir}$ is defined as

$$\boldsymbol{J}^{Nadir} = \left[J_1^{Nadir}\ J_2^{Nadir}\right] \tag{15}$$

where each component J_i^{Nadir} is determined by

$$J_i^{Nadir} = \max[J_i(x^{1*})J_i(x^{2*})] \tag{16}$$

Now the normalized objective function $\overline{J_i}$ is obtained as

$$\overline{J_i} = \frac{J_i - J_i^{Utopia}}{J_i^{Nadir} - J_i^{Utopia}} \tag{17}$$

Step 2**:** Weighted Sum.

The weighted single objective function J_{Total} is obtained as

$$J_{Total} = \alpha J_1 + (1-\alpha)J_2 \tag{18}$$

where α is the weighting factor.

From there, we choose a set of α.

Step 3: ECM

The bi-objective optimization model takes initially the form of

$$\begin{gathered} \min J_1(x) \\ \min J_2\,(x) \\ s.t.\ g(x) \leq 0 \\ h(x) = 0 \end{gathered} \tag{19}$$

where g is the inequality constraint vector and h is the equality constraint vector.

For N solutions, the ECM intervals ε_{ni} $(n = 1, \ldots, N)$ for the objective i are built as such

$$gap = \frac{J_i^{Nadir} \ - J_i^{Utopia}}{N+1} \tag{20}$$

$$\varepsilon_{ni} = \ \varepsilon_{ni-1} + gap\ if\ n > 1 \tag{21}$$

$$\varepsilon_{ni} = \ J_i^{Utopia} + gap\ if\ n = 1 \tag{22}$$

Now, the N bi-objective optimization models takes the form of

$$\begin{gathered} \min J_{in}(x) \\ s.t.\ J_k(x) \leq \ \varepsilon_{nk} \\ g(x) \leq 0 \\ h(x) = 0 \end{gathered} \tag{23}$$

***Step 4a*:** Euclidian distance to $\boldsymbol{J}^{Utopia}$

We minimize the Euclidian distance between a normalized solution and the normalized utopia point $\boldsymbol{J}^{Utopia}$, which is then 0. The closest solution to Utopia point is given with

$$min\sqrt{(\overline{J_1})^2 + (\overline{J_2})^2} \tag{24}$$

***Step 4b*:** Euclidian distance to $\boldsymbol{J}^{Nadir}$

We maximize the Euclidian distance between a normalized solution and the normalized utopia point $\boldsymbol{J}^{Nadir}$, which is then 1. The furthest solution from pseudo Nadir is given with

$$max\sqrt{(\overline{J_1} - 1)^2 + (\overline{J_2} - 1)^2} \tag{25}$$

In section 3, the intermodal bi-objective optimization model and the Pareto set construction is mathematically defined. In section 4, this model is applied in a case study about the Belt and Road Initiative.

4 Case study: Belt and Road Initiative

4.1 Context

Designed by China, the Belt and Road Initiative (BRI) was announced by President Xi Jinping in 2013 under the name ‘One Belt, One Road’ (OBOR) to boost Chinese economy. It was later renamed the “Belt and Road Initiative” in 2017. In 2019 - only 6 years after the launch – 131 countries and 30 international organisations had already adhered to this initiative. By adhering, those countries are willing to show their openness to the standards, technologies and influence of Beijing. (Tohry, 2019; Zhu, 2019)

The objective is building a new Silk Road, which was an Ancient network of trade routes connecting Asia and Europe dating back more than three thousand years. This new Silk Road aims at improving connectivity between Europe, Asia and Africa through the construction of soft and hard infrastructures such as highways, railways, tunnels, bridges, pipelines, industrial parks, ports, etc. (Pencea, 2018) The BRI has two main components: the Silk Road Economic Belt and the 21st Century Maritime Silk Road. The 'Belt' refers then to the land portion while the 'Road' to the maritime route. (Baker McKenzie, 2017; de Soyres et al., 2018; Pencea, 2018; Schramm & Zhang, 2018)

The BRI is constituted of several corridors that are a mix of railways, highways and waterways. The first one is the trans-Siberian corridor that goes through Russia with the Trans-Siberian Railway (TSR) and includes three rail sub-corridors. The most used one is called 'Eurasian Landbridge' and starts at the Chinese-Kazakh border and runs through Kazakhstan to join the TSR in Russia. Then the second most used one starts in the Far East of Russia, and finally the least used one joins the TSR from China via Mongolia. The traditional TSR line starts at Vladivostok in the Far East of Russia that can be connected to China by ship but it is not considered in the BRI development strategy (Schramm & Zhang, 2018). The trans-Siberian corridor usually enters Europe via the Polish-Belarussian border while a few trains end in the Baltic states. Trains coming from the TSR do not usually enter Europe via Ukraine because Russia has blocked Ukrainian railways due to geopolitical reasons since 2013, even though is it likely to change following a decision of the WTO (World Trade Organization). (Farge et al., 2020; Jakóbowski et al., 2018) The second corridor is the trans-Caspian corridor which is particularly intermodal as it alternates land and sea transportation. It starts in China, runs through Central Asian states until Caspian Sea ports where cargoes are loaded onto ferries and shipped in Azerbaijan. There, cargoes are transported on inland routes to Georgia where they are once more loaded onto ferries to cross the Black sea to eventually reach EU. This corridor is meant to provide an alternative route to TSR that bypasses Russia. Another corridor that bypasses Russia is the Southern corridor that runs through Turkey. The train travels along the trans-Caspian routes until Azerbaijan where the train heads for the European port of Turkey through Georgia. An alternative sub-corridor does not need ferries but runs through Iran to Turkey. In Istanbul, the train uses the Marmaray undersea railway tunnel to avoid transhipment. Finally, the BRI has a Land-Sea corridor that provides a maritime route from Chinese ports to the Greek port of Piraeus from which goods are transported by rail in Europe either via Romania, either via Serbia and Northern Macedonia but the latter is much slower than the former and then a lot less attractive. This corridor competes with the traditional maritime route from China to the North Sea and Baltic Sea ports via the Strait of Gibraltar. (Jakóbowski et al., 2018)

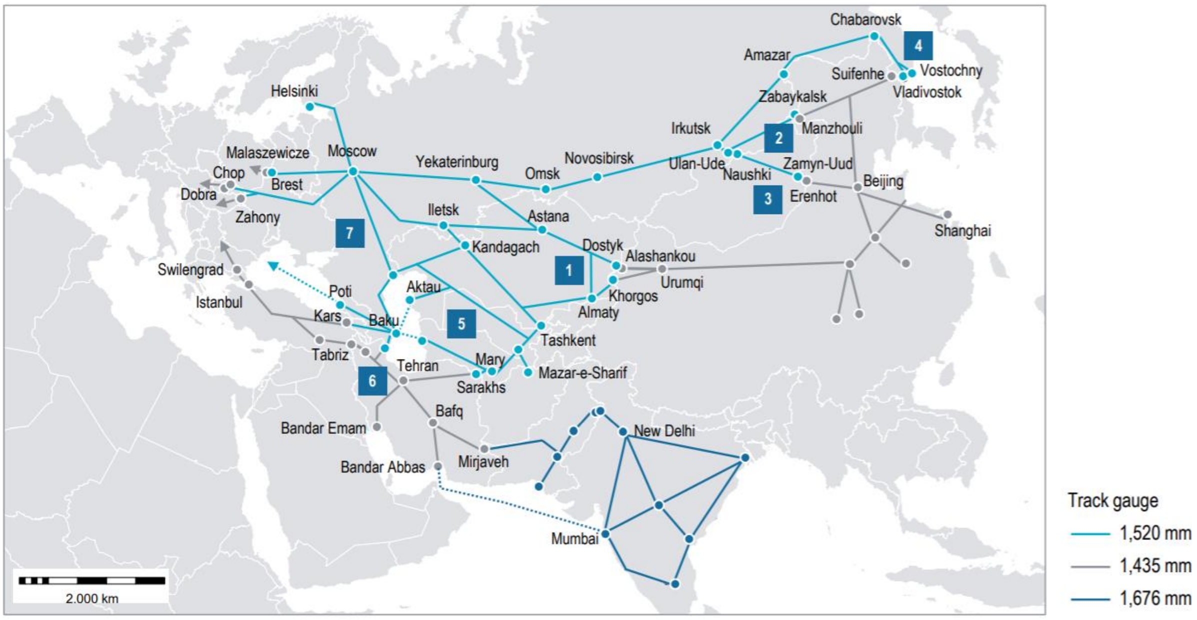


Figure 3:Source:Main Eurasian routes with track gauge. (Roland Berger, 2017)

Regarding trains from China to Europe, it is important to note that there is a difference in gauge in the former USSR and most Commonwealth of Independent States (CIS) (1,520 mm), and in Europe and China (1,435 mm), aside from some exceptions such as Finland.

Interoperability between rail systems is then difficult because standards differ between countries. (Jakóbowski et al., 2018; Railfreight.com, 2019b; Schramm & Zhang, 2018)

Currently, China provides subsidies for rail freight traffic to Europe but those will be lowered in 2020. The subsidy ceiling was set at 0.8 USD/container/km by the Ministry of Finance so the support by the government is usually between 3000-5000 USD per forty-foot container depending on the region. (Railfreight.com, 2019a) One could argue that those subsidies create an economic bubble and unfair competition that are not sustainable in the long run. What would happen if China stopped providing subsidies?

There is a complex legal environment to consider in the BRI, including transport documentation and border crossing procedures (Schramm & Zhang, 2018). The border crossing procedures have already been simplified by some agreements. The International Rail Transport Committee has established in 2013 a combined CIS-SMGS consignment note commonly accepted along the BRI routes that simplifies border crossing procedure for trains (International Rail Transport Committee, n.d.). There is also a Eurasian customs union between ex-URSS countries.

The BRI routes are often experiencing important delays due to congestion, climate, opening hours, absence of unified regulations and technical standards, border clearance, speed reduction due to fuel saving for ships, price fluctuation, etc. There are also physical constraints reducing the time-efficiency of the Silk Road Economic Belt such as poor infrastructure on several sections. (Jakóbowski et al., 2018; Schramm & Zhang, 2018) Nevertheless, the BRI includes projects and efforts to reduce border delays as well as improve efficiency and infrastructures. Moreover, with a better organization of transport and an improvement in congestion management, one could see the speed increase along the corridors. (de Soyres et al., 2018)

4.2 Simulation design

4.2.1 Simulation

In this section, the BRI is simplified into a simulation in order to analyse the relationships between time and cost, between the transportation modes and between the BRI routes. To do so, complex real-life aspects are translated into figures such as transhipment, goods handling and border crossing procedures.

This cost-time bi-objective optimization routing planning simulation considers multiple scenarios where China is always the origin and an EU capital the destination.

The objectives of the simulation are plural.

1. Building a Pareto set for a given set of capitals
2. Selecting solutions from the Pareto set
3. Analysing the relationship between time and cost
4. Analysing the relationship between objectives and transportation modes
5. Analysing the relationship between the transportation modes
6. Analysing the relationship between the routes and the capitals location

The simulation of the BRI is based on a network dataset composed of arcs and nodes. Each arc includes an origin, a destination, a speed, a distance, a cost and an appurtenance to a BRI corridor. Each node is constituted of a terminal - a port, a station, a border crossing point, a road terminal, or a strait – a cost and a time spent in this node. The design of the dataset is fully explained in the next section.

The advantages of a simulation such as this one is that it helps understanding the impact of variations in factors such as subsidies, quality of infrastructure, customs regulations, etc. It gives realistic measures of the total travel cost and time considering aspects such as change of gauge, transhipment, waiting time, etc. Those measures may be realistic but can however be inexact. Indeed, that kind of simulation and network analysis has also limitations. It is important to remember that a simulation network is a simplified version of reality. The results greatly depend on the data quality. A number of factors are not taken into account such as schedules, passenger lines, climate, etc. The BRI projects also touch aspects that are hard to quantify such as customs efficiency.

This simulation is run via a code in Python written on Spyder using Gurobi Solver. It is run on an ASUS VivoBook with a processor Intel® Core™ i5-8250U CPU @1.60GHz and 8 Go RAM.

In the following section, the dataset construction is explained.

4.2.2 Dataset

In order to analyse the BRI, we have built a simulation dataset relying on real data. The simulation is based on a newly-built network and on primary, secondary data and estimates. In the following section, we describe our methodology for the mapping of the network, the arcs dataset and the nodes dataset.

4.2.2.1 Mapping

First, we have built a network (see Figure 4) based on the BRI routes described by Schramm and Zhang (2018), Jakóbowski et al. (2018), Davydenko et al. (2012), Neise (2018), the UN Department of Economic and Social Affairs (2019) and Railfreight.com (2019b), and based on the Trans-European Transport network (TEN-T) (European Commission, 2020).

The TEN-T is a policy aiming at building a Europe-wide network of railways, highways and waterways in order to strengthen the cohesion in the EU, improve European environmental sustainability and energy efficiency, and increase safety. This is achieved through building new infrastructure, improving existing one, and developing new technologies. The project has two layers: the core network constituted of nine ‘Core Network Corridors’ that includes the most important connections, and the comprehensive network that covers all European regions. (European Commission, 2020) In 2013, the project was planned to be fully operational by 2030, which seems today unlikely (Railfreight.com, 2020). In our simulation, we have simplified mainly the nine Core Network Corridors.

The scope of this paper is to analyse the journey of a TEU container between China and UE capitals. It does not include railways and highways inside China. That is why our simulation network (see Figure 4) starts with a node called ‘China’. From that node, we have several ‘exit points’, border crossing points from China to the BRI corridors. Then, we have the ‘BRI network’ consisting of several ‘BRI nodes’ - which are either ports, stations, straits, border crossing points - until we reach the ‘entry points’, border crossing points in Europe. After the entry points, we consider a simplified TEN-T in order to reach our ‘destination nodes’, namely the EU capitals, excluding the Mediterranean islands.

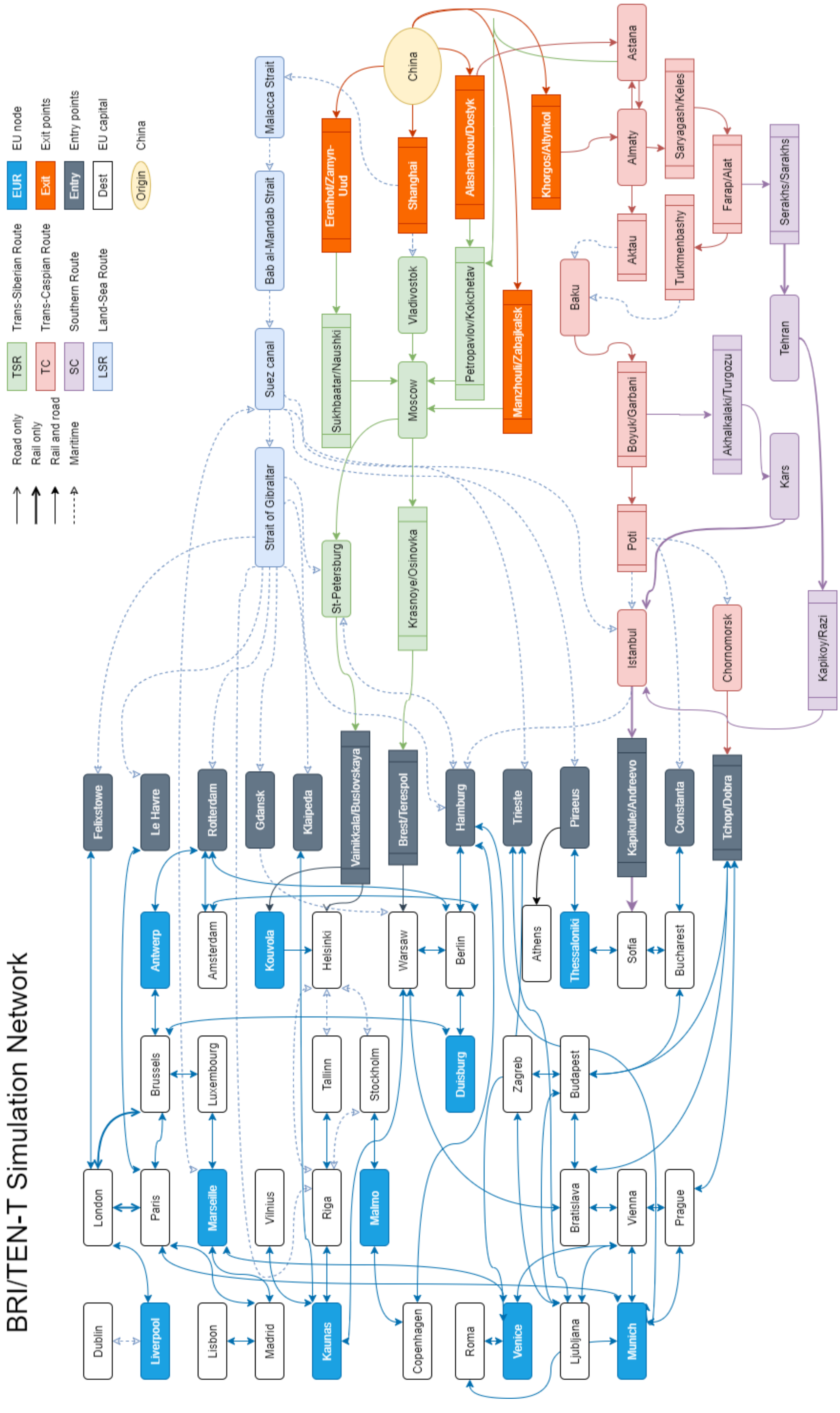


Figure 4: Simulation network of the BRI and TEN-T

4.2.2.2 Arcs dataset

Then, we have built the arcs dataset of the network, namely the cost, distance, and speed related to each arc (see Appendix 1.1). To do so, we have used different kind of sources (see Appendix 1.4). For costs and distances, we have collected data mainly from the website SeaRates.com (2020) – which provides tools such as a real-time freight rates calculator - using one TEU container, Full Wagon Load (FWL) and Full Container Load (FCL) 33 CBM as parameters, for rail routes and sea routes respectively, in combination with some data extracted from a book edited by Neise (2018). We have also used additional sources for the arcs using a maritime transportation mode such as Freightos.com (2020)- another website providing a freight rates calculating tool but specialized in sea freight - and several specific sources (Freightlink, 2020; Trans-Logistics LLC, n.d.; UN/ECE, 2019). For road transport cost, we have contacted Ziegler, a container carrier company. Regarding the speed of transportation modes, we have derived the speed of each mode for each region, route or arc from numerous secondary sources (see Appendix 1.3).

4.2.2.3 Nodes dataset

If the arcs dataset is primarily built on primary data, the nodes dataset (see Appendix 1.2) is mainly built on secondary data as the information is much trickier to find, especially in times of COVID-19. Referring to articles between 2012 to 2020 and phone enquiries to carriers, we have estimated several parameters on which are based the cost and time spent in each node. It is not possible to give exact estimates to determine the cost and time spent in each node because congestion is very volatile and delays can occur at any time. Time spent at a node depends on too many factors such as climate, opening hours, congestion, border procedures, etc. In this context, one can spend up to three days at a port without knowing the exact number of days beforehand. (Ziegler, 2020) Therefore, we have calculated estimates of node parameters to determine the cost and time spent in each node (see Appendix 1.5).

In order to check the validity of the parameters, we have run the simulation and we did a reality check based on secondary data. The results are listed in Table 1 and 2. The output is close enough to the expected values to consider the simulation as realistic.

Table 1: Expected time versus simulation

Routes	Simulation	Expected	Secondary source
China- Hamburg	36 days by sea 16 days by rail	32 days by sea 16 days by rail	Schramm and Zhang (2018)
China- Warsaw	13-14 days by rail	12-14 days by rail	Jakóbowski et al. (2018)
China- St Petersburg	9.3 days by road	10 days by road	Pradt (2020)
China- Rotterdam	17 days by rail 35-36 days by sea	18 days by rail 27-37 days by sea	Jakóbowski et al. (2018)
China – Helsinki	13 days by rail	12-14 days by rail	Railfreight.com (2019b)

Table 2: Expected cost versus simulation [USD]

Routes	Simulation	Expected[1]	Secondary source
China-Hamburg	3,979 by rail 1,409 by sea	3,700 by rail 1687 by sea	Schramm and Zhang (2018)
China-Warsaw	3,243 by rail	3,700 by rail	Jakóbowski et al. (2018)
China-Rotterdam	5,351 by rail (TEU) 1,697 by sea (TEU)	5,000 by rail (FEU) 2,200 by sea (FEU)	Jakóbowski et al. (2018)

4.2.2.4 Assumptions

Assumptions:

- The TEN-T network is not finished yet but it is assumed that the whole core network is operational.
- The consignment of goods is transported in a TEU full of freight-all-kinds and is assumed to weight no more than 14.2 tons. (Laursen, 2015)

[1] The expected costs were originally for FEU. As a result of experiments on SeaRates.com, we have concluded that the cost for a TEU represents 60-80% of the cost of a FEU. Therefore, we consider 70% of the original costs.

- The model specifications require a transhipment at each node. If the goods keep the same transportation mode, we assume that the goods are not really handled so no charge or delay occur.
- An MTO - single organizer - is assumed.
- The nodes parameters are generalized to the type of infrastructure.
- For the Land-Sea Route, we consider the cost on the arcs between straits as null apart from the last segment because the total cost of that route varies a lot depending on the destination and there is no need to break the cost into a common ground for the maritime destinations.
- Regarding the speed of trucks, a day of 15 hours is considered. So if the original speed is 60km/h, it becomes 37.5km/h[2].

4.2.2.4 Data collection summary

Data collection is summarized in Table 3.

Primary data reflects the current market situation as it is collected between the end of May and the end of July 2020. Quotations can vary due to the volatility of the freight rates in the marketplace. As the primary data is very volatile in this context, it should be considered as precise estimates rather than exact data in the context of our simulation, as it is more general.

[2] $37.5 = 60 \times \frac{15}{24}$

Table 3: Data collection summary

Data Collected	Data Type	Source	Collection Method
Arcs	TEU FWL and FCL freight rate for routes from China to Europe, distance on those routes, and regional average speed	SeaRates.com (2020) Freightos.com (2020) Neise (2018) Trans-Logistics LLC UN/ECE, 2019	Online enquiries Site visits Secondary data collection
Nodes	Border crossing time and cost, handling charges and time, transhipment time and cost.	Davydenko et al. (2012), European Commission (2017), Ziegler (2020), Neise (2018), Jinno (2018), de Soyres et al. (2018), SeaRates.com (2020), Asian Development Bank (2019), ESCAP (2018), Schramm and Zhang (2018), Doceul and Tabarly (2018), Massard (2007), Couper (2019), UNCTAD (2018), Inland Transport Committee (2018), (Yin et al., 2020)	Phone enquiries Secondary data collection

4.3 Pareto Set and Analysis

4.3.1 Observations

At first, four EU capitals are considered: Brussels, Helsinki, Budapest and Madrid. The transit period of goods is set to 1000 hours, namely 41-42 days. The consignment of good is carried by one TEU container. The results of the calculation of Gurobi is shown in Table 4. Twenty-nine optimisations are run, and duplicates are removed to build the Pareto set. The number of identical solutions is given is Table 6 and is considered as the 'weight' of the solution in the Pareto set. The Table 5 gives complementary information, namely the methods of optimization (NWSA, ECM, etc.). Appendix 2.1 maps the Pareto set.

Table 4: NWSA and ECM Pareto solutions of Gurobi.

No.	**Pareto Solutions**							
	Brussels		**Helsinki**		**Madrid**		**Budapest**	
	Cost (USD)	**Time (h)**	**Cost (USD)**	**Time (h)**	**Cost (USD)**	**Time (h)**	**Cost (USD)**	**Time (h)**
Obj1	2526	920	2423	980	3554	753	2589	753
Obj2	15371	306	12249	253	18759	356	14339	289
3	8236	309	5114	256	11624	359	7204	292
4	5603	422	4683	264	11428	366	3934	406
5	2539	902	4487	271	10968	394	6352	334
6	7384	351	4253	324	10126	434	5242	379
7	4108	763			8990	471	3265	733
8	3047	894			8107	510	4130	399
9	5799	415			7878	536	6094	337
10	7580	344			9187	466		
Utopia	2526	306	2423	253	3554	356	2589	289
Pseudo Nadir	15371	920	12249	980	18759	753	14339	753

Table 5: Details on the Pareto solutions related to the methods of bi-objective minimization.

Pareto Solutions													
Brussels	**NWSA**	**Obj1**	**Obj2**	**3**	**4**	**5**	**ECM**	**9**	**10**	**ECM**	**6**	**7**	**8**
	OBJ1 weight	100%	0%	10-30%	50-70%	80-90%	**OBJ2 constr**	367	797	**OBJ1 constr**	3810	6379	7664
Helsinki	**NWSA**	**Obj1**	**Obj2**	**3**	**4**	**5**	**6**						
	OBJ1 weight	90-100%	0%	10-20%	30%	40-70%	80%						
Madrid	**NWSA**	**Obj1**	**Obj2**	**3**	**4**	**ECM**	**5**	**6**	**7**	**8**	**9**	**ECM**	**10**
	OBJ1 weight	70-100%	0%	10-50%	60%	**OBJ2 constr**	396	436	475	515	555	**OBJ1 constr**	9636
Budapest	**NWSA**	**Obj1**	**Obj2**	**3**	**4**	**ECM**	**5**	**6**	**ECM**	**7**	**8**	**9**	
	OBJ1 weight	90-100%	0%	10-40%	50-80%	**OBJ2 constr**	336	382	**OBJ1 constr**	3764	4939	6114	

The Pareto frontier for each capital can be gained by connecting the coordinate points (Cost, Time) in the Table 4. The Pareto frontier is shown in Figure 5.

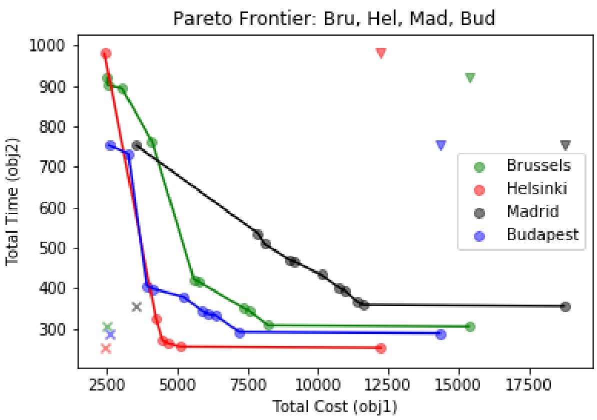


Figure 5: Pareto frontier, Utopia (×) and pseudo Nadir points (∇), for Brussels, Helsinki, Madrid and Budapest.

The trade-off between minimizing the total cost and the total time is clearly shown in Figure 5. When the total cost increases, the total time decreases. The Pareto frontier indicates a compromise between the two objectives.

Regarding the general trends, one can observe that the routes between China and Helsinki are the cheapest and the fastest while the routes between China and Madrid are the most expensive and slowest ones. That can be explained by the fact that Helsinki is closer to China than Madrid. That is true as far as inland transportation is concerned. The extreme left point is indeed slower for Helsinki than Madrid because this solution uses the Land-Sea Route (LSR) - until Riga for Helsinki and Marseille for Madrid – which takes longer to reach the Northern Europe than the South.

One can also observe that the number of Pareto solutions constituting the Pareto set varies with the destination. In a network, the size of the set of potential routes from one point to another is just not the same for every destination.

Table 6 shows the proportion of arcs using each route and transportation mode for each solution.[3] In terms of general trends, the table shows that the Southern (SC) and Trans-Caspian (TC) routes are not selected by any of the Pareto solutions. It is also clear that the consignment of goods from China to Helsinki primarily -and more than to other cities - moves along the TSR apart from one solution where only the total cost is minimized. That echoes what was stated previously: Helsinki is the closest to China by inland transportation but the furthest by maritime transportation.

[3] As some arcs belong to more than one route, the sum of the percentage can be higher than 100.

Table 6: proportion of arcs using each mode of transportation and belonging to each BRI route for each pareto solution and weight of the solution in the total set of optimizations.

% of	No.	Obj1	Obj2	3	4	5	6	7	8	9	10
Count on nwsa solutions	**Brussels**	1	1	4	3	2					
	Helsinki	2	1	2	1	4	1				
	Madrid	4	1	5	1						
	Budapest	2	1	4	4	1					
Count on 29 solutions	**Brussels**	1	1	9	9	2	1	3	1	1	1
	Helsinki	3	1	9	1	4	11				
	Madrid	6	1	9	1	2	1	1	2	5	1
	Budapest	2	1	10	11	1	1	1	1	1	
TSR	**Brussels**	13%	67%	63%	67%	13%	67%	14%	13%	63%	63%
	Helsinki	14%	83%	80%	80%	83%	100%				
	Madrid	17%	55%	50%	55%	50%	50%	50%	50%	55%	50%
	Budapest	14%	75%	71%	75%	75%	75%	14%	71%	71%	
LSR	**Brussels**	75%	0%	0%	0%	75%	0%	57%	63%	0%	0%
	Helsinki	71%	0%	0%	0%	0%	0%				
	Madrid	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Budapest	57%	0%	0%	0%	0%	0%	57%	0%	0%	
SC	**Brussels**	0%	11%	0%	11%	0%	11%	0%	0%	0%	0%
	Helsinki	0%	17%	0%	0%	17%	14%				
	Madrid	0%	9%	0%	9%	0%	0%	0%	0%	9%	0%
	Budapest	0%	13%	0%	13%	13%	13%	0%	0%	0%	
TC	**Brussels**	0%	11%	0%	11%	0%	11%	0%	0%	0%	0%
	Helsinki	0%	17%	0%	0%	17%	14%				
	Madrid	0%	9%	0%	9%	0%	0%	0%	0%	9%	0%
	Budapest	0%	13%	0%	13%	13%	13%	0%	0%	0%	
EUR	**Brussels**	25%	33%	38%	33%	25%	38%	38%	33%	43%	38%
	Helsinki	29%	17%	20%	20%	17%	0%				
	Madrid	33%	45%	50%	45%	50%	50%	50%	50%	45%	50%
	Budapest	43%	25%	29%	25%	25%	25%	43%	29%	29%	
rail	**Brussels**	38%	11%	25%	78%	13%	44%	14%	13%	75%	38%
	Helsinki	14%	17%	40%	60%	67%	100%				
	Madrid	17%	9%	20%	27%	30%	40%	60%	80%	91%	60%
	Budapest	43%	13%	29%	100%	50%	75%	14%	100%	57%	
road	**Brussels**	0%	89%	75%	22%	25%	56%	29%	25%	25%	63%
	Helsinki	0%	83%	60%	40%	33%	0%				
	Madrid	17%	91%	80%	73%	70%	60%	40%	20%	9%	40%
	Budapest	0%	88%	71%	0%	50%	25%	29%	0%	43%	
ship	**Brussels**	63%	0%	0%	0%	63%	0%	57%	63%	0%	0%
	Helsinki	86%	0%	0%	0%	0%	0%				
	Madrid	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Budapest	57%	0%	0%	0%	0%	0%	57%	0%	0%	

In combination with Table 4 and 5, Table 6 reveals new trends. There seems to be a threshold in the importance given to each objective. Sea transport is preferred only as from a given weight to minimizing the total cost. It means that sea transport is cheaper and slower than inland transportation. Regarding inland transportation, it seems that the preferred choice is road when the first objective - minimizing the total cost - weights little in the bi-objective minimization but when the importance of the first objective increases, it seems that rail becomes the preferred choice. It means that road is more expensive but faster than rail.

Table 6 also displays that the maritime transportation mode only represents a small part of the Pareto set. It seems that sea transport is then less preferred than the other transportation modes but it is not necessarily true. For instance, sea transport represents only one solution in the Pareto set of Madrid but it optimises NWSA between 70 to 100% weight on the first objective (see Table 5). It represents then 30% of the solutions found via NWSA. As another selection method, the weight of a solution can be roughly considered as the probability to be chosen.

Moreover, Table 4 shows that the difference between the objective values of the LSR solutions and the others is huge. According to Tables 4 and 6, the solutions implying maritime transport involve on average only 40% of the cost of the other solutions and are more than twice slower. As regard road and rail transport, rail transport costs approximately 60% of road transport cost and is slightly slower.

To sum up, the preferred transportation mode[4] when increasing the weight on the first objective - the total cost - and decreasing the importance of the second objective – the total time - is first road, then rail, and finally sea.

4.3.2 Selection

With the Pareto set, the MTO can select the solution that best suits its needs and preferences. For example, if the customer is satisfied with a total transportation time from China

[4] The notion of preferred transportation mode (or route) refers to the one that is the most present in the Pareto solutions.

to Madrid of maximum 15 days – namely 360 hours – the MTO can choose solution No. 2 or 3 (see Table 4).

However, there are other techniques to select a solution from the Pareto set. For instance, the MTO can choose the solution that is the closest to the Utopia point, or the furthest from the pseudo Nadir point (see Table 7). In that case, the best solution for Madrid would be either No.3 or No.7. The MTO can also use the NWSA to choose amongst the solutions (see Tables 4 and 5). In the case where both objectives have the same weight, the optimal solution would also be solution No.3. It is also the solution with the highest weight (see Table 6).

Table 7: Evaluation of distance of the Pareto normalized solutions to referential points

No.	Pareto Solutions: distance to referential points							
	Brussels		Helsinki		Madrid		Budapest	
	Utopia	Nadir	Utopia	Nadir	Utopia	Nadir	Utopia	Nadir
Obj1	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Obj2	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
3	0,445	1,140	0,274	1,233	0,531	1,098	0,393	1,165
4	0,305	1,112	0,231	1,250	0,518	1,088	0,277	1,159
5	0,970	0,999	0,212	1,255	0,497	1,039	0,335	1,130
6	0,385	1,116	0,211	1,215	0,474	0,985	0,297	1,118
7	0,754	0,913			0,460	0,958	0,958	0,943
8	0,958	0,960			0,489	0,931	0,271	1,156
9	0,311	1,109			0,535	0,901	0,315	1,139
10	0,398	1,117			0,462	0,960		

4.3.3 Hypotheses

From the observation phase, several hypotheses can be made regarding the transportation mode preference, the route preference and the cities.

First, the transportation mode preferences seem to rely on the importance given to both objectives. Each mode seems to be optimal within a range of objective weight (from 10 to 40% on objective 1 for instance). It is observed that sea transport is optimal when the first objective – the total cost - is primarily minimized, while road transport is optimal when the second objective – the total time – is mainly minimized. Rail transport is optimal in more of a situation of compromise.

H1: Preference to a transportation mode decreases when its cost increases.

H2: Preference to a transportation mode increases when its speed increases.

It is also observed that sea transport is less present in the Pareto set but it weighs more because it represents many duplicates in the twenty-nine optimisations. It was stated that the solutions opting for maritime transport are quite far from the other solutions on average, both in terms of cost and time. Therefore, a variation in ship cost or speed is unlikely to affect the transport mode preferences. On the other hand, rail and road transport are pretty close in terms of total time of journey. A slight increase in train speed or decrease in truck speed can affect the transport mode preferences in favour of rail transportation

H3: Sea transport is less sensitive to cost and time variations than truck and rail transport.

H4: The model is not affected by variations in ship speed or cost.

Secondly, it is observed that the position of the destination city may affect the selection of the routes and transportation modes. For Helsinki and Brussels, it is clear that the TSR is preferred to the LSR because the maritime route takes much longer. For Budapest, TSR is also the one mostly present in the Pareto set because Budapest is closer to China by inland transportation.

H5: The TSR is the route the most present in the Pareto sets of Northern EU capitals as destinations.

H6: The TSR is the route the most present in the Pareto sets of Western EU capitals as destinations.

H7: The TSR is the route the most present in the Pareto sets of Eastern EU capitals as destinations.

For Madrid, the LSR is much more present in the Pareto solutions than in the other cities solutions because the maritime route is shorter than the inland routes. Nevertheless, the TSR is more present but LSR is a close second. Following the same logic of distance, other Southern capitals - close to the Mediterranean Sea - should prefer the LSR.

H8: The LSR is the route the most present in the Pareto sets of Southern EU capitals as destinations.

Finally, it is observed that neither the Southern Corridor (SC), nor the Trans-Caspian Corridor (TC) is chosen amongst the Pareto solutions. Nevertheless, those are alternative solutions that can be optimal solutions with a change in speed or cost.

H9: Solutions on the SC with 50% higher speed or lower cost appear in the Pareto set for South-Eastern capitals

H10: Solutions on the SC with 50% higher speed or lower cost appear in the Pareto set for South-Eastern capitals

In the following section – Sensitivity Analysis – those hypotheses are confronted.

4.4 Sensitivity Analysis

4.4.1 Cost and time

4.4.1.1 Sensitivity to speed variations

4.4.1.1.1 Train

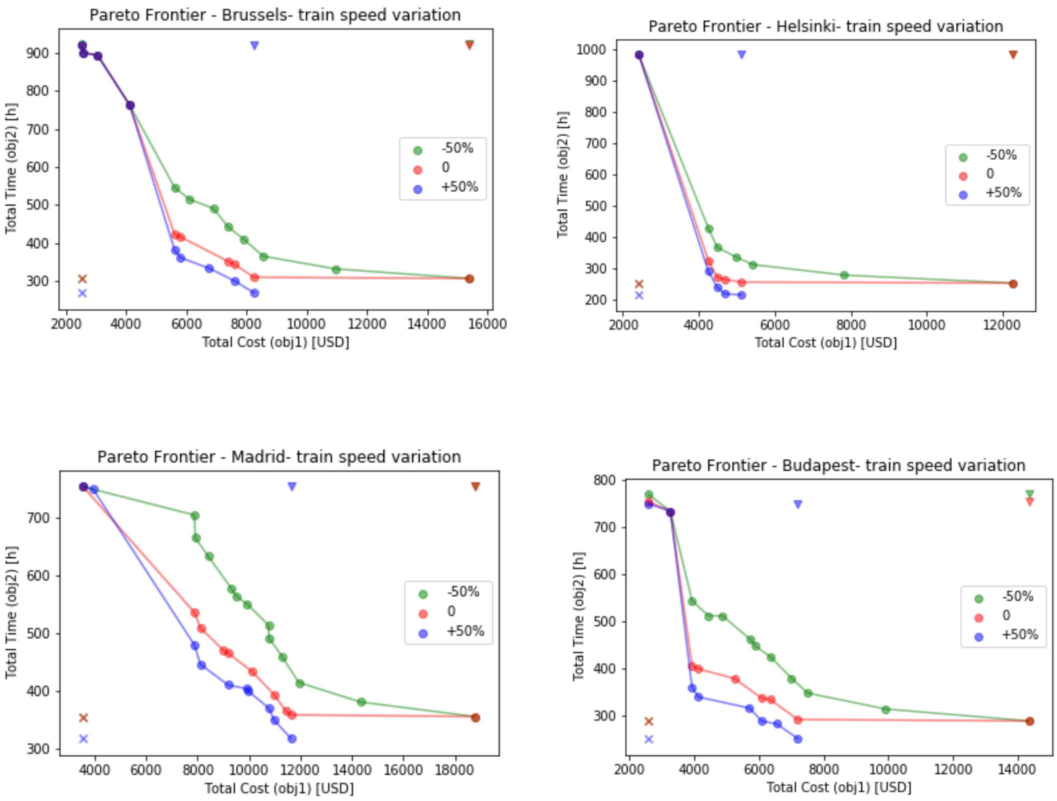


Figure 6: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the train speed

Figure 6 shows the variation of the Pareto frontier for the four cities of interest when the speed of the rail transport varies from 50% to 150% of its original value. The curve moves from left to right when speed decreases. That means that for the same cost, the journey takes more time. There is also no change at the extreme points when speed decreases, which means that the rail transportation mode is not selected in those solutions. Nevertheless, there is a change in the extreme point minimizing only the total time. When train speed increases by a determined percentage, it seems that rail becomes the preference instead of road in terms of time minimizing. It is also worth noting that when speed decreases, a solution appears on the right, where the cost is higher. It can be deduced that the decrease in speed increases the road preference. The Pareto set is also bigger when speed decreases. That means that there are more routing options. The variation is especially visible in the middle of the curves.

Table 8 confirms what is stated above, namely that the use of train decreases[5] while the use of trucks increases when the speed of train decreases, and vice versa. In particular, road transport is drastically negatively impacted when the train speed increases. There is also an increase in the use of ships when the speed of trains increases because of the weighted average. Indeed, the first solutions (selecting LSR and maritime transport) of the three optimisation models (without any variation, with an increase in speed of 50%, with a decrease in speed of 50%) are the same in Table 6 in terms of proportion of arcs choosing maritime transport and LSR. What changes is the weight of the solutions, in other words the number of duplicates of those solutions in the twenty-nine optimisations. It means that the LSR solution is more often selected in the ECM optimisations when the speed of the train increases. It can be deduced that the first solutions – which select LSR as transportation route, and ship and train as transportation

[5] The notion of use of a transportation mode refers to its presence in the Pareto solutions.

modes – have a bigger increase in their number of duplicates amongst the twenty-nine optimisation – and then in their 'weight' in the Pareto set- when speed of the train increases.

Table 8: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when speed of trains varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	51,71%	78,49%	45,14%	66,13%	-0,88%
0	52,20%	81,36%	44,20%	67,24%	
50%	43,12%	63,00%	39,76%	62,93%	-9,05%
LSR					
-50%	15,83%	7,39%	13,79%	5,91%	0,00%
0	15,83%	7,39%	13,79%	5,91%	
50%	27,09%	27,09%	22,99%	9,85%	11,03%
SC					
-50%	11,19%	17,08%	9,82%	14,22%	7,89%
0	4,21%	8,29%	2,19%	6,03%	
50%	2,68%	7,14%	2,51%	4,74%	-0,92%
TC					
-50%	11,19%	17,08%	9,82%	14,22%	7,89%
0	4,21%	8,29%	2,19%	6,03%	
50%	2,68%	7,14%	2,51%	4,74%	-0,92%
Rail					
-50%	37,59%	58,87%	32,99%	52,63%	-6,10%
0	41,76%	63,66%	39,69%	61,39%	
50%	42,79%	57,83%	46,80%	75,37%	4,07%
Road					
-50%	47,88%	32,27%	53,21%	41,45%	6,10%
0	43,71%	27,47%	46,52%	32,70%	
50%	32,27%	9,66%	30,21%	14,78%	-15,87%
Maritime					
-50%	14,53%	8,87%	13,79%	3,94%	-0,49%
0	14,53%	8,87%	13,79%	5,91%	
50%	24,94%	32,51%	22,99%	9,85%	11,80%

4.4.1.1.2 Truck

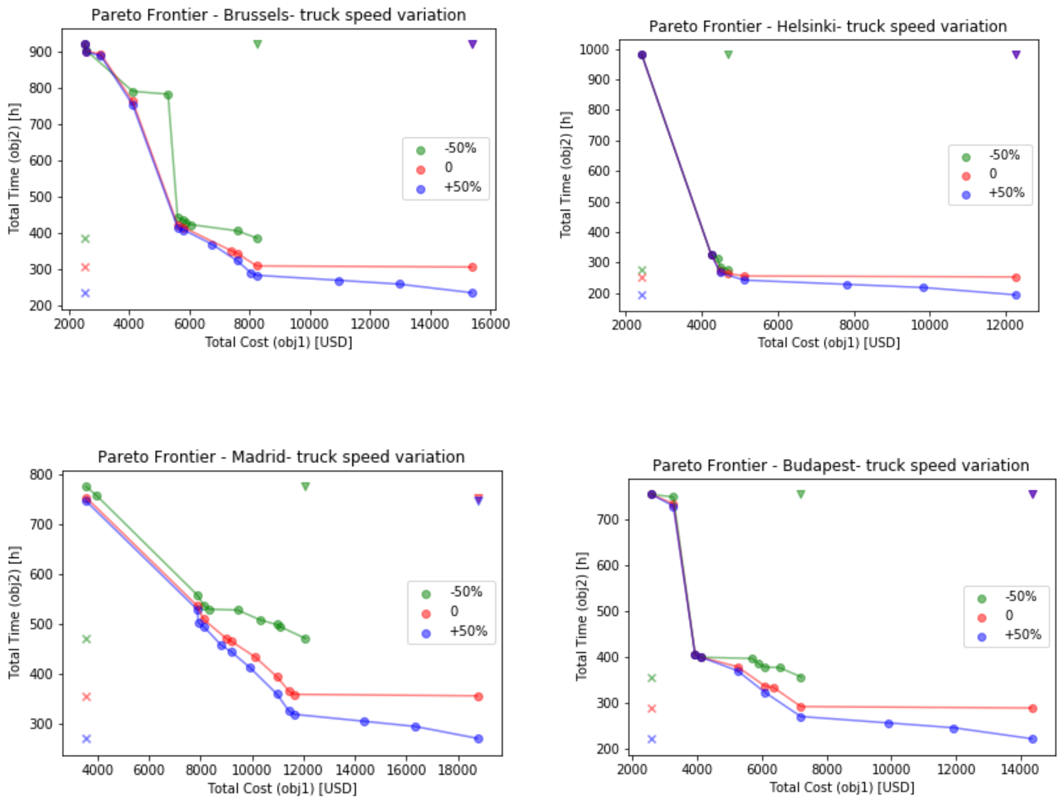


Figure 7: Pareto frontier, Utopia (×) and pseudo Nadir points (▽) sensitivity to truck speed

Figure 7 shows the variation of the Pareto frontier for the four cities of interest when the speed of the road transport varies from 50% to 150% of its original value. The curve moves from left to right when speed decreases. That means that for the same cost, the journey takes more time. It also shows that an increase of speed increases the size of the Pareto set. There is a clear variation at the extreme point minimizing only the total time. When truck speed decreases, the cost of that extreme point drastically decreases. That gives a hint that there is a switch of transport mode from road to rail. On the contrary, the blue curve indicates that an increase in truck speed favours the road preference as there are more solutions visible in the high cost area of the graph.

Table 9 shows indeed that a reduction in truck speed results in a rise in the presence trains and ships in the Pareto sets, especially in the presence of the LSR. However, a decrease in speed does not affect the sea preference and barely affects the train and truck preference. Road transport is drastically more impacted by a decrease in speed than an increase.

While an increase in speed of truck almost has no impact on the route choice, a decrease has a remarkable impact on the traffic. There is a switch from the LSR to the TSR.

Table 9: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when speed of trucks varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	45,42%	58,47%	40,07%	64,41%	-9,16%
0	52,20%	81,36%	44,20%	67,24%	
50%	52,48%	80,43%	46,71%	66,91%	0,38%
LSR					
-50%	25,37%	32,02%	22,99%	9,85%	11,83%
0	15,83%	7,39%	13,79%	5,91%	
50%	15,83%	7,39%	13,79%	5,91%	0,00%
SC					
-50%	4,21%	7,14%	3,13%	6,47%	0,06%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,98%	11,49%	4,45%	7,57%	1,94%
TC					
-50%	4,21%	7,14%	3,13%	6,47%	0,06%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,98%	11,49%	4,45%	7,57%	1,94%
Rail					
-50%	53,88%	55,94%	56,33%	77,43%	9,27%
0	41,76%	63,66%	39,69%	61,39%	
50%	46,54%	60,57%	37,12%	58,06%	-1,05%
Road					
-50%	23,34%	5,63%	20,68%	12,72%	-22,01%
0	43,71%	27,47%	46,52%	32,70%	
50%	38,92%	30,56%	49,09%	36,03%	1,05%
Maritime					
-50%	22,78%	38,42%	22,99%	9,85%	12,74%
0	14,53%	8,87%	13,79%	5,91%	
50%	14,53%	8,87%	13,79%	5,91%	0,00%

4.4.1.1.3 Ship

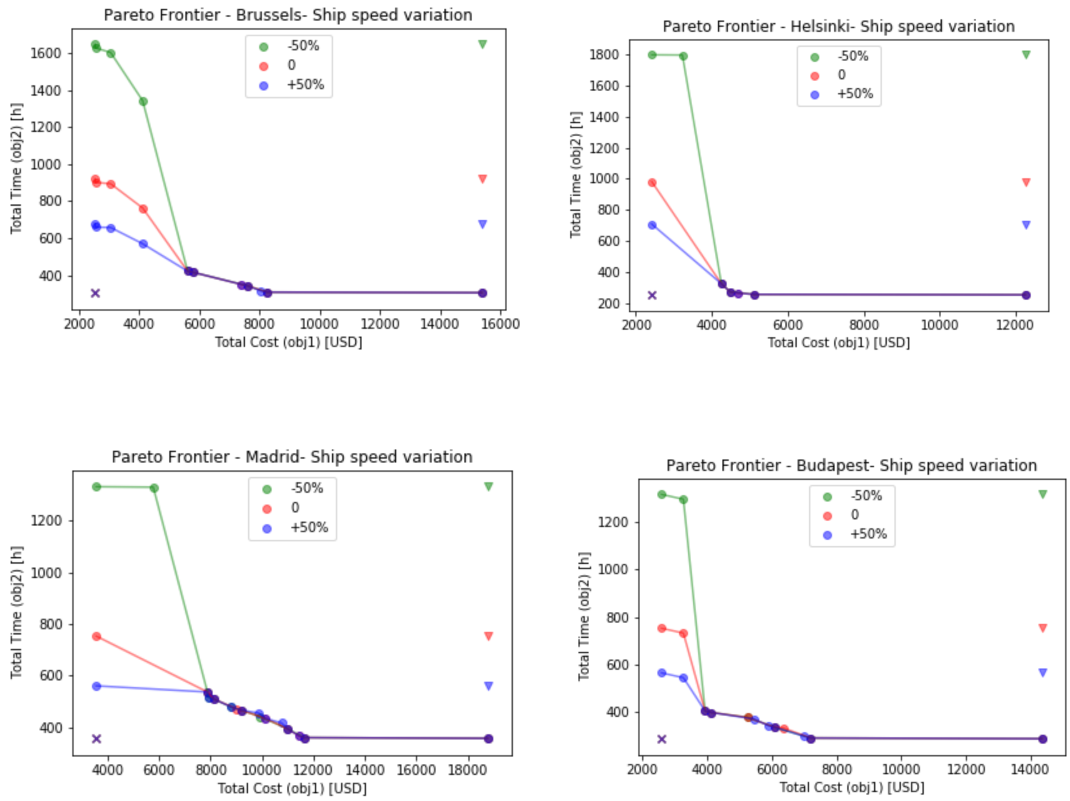


Figure 8: Pareto frontier, Utopia (×) and pseudo Nadir points (▽) sensitivity to the ship speed

Figure 8 shows the variation of the Pareto frontier for the four cities of interest when the speed of the maritime transport varies from 50% to 150% of its original value. The curve barely moves, apart from the extreme side related to primarily minimizing the cost. Sea transport is indeed only chosen when time has very little importance. When the speed decreases, there is no difference in the transportation mode choice. Nevertheless, looking at the case of Helsinki and Budapest, there seems to be a tiny increase in sea preference when ship speed increases. However, it is not confirmed by the figures in Table 10. On the contrary, it shows a tiny decrease in the popularity of the ship when its speed decreases. The train use increases while the truck use decreases when ship speed decreases, and the other way around when the ship speed increases. It is funny to notice that train and truck are more affected than sea transport by a ship variation. Regarding the routes, the TCR is slightly more present in the Pareto solutions when ship speed decreases.

Table 10: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when speed of ships varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	52,48%	83,11%	46,30%	67,49%	5,00%
0	52,20%	81,36%	44,20%	67,24%	
50%	51,91%	80,10%	44,36%	66,87%	-0,44%
LSR					
-50%	15,83%	7,51%	10,92%	5,91%	-0,29%
0	15,83%	7,39%	13,79%	5,91%	
50%	15,83%	7,39%	13,79%	5,91%	0,00%
SC					
-50%	4,98%	9,28%	4,39%	6,90%	1,80%
0	4,21%	8,29%	2,19%	6,03%	
50%	3,45%	7,88%	2,51%	4,74%	-0,54%
TC					
-50%	4,98%	9,28%	4,39%	6,90%	1,80%
0	4,21%	8,29%	2,19%	6,03%	
50%	3,45%	7,88%	2,51%	4,74%	-0,54%
Rail					
-50%	46,54%	67,05%	51,04%	68,04%	6,30%
0	41,76%	63,66%	39,69%	61,39%	
50%	36,77%	61,13%	33,35%	57,08%	-4,54%
Road					
-50%	38,92%	24,89%	38,04%	26,05%	-5,92%
0	43,71%	27,47%	46,52%	32,70%	
50%	48,69%	30,00%	52,85%	37,01%	4,54%
Maritime					
-50%	14,53%	8,07%	10,92%	5,91%	-0,38%
0	14,53%	8,87%	13,79%	5,91%	
50%	14,53%	8,87%	13,79%	5,91%	0,00%

4.4.1.2 Sensitivity to cost variations

4.4.1.2.1 Train

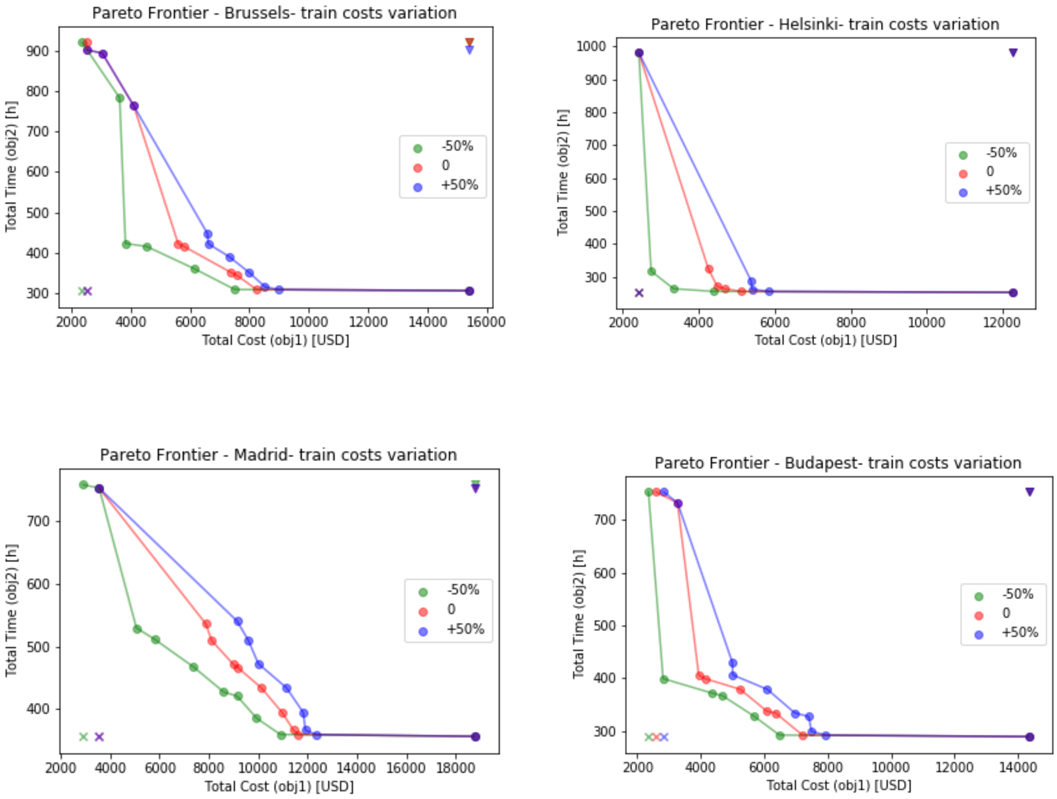


Figure 9: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the cost of rail.

Figure 9 shows the variation of the Pareto frontier for the four cities of interest when the cost of the rail transport varies from 50% to 150% of its original value. The curve moves from left to right when the cost increases. There is no change at the extreme points.

According to Table 11, there is a net switch of transportation when train cost increases or decreases. In the first case, train use decreases in favour of truck and ship use, and reciprocally. The variations affect more the road and rail transport than sea transport. The rail transport is more positively affected by a 50% speed increase than negatively impacted by a 50% decrease in speed.

Regarding the BRI route presence, when the cost of train increases, the traffic switches from TSR to LSR and reciprocally.

Table 11: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when cost of trains varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	54,21%	86,81%	46,71%	69,58%	3,08%
0	52,20%	81,36%	44,20%	67,24%	
50%	49,96%	64,55%	42,74%	63,92%	-5,96%
LSR					
-50%	11,08%	2,46%	6,90%	1,97%	-5,13%
0	15,83%	7,39%	13,79%	5,91%	
50%	17,80%	14,78%	16,09%	7,88%	3,41%
SC					
-50%	0,38%	0,57%	0,31%	0,43%	-4,76%
0	4,21%	8,29%	2,19%	6,03%	
50%	7,28%	12,89%	4,44%	9,34%	3,30%
TC					
-50%	0,38%	0,57%	0,31%	0,43%	-4,76%
0	4,21%	8,29%	2,19%	6,03%	
50%	7,28%	12,89%	4,44%	9,34%	3,30%
Rail					
-50%	59,99%	69,34%	53,88%	63,98%	10,17%
0	41,76%	63,66%	39,69%	61,39%	
50%	39,14%	41,26%	37,86%	58,99%	-7,31%
Road					
-50%	29,79%	27,70%	39,23%	34,05%	-4,91%
0	43,71%	27,47%	46,52%	32,70%	
50%	44,36%	41,00%	46,05%	33,13%	3,54%
Maritime					
-50%	10,22%	2,96%	6,90%	3,94%	-4,77%
0	14,53%	8,87%	13,79%	5,91%	
50%	16,50%	17,73%	16,09%	7,88%	3,78%

4.4.1.2.2 Truck

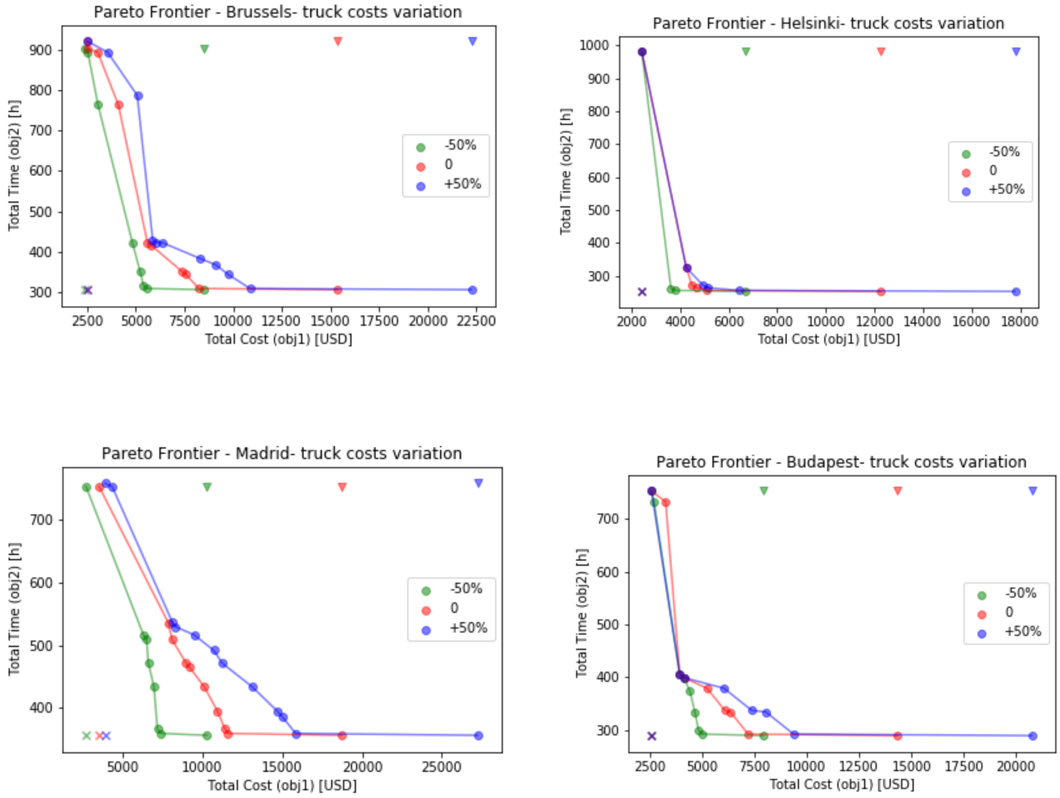


Figure 10: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the cost of road.

Figure 10 shows the variation of the Pareto frontier for the four cities of interest when the cost of the road transport varies from 50% to 150% of its original value. The curve moves from left to right when the cost increases. There is no change of transport mode in the extreme points. Madrid seems to be more affected by the change than the other cities. Helsinki's curves on the other hand are very close to each other.

Table 12 shows that the use of road is generally less affected by road cost variations than rail is affected by rail cost variations. When the cost of truck decreases, use of truck and ship increases detrimental to rail transport and reciprocally.

Regarding the route presence, the traffic switches from the TCR to the LSR especially when the cost decreases rather than the opposite.

Table 12: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when cost of trucks varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	49,24%	70,62%	42,84%	63,55%	-4,69%
0	52,20%	81,36%	44,20%	67,24%	
50%	55,58%	81,13%	46,72%	71,31%	2,44%
LSR					
-50%	20,38%	12,32%	18,39%	9,85%	4,51%
0	15,83%	7,39%	13,79%	5,91%	
50%	11,27%	7,39%	9,20%	1,97%	-3,27%
SC					
-50%	5,36%	9,77%	4,08%	6,90%	1,34%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,21%	7,14%	3,13%	6,47%	0,06%
TC					
-50%	5,36%	9,77%	4,08%	6,90%	1,34%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,21%	7,14%	3,13%	6,47%	0,06%
Rail					
-50%	35,73%	40,28%	37,01%	56,71%	-9,19%
0	41,76%	63,66%	39,69%	61,39%	
50%	55,61%	63,89%	51,71%	65,46%	7,54%
Road					
-50%	45,61%	44,94%	44,60%	33,44%	4,55%
0	43,71%	27,47%	46,52%	32,70%	
50%	33,98%	27,24%	39,10%	32,57%	-4,38%
Maritime					
-50%	18,66%	14,78%	18,39%	9,85%	4,64%
0	14,53%	8,87%	13,79%	5,91%	
50%	10,41%	8,87%	9,20%	1,97%	-3,17%

4.4.1.2.3 Ship

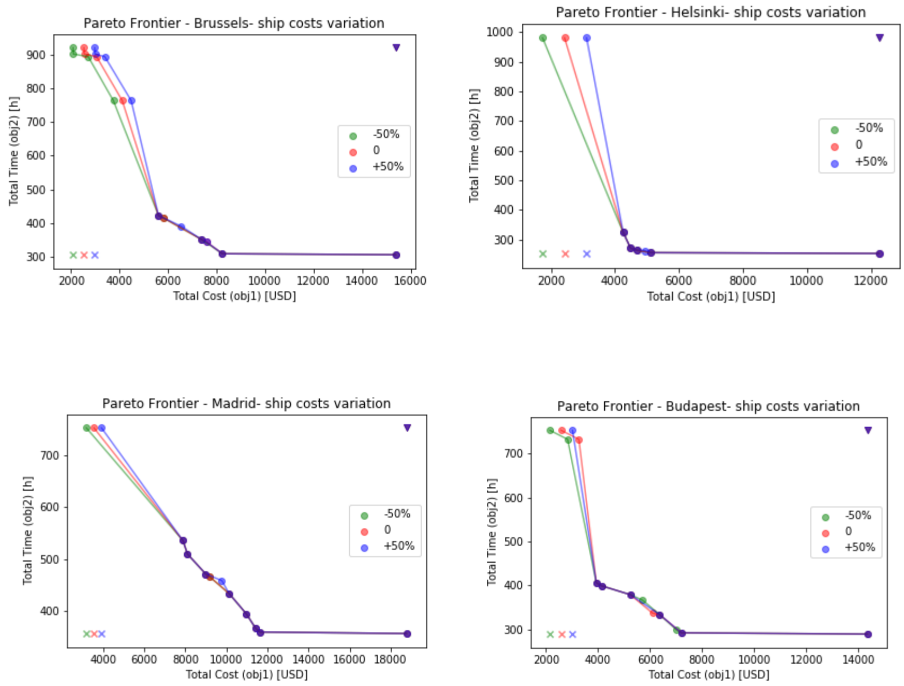


Figure 11: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the cost of sea.

Figure 11 shows the variation of the Pareto frontier for the four cities of interest when the cost of the maritime transport varies from 50% to 150% of its original value. The curve barely moves. There is no noticeable change in transportation choice.

Table 13 shows that ship variations generally have marginal effects on the transport mode choice except for Helsinki where the weight of the LSR solutions, and consequently the maritime transport use, increases noticeably.

Table 13: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when cost of ships varies.

Variations	Brussels	Helsinki	Madrid	Budapest	Average
TSR					
-50%	52,34%	75,45%	42,62%	67,36%	-1,81%
0	52,20%	81,36%	44,20%	67,24%	
50%	52,34%	80,79%	44,36%	71,55%	1,01%
LSR					
-50%	15,83%	12,32%	16,09%	5,91%	1,81%
0	15,83%	7,39%	13,79%	5,91%	
50%	15,83%	7,39%	13,79%	1,97%	-0,99%
SC					
-50%	4,60%	7,31%	2,19%	6,47%	-0,04%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,60%	8,37%	2,51%	7,33%	0,52%
TC					
-50%	4,60%	7,31%	2,19%	6,47%	-0,04%
0	4,21%	8,29%	2,19%	6,03%	
50%	4,60%	8,37%	2,51%	7,33%	0,52%
Rail					
-50%	42,00%	58,44%	37,16%	61,70%	-1,80%
0	41,76%	63,66%	39,69%	61,39%	
50%	41,09%	62,63%	39,50%	65,21%	0,48%
Road					
-50%	43,47%	26,78%	46,75%	32,39%	-0,25%
0	43,71%	27,47%	46,52%	32,70%	
50%	44,38%	28,51%	46,71%	32,82%	0,50%
Maritime					
-50%	14,53%	14,78%	16,09%	5,91%	2,05%
0	14,53%	8,87%	13,79%	5,91%	
50%	14,53%	8,87%	13,79%	1,97%	-0,99%

4.4.1.3 Summary and Hypotheses Confrontation

The LSR presence is more impacted by a variation in train or truck speed than a respective cost variation. It is however not impacted by variations in ship parameters. It increases when rail speed increases or truck speed decreases. It increases when rail cost increases and truck cost decreases.

There seems to be a trade-off between the LSR and the TSR. Depending on the variation, the traffic switches from one corridor to the other. This switch is impacted more by variations in inland speed than inland cost. Regarding speed variation, the traffic switches from the TSR to the LSR for an increase in train speed, and from the LSR to the TSR for a decrease in truck speed.

Regarding inland variations, ship preference seems to be positively correlated with train preference when there is a variation in speed, and positively correlated with truck preference when there is a variation in cost. On the other hand, there seems to be a trade-off between the rail and road preference as they remain negatively correlated in either situation.

Variations in ship parameters appear to barely affect the Pareto set. The H4 is then confirmed. However, ship preference seems to be affected mostly by variations in speed of inland transportation. That means that H3 is not verified. Sea transport seems to be as sensitive as road and rail to cost and speed variations. Nevertheless, the model is less sensitive to variations in maritime cost and speed than truck and rail.

H3: Sea transport is less sensitive to cost and time variations than truck and rail transport.

H4: The model is not affected by variations in ship speed or cost.

It also means that H1 and H2 are partially confirmed. If rail and road transport preferences increase and decrease indeed when their speed and their cost increase respectively, sea transport is more affected by other transportation parameters variations than ship parameters variations.

H1: Preference to a transportation mode decreases when its cost increases.

H2: Preference to a transportation mode increases when its speed increases.

Regarding transportation modes, it is observed that a decrease in cost of inland transportation has slightly more impact than an increase. Moreover, an increase of train speed has more impact than a decrease while it is the opposite for trucks. Ship is more impacted by inland speed variation than train but less than truck. Ship seems also to be more affected by inland speed variation than by inland cost variations.

In terms of 50% variations for solutions including Brussels, Helsinki, Madrid and Budapest as destination, a decrease in train speed results in the highest increase in truck preference. The decrease in truck preference generated by an increase in train speed is bigger than the increase in truck preference generated by a decrease in train speed, while the biggest decrease in truck preference is caused by a decrease in truck speed. Truck preference seems to be more impacted by train speed variations. More generally, truck seems more impacted by inland speed variation than train. It is also observed that a 50% truck speed decrease seems to have no impact on the model.

Regarding train preference, it seems to be more impacted by cost variations as the biggest increase is generated by a reduction in train cost, and the biggest decrease results from a decrease in truck cost. In general, train transport seems more impacted by inland cost variation than truck.

If this section focuses on transportation modes and routes relationship to cost and time, the next section highlights the relationships between of the EU capitals geographical positions and the route preferences.

4.4.2 EU regions

4.4.2.1 Sensitivity to EU capitals geographical location

In this section, the EU is divided into 4 regions: North, West, South, East. A set of EU capitals is assigned to each region. The Northern EU capitals set includes Helsinki, Stockholm, Copenhagen, Warsaw, Riga, Tallinn, Vilnius. The Western EU capitals set includes Berlin, Amsterdam, Paris, Brussels, London, Dublin. The Southern EU capitals set includes Madrid, Lisbon, Roma, Zagreb, Athens, Ljubljana. The Eastern EU capitals set includes Budapest, Bucharest, Sofia, Prague, Bratislava, Vienna.

Figure 12 shows the Pareto frontier for each capital in each region. The axis ranges differ between the regions. As a general trend, the slowest solutions for Northern capitals are slower than the slowest solutions of the others while the most expensive solutions are cheaper than the others. In the Western region, Dublin seems to be the outlier with higher costs and times while in the Southern region, the curve of Athens is leaner than the others. Otherwise, the regions seem rather homogeneous.

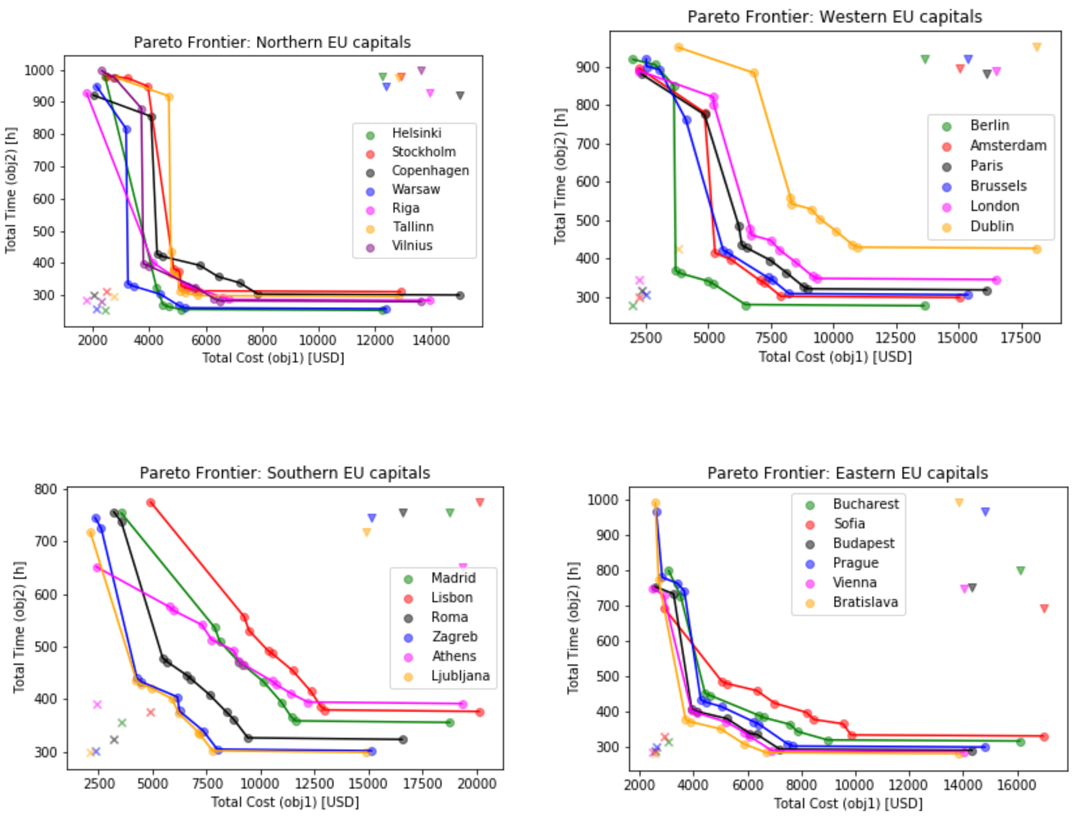


Figure 12: Pareto frontier, Utopia (×) and pseudo Nadir points (▽) of the EU regions.

Table 14 indicates the weighted average of the presence of each route and transportation mode in the Pareto set of each capital and region. Details are available in Appendix 3. On average, the TSR is mostly present in Northern region Pareto sets while the LSR is mostly present in Western region Pareto sets. The SC and TC remain absent.

The TSR and the rail transportation mode are the most present in the Pareto set of all the regions.

Regarding the transportation modes, rail transport is most present in the North, followed by the East, the West and finally the South. Road transport is mostly present in the South, the West, closely followed by the East and finally the North. Sea transport is mostly present in the West, the North, the South and finally the East.

Table 14: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route for EU regions.

Cities/Regions	TSR	LSR	SC	TC	rail	road	sea
Helsinki	81,36%	7,39%	8,29%	8,29%	63,66%	27,47%	8,87%
Stockholm	64,81%	11,99%	6,40%	6,40%	50,49%	24,74%	24,77%
Copenhagen	57,28%	10,25%	4,21%	4,21%	60,58%	30,65%	8,77%
Warsaw	88,07%	10,40%	8,62%	8,62%	66,71%	24,37%	8,92%
Riga	67,49%	8,62%	8,00%	8,00%	60,59%	28,82%	10,59%
Tallinn	62,15%	8,54%	6,01%	6,01%	58,33%	23,56%	18,10%
Vilnius	65,03%	7,72%	6,47%	6,47%	60,63%	31,65%	7,72%
North	**69,46%**	**9,27%**	**6,86%**	**6,86%**	**60,14%**	**27,32%**	**12,53%**
Berlin	74,81%	10,25%	6,90%	6,90%	65,45%	25,78%	8,77%
Amsterdam	60,94%	16,16%	5,17%	5,17%	51,39%	34,91%	13,69%
Paris	48,73%	13,30%	4,14%	4,14%	42,18%	44,52%	13,30%
Brussels	52,20%	15,83%	4,21%	4,21%	41,76%	43,71%	14,53%
London	47,31%	15,76%	4,14%	4,14%	48,70%	35,54%	15,76%
Dublin	39,13%	12,34%	3,74%	3,74%	46,07%	32,43%	21,50%
West	**56,08%**	**13,27%**	**5,02%**	**5,02%**	**50,81%**	**34,89%**	**14,30%**
Madrid	44,20%	13,79%	2,19%	2,19%	39,69%	46,52%	13,79%
Lisbon	39,27%	11,82%	2,01%	2,01%	35,61%	52,57%	11,82%
Roma	51,55%	7,88%	3,79%	3,79%	53,85%	38,26%	7,88%
Zagreb	59,24%	5,91%	4,60%	4,60%	57,57%	36,52%	5,91%
Athens	38,59%	14,37%	2,12%	2,12%	48,08%	40,43%	11,49%
Ljubljana	59,63%	6,90%	4,98%	4,98%	56,90%	36,21%	6,90%
South	**49,79%**	**10,56%**	**3,53%**	**3,53%**	**48,93%**	**40,77%**	**10,30%**
Budapest	67,24%	5,91%	6,03%	6,03%	61,39%	32,70%	5,91%
Bucharest	57,33%	7,76%	4,60%	4,60%	60,87%	32,23%	6,90%
Sofia	51,86%	9,85%	4,14%	4,14%	52,39%	39,73%	7,88%
Bratislava	72,19%	9,48%	6,40%	6,40%	64,59%	26,35%	9,05%
Prague	53,88%	11,21%	4,60%	4,60%	55,41%	33,81%	10,78%
Vienna	67,36%	5,91%	6,47%	6,47%	61,15%	32,94%	5,91%
East	**59,95%**	**8,67%**	**5,11%**	**5,11%**	**57,82%**	**34,08%**	**8,10%**

4.4.2.1.1 European hubs

Table 15 shows the top most travelled TEN-T cities for each region, which are referred to as regional 'hubs' in this paper. Warsaw ranks first in every region of the simulation. Details can be seen in Appendix 3.6. Except for Warsaw, there is a clear difference in the main regional hubs depending on the region. It is worth noting that in the North, two of the top hubs are ports.

Table 15: Top 4 hubs per region according to non weighted Pareto set.

North	West	South	East
Warsaw	Warsaw	Warsaw	Warsaw
Kaunas	Berlin	Bratislava	Bratislava
Helsinki	Brussels	Vienna	Budapest
Riga	Madrid	Budapest	Ljubljana
Kouvola	Bucharest	Venice	Trieste

4.4.2.2 Southern region

If all regions seem relatively homogeneous, it may be interesting to discuss the case of the Southern region more in depth. The curve of Athens is leaner than the others (see Figure 12). It means that the solutions are closer to each other in terms of time. Transportation time from China to Athens varies less with different solutions than other cities. This is due to the fact that Athens is the closest capital on the sea route, hence the fastest delivered by sea. As the sea delivery is faster in Athens than in the other cities, the gap between rail and sea delivery is smaller for Athens but rail delivery is not necessarily faster than other destinations.

As Athens is an interesting case, it is examined closely in the next section.

4.4.2.2.1 Discussion: Athens

To discuss the case of import from China to Athens, the perspective of an MTO – single decision-maker of the routing planning problem - is taken via four concrete examples.

Table 16 summarizes both the Pareto set of Athens as a destination and the results of the selection methods. The total cost of travel oscillates between 2387 and 19316 USD while the total time of travel oscillates between 392 and 652 hours, i.e. 16 days and 27 days. The solution with the highest weight is solution No. 3 which is optimal 9 times on the 29 optimizations. No. 3 is also the optimal solution in terms of maximal distance to the pseudo Nadir point, while solution No. 6 is the closest to the Utopia point. With regard to the NWSA, No. 3 is optimal when 40 to 50% weight is given to the first objective, whereas No. 4 is optimal from 60% weight on the first objective. The mapping of those solutions is presented in Appendix 3.3.2. Theoretically, solution No. 3 seems to be the best solution but in practice, it is not especially the case as shown in the following examples.

Example 1: import 1 TEU of raw materials.

Raw materials are inexpensive. It is a product with a low profit margin. Therefore, the MTO is likely to choose the solution with the lowest cost, namely solution No. 1 that takes the LSR (see Appendix 3.3.2). In this case, the total cost objective is probably significantly more important that the total time objective.

Example 2: import 1 TEU of clothes with medium profit margin for the opening of new collection in three weeks.

In this situation, time is important because the clothes must be in the shop for the opening of the new collection. The opening is in three weeks, i.e. 21 days, and the customer needs the clothes a few days prior to the opening to set up the store. Therefore, the MTO can consider 19 days as the maximum time of travel, i.e. 456 hours. In the Pareto set, the MTO needs to select a solution amongst the solutions with a total time lower than 456 hours. In that case, the MTO is likely to choose a solution obtained via ECM, where the constraint on the time is the closest to 456 hours, while smaller. In table 16, ECM solution No. 5 is optimal when the cost is minimized, given the constraint that the total time must not exceed 444 hours. The MTO is likely to select No.5 that represents 435 hours and 10533 USD. This may be too expensive for a customer who deals a medium profit margin product. If so, the MTO has to explain to the customer that if the goods can be delivered 1.5 days later, the cost savings can amount to 1300 USD and more (solution No. 6) and up to 1800 USD if 2.5 days later (solution No. 7). In fact, the road transport gives way to rail transport gradually from solution No. 5 to No.7 (see Appendix 3.3.2).

Example 3: import 1 TEU of perishable foodstuff with average-level profit margin and a 1-month selling period.

In this case, both time and cost are important here. The foodstuff does not have a significant margin but it is perishable. Obviously, there is a time-constraint that the MTO can set at about 23 days, i.e. 552 hours, giving the fact that the customer needs time to sell the foodstuff. Consequently, the MTO is likely to consider the solutions that minimize the cost given the time-constraint, similar to example 4. This is why, the MTO probably selects solution No. 9 of 541 hours for 7275 USD. However, if the customer agrees for the travel time to be extended by slightly more than one day, cost savings amount to 1300 USD (solution No. 10). As the profit margin is average, the customer may be interested in this solution. The difference comes from the fact that solution No. 10 only includes rail transport while No. 5 has a road portion (see Appendix 3.3.2).

Example 4: import 1 TEU filled with machines intended for a relatively urgent technical intervention in the factory.

These machines are high-value goods and capital intensive. In that case, the MTO knows that the faster, the better. As the goods are high-value, they are not as cost-sensitive as in the previous examples. The fastest the MTO can get the machines to Athens is 392 hours (solution

No. 2). However, the MTO may also suggest solution No.3 as delivery time takes only 3 hours more to reach the destination for 7135 USD less because of one rail portion instead of road.

In a nutshell, the examples above give a concrete aspect to the Pareto set. Factors such as the product type or the intended purpose of the product can be translated into cost and time constraints for the MTO. In addition, in real life, the MTO also has to take into account other factors that are not always translatable into cost and time constraint such as security, delays, environment, vulnerability to damage, size, etc.

Table 16: Pareto set of Athens and selection methods.

NSWA/ ECM	No.	OBJ1	OBJ2	Weight	Distance Utopia	Distance Nadir	40% on obj1	50% on obj1	60% on obj1
OBJ1	**1**	2387	652	5	1,00	1,00	0,60	0,50	0,40
OBJ2	**2**	19316	392	1	1,00	1,00	0,40	0,50	0,60
10%	**3**	12181	395	***9***	0,58	***1,07***	***0,24***	***0,29***	0,35
60%	**4**	11400	411	2	0,54	1,04	0,26	0,30	***0,35***
444	**5**	10533	435	1	0,51	0,98	0,29	0,32	0,35
470	**6**	9198	467	1	***0,49***	0,93	0,33	0,34	0,36
496	**7**	8725	493	1	0,54	0,87	0,38	0,38	0,38
522	**8**	7735	513	1	0,56	0,87	0,41	0,39	0,38
548	**9**	7275	541	2	0,64	0,83	0,46	0,43	0,40
574	**10**	5967	569	1	0,71	0,85	0,49	0,45	0,40
600	**11**	5771	575	3	0,73	0,85	0,50	0,45	0,40
9158	**12**	9002	473	1	0,50	0,92	0,34	0,35	0,36
10851	**13**	10729	428	1	0,51	1,00	0,28	0,32	0,35
	Utopia	**2387**	**392**						
	Nadir	**19316**	**652**						

4.4.2.3 South-Eastern capitals and SC and TC.

The EU capitals located in the South-East of Europe are the ones that have most likely the SC and the TC in their Pareto set. In this section, variations are applied to the speed and the cost of the arcs belonging to the SC and TC to find out the change level required by the SC and TC to appear in the Pareto set. The South-Eastern EU capitals set includes Athens, Sofia, Bucharest.

4.4.2.3.1 Variations in speed

First, variations in speed along the TC and SC, namely an increase of 50%, 100%, 200% and 400% along the TC and SC, were tested.

Figures 13 and 14 show the Pareto frontier of this city set before and after increasing the speed on the SC and TC. More details are available in appendix 3.5.1 and 3.5.2. It appears that there is no improvement in the presence of the SC or the TC in the Pareto set until the speed is increased by 400%. Regarding the presence of the SC, when the speed increases by 400%, two solutions along the SC appear in the Sofia Pareto set and one in the Athens Pareto set, while still none in the Bucharest Pareto set. On the other hand, TC becomes more popular. When the speed increase by 400%, Sofia Pareto set includes two solutions along the TC, Athens three and Bucharest one.

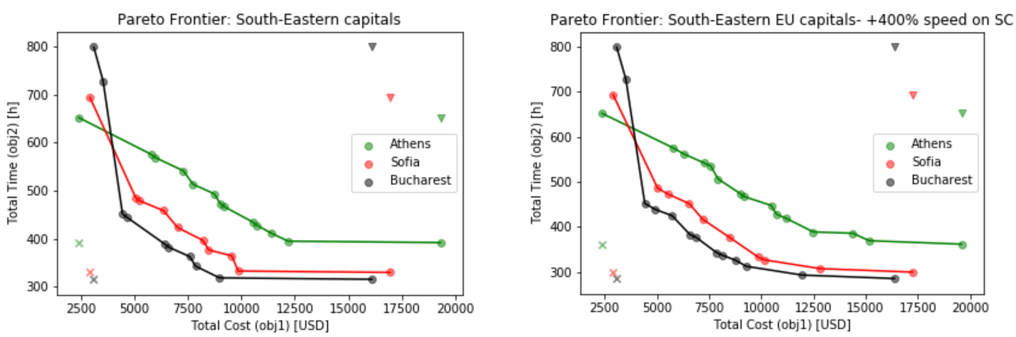


Figure 13: Pareto frontier, Utopia (×) and pseudo Nadir points (▽) of the South-Eastern EU capitals before SC and TC are altered (on the left) and when the speed on SC is increased by 400%.

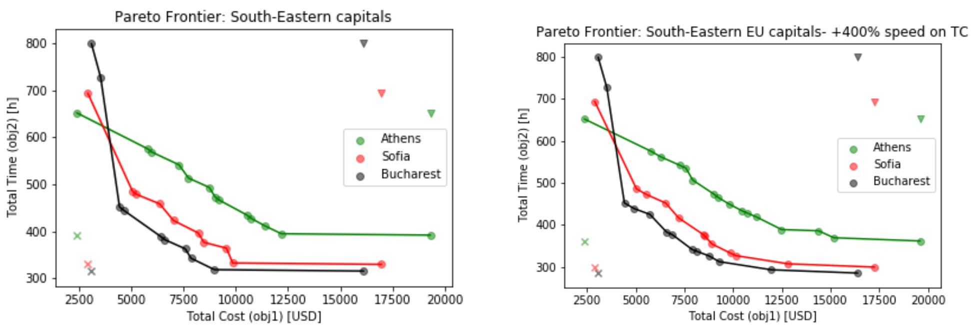


Figure 14: Pareto frontier, Utopia (×) and pseudo Nadir points (▽) of the South-Eastern EU capitals before SC and TC are altered (on the left) and when the speed on TC is increased by 400%.

4.4.2.3.2 Variations in cost

Then, cost variations, namely a decrease of 50%, 70% and 90% along the TC and SC were tested.

Figures 15 and 16 show the Pareto frontier before and after decreasing the cost on the SC and TC. More details are available in appendix 3.5.3 and 3.5.4. It appears that there is no improvement in the presence of the SC or the TC in the Pareto set until the cost is decreased by 90%, except for Sofia which has two solutions along the SC in its Pareto set when the SC cost is decreased by 70%. Regarding the presence of the SC, there is one solution in the Athens Pareto set, three in the Sofia Pareto set and two in the Bucharest Pareto set. The results for TC are similar: one for Athens, two for Sofia, two for Bucharest.

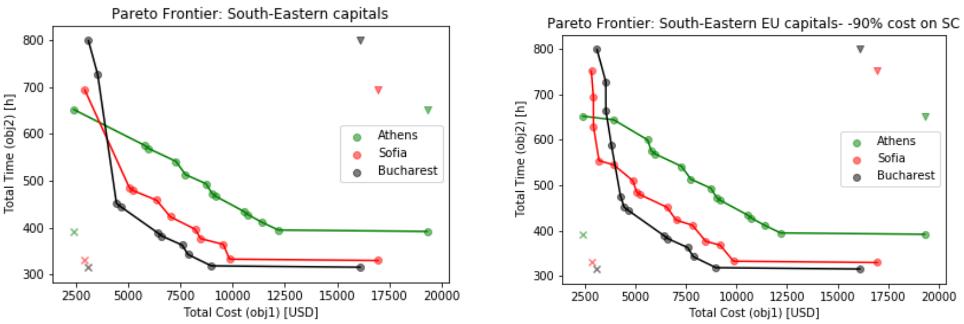


Figure 15: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) of the South-Eastern EU capitals before SC and TC are altered (on the left) and when the speed on SC is decreased by 90%.

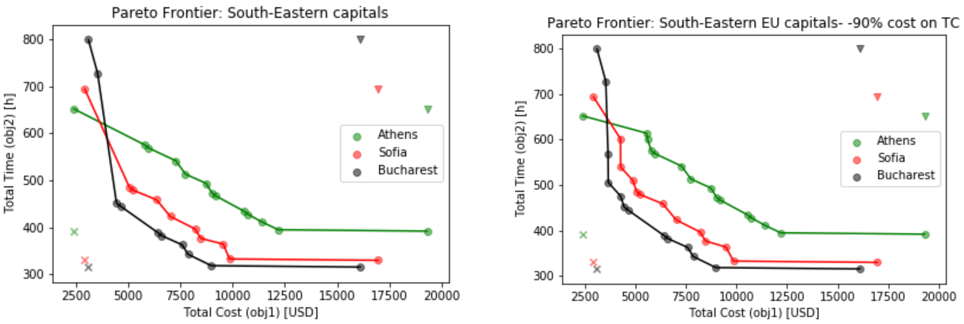


Figure 16: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) of the South-Eastern EU capitals before SC and TC are altered (on the left) and when the speed on TC is decreased by 90%.

Worth noting is that for Sofia as destination, when the LSR is used, the port of Piraeus is always the best choice except when cost on SC is reduced by 90%, then it switches to Istanbul.

4.4.2.4 Summary and hypotheses confrontation

The TSR is indisputably the route the most present in the Pareto set regardless of the regions. That means that H5, H6, H7 are confirmed. H8 is not confirmed as the Southern capitals also prefer TSR.

H5: The TSR is the route the most present in the Pareto sets of Northern EU capitals as destinations.

H6: The TSR is the route the most present in the Pareto sets of Western EU capitals as destinations.

H7: The TSR is the route the most present in the Pareto sets of Eastern EU capitals as destinations.

H8: The LSR is the route the most present in the Pareto sets of Southern EU capitals as destinations.

When studying the necessary change to make the TC and SC attractive, it is clear that the cost along the TC and SC, if alone, needs to be reduced by 90% to increase the popularity of those routes. It is also clear that the speed along the TC and SC, if alone, needs to be increased by 400% to increase the popularity of those routes. That means that the SC and TC need tremendous investment to compete with the other routes. As the level of change required by TC and SC to appear in the Pareto set is bigger than 50%, H8 and H9 are not confirmed.

H9: Solutions on the SC with 50% higher speed or lower cost appear in the Pareto set for South-Eastern capitals

H10: Solutions on the SC with 50% higher speed or lower cost appear in the Pareto set for South-Eastern capitals

4.4.3 Reality: train subsidies and truck speed

In this section, some realistic variations are studied.

4.4.3.1 Variations in train subsidies

Currently, China provides subsidies to rail transportation. However, the Chinese subsidies are about to be reduced. As stated in section 4.1, the ceiling of those subsidies is 0.8USD/KM. Therefore, it is interesting to analyse the scenarios shown in Figure 12: adding 0.8USD/km to each arc travelled by train, and deduce 0.8 USD/km, which corresponds to doubling and cancelling the subsidies respectively.

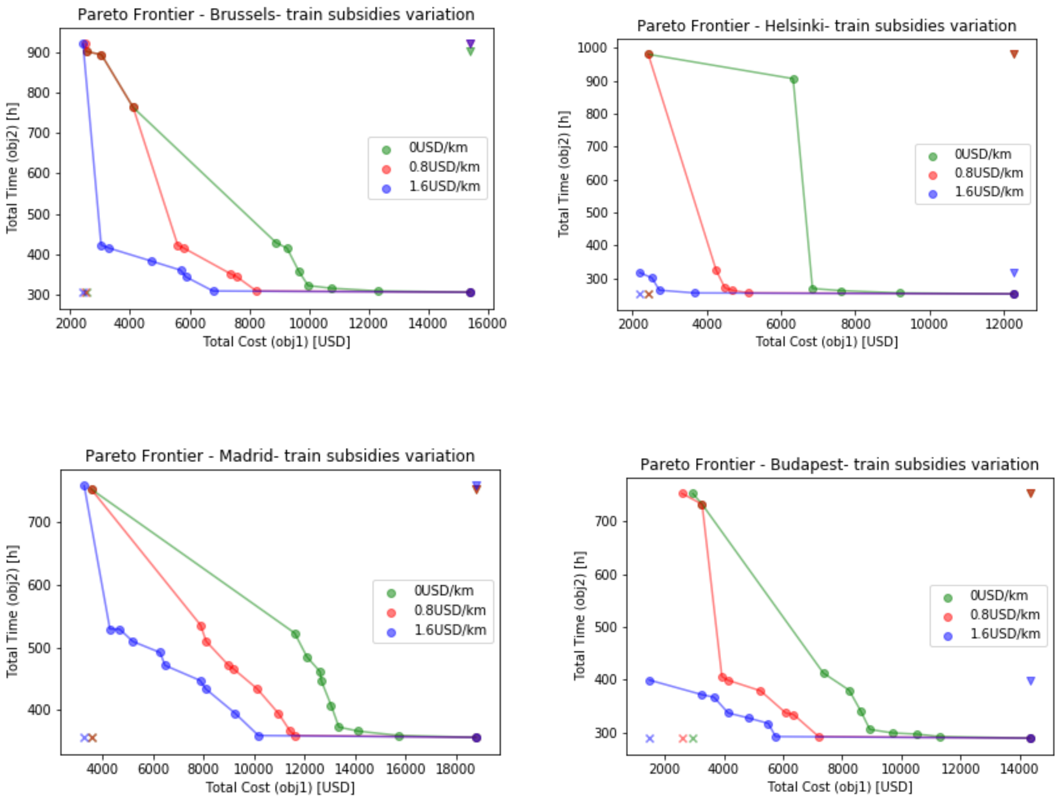


Figure 17: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the amount of train subsidies

Figure 17 shows that the Pareto frontier moves from right to left when the Chinese train subsidies increase. It means that the average cost decreases. Comparing Figure 17 with Figure 9, it appears that variation in subsidies represents more than 50% of the current cost. The impact on transport preference is then expected to be bigger than in section 4.4.

According to the previous sensitivity analysis, it is expected that train is more impacted by the elimination of subsidies than truck. The use of train should be positively correlated to the amount of subsidies.

Table 17 shows that the cancellation of subsidies has more impact than its doubling. The abolition dramatically affects the train preference that is only slightly affected by the doubling of the subsided amount. Maritime preference is positively affected by a removal of the subsidies. The road transport is positively affected whatever variation. Regarding the use of route, the TSR preference is considerably affected by the withdrawal of subsidies while some traffic is transferred from LSR to TSR when the subsidies are doubled.

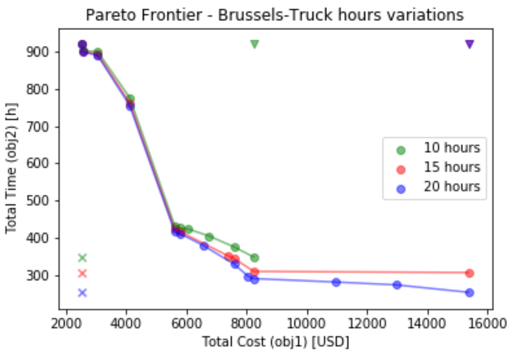
Table 17: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when subsidies of trains varies.

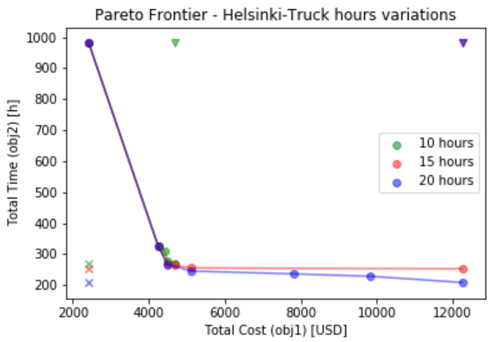
Train subsidies	**Brussels**	**Helsinki**	**Madrid**	**Budapest**	**Average**
TCR					
1.6 USD/km	60,92%	80,80%	47,86%	71,55%	4,03%
0.8 USD/km	52,20%	81,36%	44,20%	67,24%	
0 USD/km	44,79%	55,40%	38,98%	55,50%	-12,58%
LSR					
1.6 USD/km	2,59%	0,00%	4,60%	0,00%	-8,93%
0.8 USD/km	15,83%	7,39%	13,79%	5,91%	
0 USD/km	22,35%	19,54%	22,99%	13,79%	8,94%
SC					
1.6 USD/km	0,38%	0,57%	0,31%	0,43%	-4,76%
0.8 USD/km	4,21%	8,29%	2,19%	6,03%	
0 USD/km	10,80%	15,52%	8,41%	13,98%	7,00%
TC					
1.6 USD/km	0,38%	0,57%	0,31%	0,43%	-4,76%
0.8 USD/km	4,21%	8,29%	2,19%	6,03%	
0 USD/km	10,80%	15,52%	8,41%	13,98%	7,00%
Rail					

1.6 USD/km	65,47%	51,61%	52,61%	46,24%	2,36%
0.8 USD/km	41,76%	63,66%	39,69%	61,39%	
0 USD/km	33,16%	34,60%	32,71%	48,10%	-14,48%
Road					
1.6 USD/km	32,38%	48,39%	42,79%	53,76%	6,73%
0.8 USD/km	43,71%	27,47%	46,52%	32,70%	
0 USD/km	46,21%	41,84%	44,30%	38,10%	5,01%
Maritime					
1.6 USD/km	2,16%	0,00%	4,60%	0,00%	-9,09%
0.8 USD/km	14,53%	8,87%	13,79%	5,91%	
0 USD/km	20,63%	23,56%	22,99%	13,79%	9,47%

4.4.3.2 Variation in truck working hours

One assumption of the model is to consider a day of 15 hours for truck driver to adapt the average speed. It has been previously observed that ship preference is positively correlated to truck train and train preference negatively correlated to truck preference when there is a 50% variation. When truck speed increases, it is expected that ship preference increases and train preference decreases, and reciprocally. In this section, a realistic variation based on previous assumptions is considered, namely 10 hours and 20 hours.





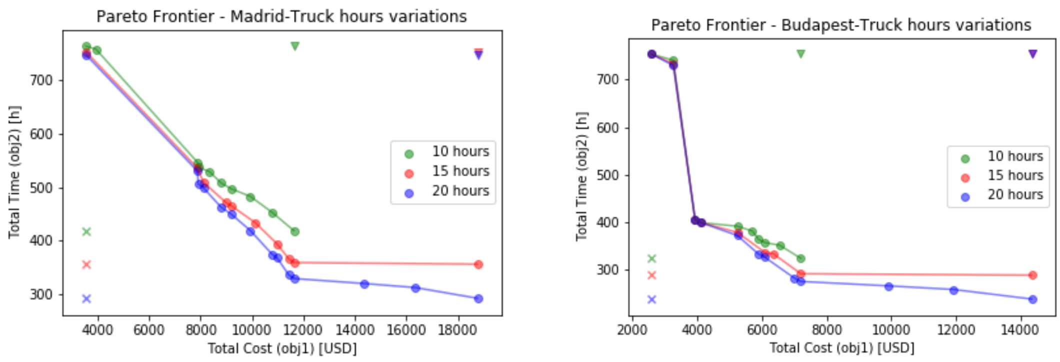


Figure 18: Pareto frontier, Utopia (×) and pseudo Nadir points (∇) sensitivity to the truck speed

According to the previous sensitivity analysis, it is expected that a decrease in the hours/day ratio of truck drivers has more impact on the model than an increase. Road is also expected to be more affected than rail. Sea transport is also expected to be more affected than train but less than truck.

Table 18 indicates that a decrease in the ratio is indeed more impactful than an increase. A decrease in the ratio induces a transfer of traffic from the TSR to LSR. The switch is then more from truck to ships than from truck to train. Rail gets some traffic but less than ships. An increase in the ratio has neglectable impact.

Table 18: weighted average on the 29 solutions of the proportion of arcs using each mode of transportation and belonging to each BRI route when the hours/day of truck drivers varies.

Truck hours	Brussels	Helsinki	Madrid	Budapest	Average
TCR					
10 hours	45,28%	58,59%	40,39%	63,55%	-9,30%
15 hours	52,20%	81,36%	44,20%	67,24%	
20 hours	52,79%	80,43%	46,87%	67,16%	0,56%
LSR					
10 hours	24,51%	32,02%	22,99%	9,85%	11,61%
15 hours	15,83%	7,39%	13,79%	5,91%	
20 hours	15,83%	7,39%	13,79%	5,91%	0,00%
SC					
10 hours	3,83%	7,72%	3,76%	6,90%	0,37%
15 hours	4,21%	8,29%	2,19%	6,03%	
20 hours	5,47%	11,49%	4,76%	8,43%	2,36%
TC					
10 hours	3,83%	7,72%	3,76%	6,90%	0,37%
15 hours	4,21%	8,29%	2,19%	6,03%	

20 hours	5,47%	11,49%	4,76%	8,43%	2,36%
Rail					
10 hours	46,09%	56,17%	47,05%	74,69%	4,38%
15 hours	41,76%	63,66%	39,69%	61,39%	
20 hours	40,05%	60,57%	37,65%	58,55%	-2,42%
Road					
10 hours	31,12%	5,40%	29,96%	15,46%	-17,12%
15 hours	43,71%	27,47%	46,52%	32,70%	
20 hours	45,42%	30,56%	48,56%	35,54%	2,42%
Maritime					
10 hours	22,78%	38,42%	22,99%	3,94%	11,26%
15 hours	14,53%	8,87%	13,79%	5,91%	
20 hours	14,53%	8,87%	13,79%	5,91%	0,00%

4.4.4 Discussion and conclusion of the analysis

In this section 4, the Pareto set of four cities - Brussels, Helsinki, Madrid and Budapest - is built and observed. To select the best solution of a Pareto set, there are several methods that are developed. Those methods are applied on the Pareto set of the four cities. Even if such methods can theoretically help finding the best solution of set, all the solutions of the set are optimal solutions for at least one situation, for at least one combination of needs. In practice, the best solution of the set is left to the MTO to decide.

In this first phase, several observations are made. First, there is a clear trade-off between minimizing the total cost and the total time. When one increases, the other decreases. Secondly, the Southern and Trans-Caspian corridors are not part of any Pareto set. Thirdly, it is observed that sea transport is chosen when the first objective – the total cost - is primarily minimized, while road transport is preferred when the second objective – the total time – is mainly minimized. Rail transport is preferred more in more of a situation of compromise. That means that sea transport is cheaper and slower than inland transport, while road is more expensive but faster that rail with regard to inland transportation.

Based on those observations, ten hypotheses have been made, on the sensitivity of transportation modes to cost and speed variations, the sensitivity of the corridors to the region of the destination, and on the change needed to make the SC and TC optimal solutions. Finally the findings were confronted to realistic variations on train subsidies and the ratio hours/day of truck drivers.

With regard to transportation modes, it is observed that train seems to compete with truck regarding the speed. Indeed, truck preference is negatively impacted particularly by an increase in train speed. Train also seems to be more affected by a decrease in inland cost transportation. It is also observed that ship preference is more affected by an increase in train speed or a decrease in truck speed. In general, an increase of train speed has more impact than a decrease. It is the opposite for trucks. As a general trend, it is concluded that rail and road transport preferences increase and decrease when their speed and their cost increase respectively. Moreover, it seems that variation in ship parameters have a neglectable effect on the optimisation results. As the world currently faces an environmental crisis, environmentally friendly policies are implemented towards international transportation such as a fuel-saving policy concerning sea freight that reduces the average ship speed. According to the simulation results, this policy is unlikely to impact the routing planning decisions.

When confronting those findings to realistic situation, the conclusion is that the cancellation of train subsidies dramatically affects the train preference that is only slightly affected by the doubling of the subsided amount. Maritime preference is positively affected by a withdrawal of the subsidies. Therefore, in the Pareto solutions, the weight of sea solutions increases when the subsidies are removed. It can then be expected that it is translated in reality by a transfer of a part of the traffic from rail to ship. However, preference for quality (time) over cost in transportation mode choice is stated in the relevant literature. As rail transport remains faster than sea transport, the transfer of traffic may be less than expected by the model.

It was also observed that a decrease in the number of hours a truck driver can drive per day moves traffic more from truck to ship than from truck to train.

Regarding the corridors, the TSR is indisputably the route which is the most present in the Pareto set of all the regions. Nevertheless, there seems to be a trade-off between the LSR and the TSR. Depending on the variation, the traffic switch from one corridor to the other. This switch is more impacted by variations in inland speed than inland cost. Regarding speed variation, the traffic switches from the TSR to the LSR for an increase in train speed, and from the LSR to the TSR for a decrease in truck speed. Unlike the TSR and the LSR, the TC and the SC are not very present in the Pareto sets. When studying the necessary change to make the TC and the SC attractive for South-Eastern capitals, it is clear that the cost along the TC and the SC, if alone, needs to be reduced by 90% to increase the popularity of those routes. It is also clear that the speed along the TC and SC, if alone needs to be increased by 400% to increase the popularity of those routes. That means that the SC and the TC need enormous investment to compete with the other routes. As a matter of fact, the Southern and Trans-Caspian corridors are not very popular in reality. Those routes are hardly used. That can be explained by a variety of factors: political instability, poor infrastructure hindering the speed, border crossings, transhipments, the risks of delay related to sea ferry crossings… China does not currently provide subsidies for those routes as they are not sufficiently attractive at the moment (Jakóbowski et al., 2018).

When variations are applied on the train subsidies, it appears that the TSR preference is greatly affected by the suppression of subsidies while some traffic is transferred from the LSR to the TSR when the subsidies are doubled. The TSR will be less competitive to the LSR if subsidies decrease. It is also observed that a decrease in the number of hours a truck driver can drive per day induces a transfer of traffic from the TSR to the LSR.

Currently, most of the trade traffic is done by sea. The stake is then to move a part of the traffic from that route to an inland route. If the Chinese government plans to eventually cancel train subsidies, they should invest in something else, such as reducing the border crossing or transhipment costs, to reduce the cost along the TSR. However, it is observed that a reduction in subsidies is more impactful than an increase in subsidies, that a reduction in driving time is more impactful than an increase. Both seem to have a concave function in which the popularity of a transport mode or route improves less than it degrades for the same variation. Therefore, the Chinese government will have to put more effort to compensate the loss of subsidies. When subsidies are cancelled, it is not possible to compensate a transfer of traffic from the LSR to the TSR by improving the infrastructure resulting in increasing the speed of train along the TSR because the weighted sensitivity results show that an increase in train speed increase the LSR preference. In order to decrease the cost – and increase the speed – along the inland corridors, customs clearance can be simplified, business standards set, an infrastructure for freight train only can be built to avoid the delay due to the fact that passenger trains have priority on freight trains, the existing infrastructure can be modernized, an alliance of transport companies can be formed to coordinate the transport of goods, non-stop goods tracking and information exchange systems can be developed to facilitate customs control, etc.

The preference variations are estimates of the variation of the real trade traffic on the corridor. In the model, the weight of a solution can be considered as the probability to be chosen, even though it does not match reality as the weighted average presence of the LSR is always smaller than the weighted average presence of the TSR in the model, while the LSR represents 90% of the trade in reality. Therefore, at the level of an MTO, the decision will entirely depend on the needs and preferences of the customer, and on the particularities of the goods, as it is discussed in the case of Athens. For instance, clothes need to be delivered faster to follow the latest fashion so the MTO might prefer inland transportation to ship transportation. Perishable goods such as food most likely also choose a fast transportation mode. If the customer of the MTO strives to take the most sustainable alternative, the MTO is most likely going to choose an intermodal solution where road transport is used only for last-mile delivery. In addition, the MTO also has to take into account other factors that are not always translatable into cost and time constraint such as security, delays, environment, vulnerability to damage, size, etc.

5. Conclusion

In this paper, the BRI is studied via an intermodal bi-objective optimization model considering the total cost and total time of travel. The purpose of this paper is to answer the following questions:

- How does the cost-time trade-off affect the routing planning decisions regarding the BRI?
- How can the current BRI-related topics affect those decisions in a cost-time perspective?

Referring to first question, the cost-time trade-off affects the routing planning decisions regarding the BRI in many ways. First, cost and time are important factors to consider in the MTO’s routing planning decision-making process. The MTO needs to clearly prioritise the needs in terms of cost and time, which depend on many other factors that can be translated into time or cost priority such as the product type, its intended purpose, etc. Then, the cost-time trade-off also affects the choices of transportation modes and routes, as well as intermodal choices. This is due to the fact that each transportation mode and route has its own relationship to cost and time in terms of sensitivity and order of magnitude. For instance, rail is faster than sea but slower than road. If the cost-time trade-off is properly considered - with Pareto optimality for instance - when choosing and combining the transportation modes, the MTO gains flexibility and clairvoyance in the decision-making process that allow him to select a solution that best suits his needs.

Regarding the second question, the sensitivity analysis conducted on the BRI case can give insights on the impact of many current BRI-related topics on routing planning decisions in a cost-time perspective. For instance, the Chinese cut in train subsidies is a current BRI topic. It affects the routing planning decisions in favour of the Land-Sea Route because the Trans-Siberian Route becomes less competitive. Nevertheless, this impact is to be mitigated because some aspects are not taken into account in the analysis. For instance, some goods are not cost-sensitive and the decision related to those are therefore not impacted by a variation in train subsidies. The sensitivity analysis conducted in this paper can help grasp the impact of other BRI-current topics. For example, the fuel-saving policy applied to sea freight is likely to have only a marginal effect on the routing planning decision in a cost-time perspective.

The advantages of a simulation such as this one is that it allows to model international flows and to help understanding the impact of variations in factors such as subsidies, quality of infrastructure, customs regulations, etc. It gives realistic measures of the total cost and time of travel considering aspects such as change of gauge, transhipment, waiting time, etc. Even if those measures may be realistic, they can also be inexact. Indeed, that kind of simulation and network analysis has also limitations. It is important to remember that a simulation network is a simplified version of reality. The results greatly depend on the data quality. A number of factors are not taken into account such as schedules, passenger lines, climate, etc. The BRI projects also touch aspects that are hard to quantify such as customs efficiency. This is why the simulation results have to be mitigated.

The contribution of this paper to the literature is plural. Firstly, it gives an up-to-date literature review of the intermodal freight transportation and multi-objective optimisation research fields. Secondly, the BRI is a relatively new research field as the project was only launched in 2013 so there are few existing case studies. Moreover, our paper focuses on a new case (the routes between China and many EU capitals), linked to current BRI topic such as the reduction of the train subsidies. Thirdly, the dataset used in this paper brings new data to the literature. Fourthly, the analysis of the network takes into account aspects - via the dataset - that are usually neglected such as border crossing procedures and change of gauge. Finally, the paper supports the decision making process related to routing planning problems in an international and intermodal context by analysing a concrete case study of the BRI in light of the Pareto optimality and by providing insights on the relationship between transportation modes and routes, and the travel total cost and time.

It is complicated to gain a broad knowledge on ports, stations, etc. worldwide under normal circumstances but in times of COVID 19, it has been even harder. Consequently, the dataset consists of many estimates and its accuracy is relative. For further research, it would then be interesting to build a more precise dataset and to perform the same analysis. It would also be interesting to consider other objectives such as carbon emissions, risk and operational complexity, and to consider other transportation modes such as inland waterways and airways.

6. References

Asian Development Bank. (2019). *CAREC Corridor Performance Measurement And Monitoring Annual Report 2018*. Retrieved from

Baker McKenzie. (2017). *Belt & Road: Opportunity & Risk. The prospects and perils of building China's New Silk Road*. Retrieved from https://www.bakermckenzie.com/-/media/files/insight/publications/2017/10/belt-road/baker_mckenzie_belt_road_report_2017.pdf?la=en

Ben-Tal, A. (1980). Characterization of Pareto and Lexicographic Optimal Solutions. In G. Fandel & T. Gal (Eds.), *Multiple Criteria Decision Making Theory and Application* (pp. 1-11): Springer Berlin Heidelberg.

Boros, E., Lei, L., Zhao, Y., & Zhong, H. (2008). Scheduling vessels and container-yard operations with conflicting objectives. *Annals of Operations Research, 161*(1), 149–170. doi: 10.1007/s10479-007-0260-7

Caris, A., Macharis, C., & Janssens, G. K. (2008). Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects. *Transportation Planning and Technology, 31*(3), 277-302. doi:10.1080/03081060802086397

Cheaitou, A., & Cariou, P. (2019). Greening of maritime transportation: a multi-objective optimization approach. *Annals of Operations Research, 273*(1-2), 501-525. doi:10.1007/s10479-018-2786-2

Cho, J. H., Kim, H. S., & Choi, H. R. (2012). An intermodal transport network planning algorithm using dynamic programming—A case study: from Busan to Rotterdam in intermodal freight routing. *Applied Intelligence, 36*(3), 529-541. doi:10.1007/s10489-010-0223-6

Couper, A. (2019). Felixstowe Operational Update. Retrieved from https://clipperdata.com/felixstowe-operational-update/

Crainic, T. G., & Laporte, G. (1997). Planning models for freight transportation. *European Journal of Operational Research, 97*(3), 409-438. doi:https://doi.org/10.1016/S0377-2217(96)00298-6

Cullinane, K., & Toy, N. (2000). Identifying influential attributes in freight route/mode choice decisions: a content analysis. *Transportation Research Part E: Logistics and Transportation Review, 36*(1), 41-53. doi:https://doi.org/10.1016/S1366-5545(99)00016-2

Curtin, K. M. (2009). Network Modelling. In H. A. Karimi (Ed.), *Handbook of Research on Geoinformatics* (pp. 113-122). Hershey: Information Science Reference.

Daham, H. A., Yang, X., & Warnes, M. K. (2017). An efficient mixed integer programming model for pairing containers in inland transportation based on the assignment of orders. *The Journal of the Operational Research Society, 68*(6), 678-694. doi:10.1057/s41274-016-0132-0

Danielis, R., Marcucci, E., & Rotaris, L. (2005). Logistics managers' stated preferences for freight service attributes. *Transportation Research Part E: Logistics and Transportation Review, 41*(3), 201-215. doi:https://doi.org/10.1016/j.tre.2004.04.003

Davydenko, I., Landa Maxta, I., Martens, R., Nesterova, N., Wark, T., Behrens, R., . . . Wagener, N. (2012). *Potential for Eurasia land bridge corridors & logistics developments along the corridors*. European Commission.

de Soyres, F., Mulabdic, A., Murray, S., Rocha, N., & Ruta, M. (2018). *How Much Will the Belt and Road Initiative Reduce Trade Costs?* Policy Research Working Paper Policy Research Working Paper Macroeconomics, Trade and Investment Global Practice Middle East and North Africa Region Development Research Group World Bank Group.

Demir, E., Bektas, T., & Laporte, G. (2014). The bi-objective Pollution-Routing Problem. *European Journal of Operational Research, 232*(3), 464-478.

Department of Economic and Social Affairs. (2019). Part 1 EuroAsian trade routes and freight flows. In UN/ECE (Ed.), *Euro-Asian Transport Linkages: Operationalisation of Inland Transport between Europe and Asia*.

Doceul, M.-C., & Tabarly, S. (2018). Le canal de Suez, les nouvelles dimensions d'une voie de passage stratégique. *Géoconfluences*. Retrieved from http://geoconfluences.ens-lyon.fr/informations-scientifiques/dossiers-thematiques/oceans-et-mondialisation/corpus-documentaire/canal-de-suez-strategique/

Drobne, S., & Lisec, A. (2009). Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging. *Informatica, 33*(4), 459-474.

ESCAP. (2018). *Study On Border Crossing Practices In International Railway Transport*. Retrieved from Bangkok: https://www.unescap.org/sites/default/files/Study%20on%20Railway%20Border%20crossings%204621 8.pdf

European Commission. (2011). *White paper on transport: roadmap to a single European transport area—towards a competitive and resource efficient transport system*. Publications Office of the European Union. Luxembourg.

European Commission. (2017). *Commission Staff Working Document: Impact assessment*. EC. Brussels. Retrieved from https://ec.europa.eu/transparency/regdoc/rep/10102/2017/EN/SWD-2017-362-F1-EN-MAIN-PART-1.PDF

European Commission. (2020). Trans-European Transport Network (TEN-T). Retrieved from https://ec.europa.eu/transport/themes/infrastructure/ten-t_en

European Court of Auditors. (2016). *Rail freight transport in the EU: still not on the right track* Retrieved from Luxembourg:

Finnish Transport Agency. (2020). *Finnish Railway Network Statement 2020*. Retrieved from Helsinki:

Flodén, J. (2007). *Modelling Intermodal Freight Transport. The Potential of Combined Transport in Sweden*. Göteborg University: BAS Publishing.

Freightlink. (2020). Search by Freight Ferry Route Map. Retrieved from https://www.freightlink.co.uk/map

Freightos.com. (2020). Retrieved from https://www.freightos.com/

Guo, Z., Zhang, D., Liu, H., He, Z., & Shi, L. (2018). Green transportation scheduling with pickup time and transport mode selections using a novel multi-objective memetic optimization approach. *Transportation Research Part D: Transport and Environment, 60*, 137-152. doi:https://doi.org/10.1016/j.trd.2016.02.003

Helff, F., Gruenwald, L., & d'Orazio, L. (2016). *Weighted Sum Model for Multi-Objective Query Optimization for Mobile-Cloud Database Environments.* Paper presented at the EDBT/ICDT Workshops 2016, Bordeaux.

Herrera Rodriguez, M., Agrell, P. J., Manrique-de-Lara-Peñated, C., & Trujilloe, L. (2018). *Liner ship fleet deployment models and the cost of time: the case of the China - USA maritime routes*. Paper presented at the 20th International Working Semainar on Production Economics, Innsbruck, Austria.

Inland Transport Committee. (2018). *Report on Phase III of the Euro-Asian Transport Links Project*. Retrieved from Geneva:

International Rail Transport Committee. (n.d.). SMPS/SMGS. Retrieved from https://www.cit-rail.org/en/rail-transport-law/smps-smgs/

Jakóbowski, J., Popławski, K., & Kaczmarski, M. (2018). *The Silk RailRoad The EU-China rail Connections: background, actors, interests* (Vol. 72). Warsaw: Centre for Eastern Studies (OSW).

Janic, M. (2007). Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment, 12*(1), 33-44. doi:https://doi.org/10.1016/j.trd.2006.10.004

Jinno, Y. (2018). Ports of Shanghai and Ningbo-Zhoushan: Dense Fog Prolonged Vessel Waiting Times. Retrieved from https://visibility.cargosmart.com/en/blog/details/ports-of-shanghai-and-ningbo-zhoushan-dense-fog-prolonged-vessel-waiting-times/

Kim, Y., & Weck, O. d. (2006). Adaptive weighted sum method for multiobjective optimization: a new method for Pareto front generation. *Structural and Multidisciplinary Optimization, 31*(1), 105–116. doi:https://doi.org/10.1007/s00158-005-0557-6

Laursen, W. (2015). Filling Ultra-Large Container Ships. *The Maritime Executive*. Retrieved from https://www.maritime-executive.com/article/filling-ultra-large-container-ships#:~:text=The%20average%20gross%20weight%20per,excluding%20bunkers%20and%20supplies).%E2%80%9D

Lindley, D. V. (1982). Scoring rules and the inevitability of probability. *International Statistical Review, 50*, 1-26. Retrieved from https://apps.dtic.mil/dtic/tr/fulltext/u2/a097045.pdf

Macharis, C., & Bontekoning, Y. M. (2004). Opportunities for OR in intermodal freight transport research: A review. *European Journal of Operational Research, 153*(2), 400-416. doi:https://doi.org/10.1016/S0377-2217(03)00161-9

Massard, F. (2007). Règles de transit dans le Canal de Suez et tarification. Retrieved from http://www.marine-marchande.net/FM/Nabucco/Transit_Canal_de_Suez.htm

Mathisen, T. A., & Sandberg Hanssen, T.-E. (2014). The academic literature on intermodal freight transport. *Transportation Research Procedia, 3*, 611-620. doi:https://doi.org/10.1016/j.trpro.2014.10.040

Mostert, M., Caris, A., & Limbourg, S. (2018). Intermodal network design: a three-mode bi-objective model applied to the case of Belgium. *Flexible Services and Manufacturing Journal, 30*(3), 397-420. doi:10.1007/s10696-016-9275-1

Neise, R. (2018). *Container Logistics: The Role of the Container in the Supply Chain*. London and New York: Kogan Page Publishers.

Notteboom, T. E., & Rodrigue, J.-P. (2005). Port regionalization: towards a new phase in port development. *Maritime Policy & Management, 32*(3), 297-313. doi:https://doi.org/10.1080/03088830500139885

P&O Ferries. (2020). Dublin - Liverpool. Retrieved from https://www.poferriesfreight.com/freight/content/pages/template/ports_and_routes_Dublin_-_Liverpool_Dublin_-_Liverpool.htm

Panayides, P. M. (2006). Maritime Logistics and Global Supply Chains: Towards a Research Agenda. *Marit Econ Logist, 8*(1), 3-18. doi:https://doi.org/10.1057/palgrave.mel.9100147

Pencea, S. (2018). China-Europe Bri Connectivity: What'S Wrong, What'S Next. *Global Economic Observer, 6*(2), 190-211.
Pradt, T. (2020). *The Prequel to China's New Silk Road: Preparing the Ground in Central Asia*. Berlin: Springer Nature.
Prakash, S., Gupta, A., Garg, R., Tanwar, B., Kaushik, D., & Aggarwal, S. (2016). Pareto optimal solutions providing optimal routes between every two different nodes in the cost-time trade-off routing network without the objectives being prioritized. *Opsearch, 53*(4), 778-807. doi:10.1007/s12597-016-0259-4
Railfreight.com. (2019a). Chinese subsidies for the New Silk Road on a decline. Retrieved from https://www.railfreight.com/specials/2019/10/01/chinese-subsidies-for-the-new-silk-road-on-a-decline/?gdpr=accept
Railfreight.com. (2019b). Railgate Finland in Kouvala thinks big and this is why. Retrieved from https://www.silkroadsummit.eu/news/2019/10/22/railgate-finland-in-kouvala-thinks-big-and-this-is-why/?gdpr=accept
Railfreight.com. (2020). TEN-T network will not make 2030 deadline, says EU Court of Auditors. Retrieved from https://events.railfreight.com/news/2020/06/22/ten-t-network-will-not-make-2030-deadline-says-eu-court-of-auditors/?utm_source=newsletter&utm_medium=email&utm_campaign=Newsletter%20week%202020-29
Rodrigue, J.-P., Comtois, C., & Slack, B. (2017). *The Geography of Transport Systems*. Hofstra University, Department of Global Studies & Geography. Retrieved from https://transportgeography.org
Roland Berger. (2017). Eurasion rail corridors: What opportunities for freight stakeholders? [PowerPoint presentation]. Paris.
Schramm, H.-J., & Zhang, X. (2018). *Eurasian Rail Freight in the One Belt One Road Era*. Paper presented at the NOFOMA (The Nordic Logistics Research Network), Kolding, Denmark.
Scientific and Research Institute of Motor Transport. (2016). *Euro-Asian Transport Linkages*. Retrieved from Geneva:
SeaRates.com. (2020). Retrieved from https://www.searates.com/
Shinghal, N., & Fowkes, T. (2002). Freight mode choice and adaptive stated preferences. *38*(5), 367-378. doi:https://doi.org/10.1016/S1366-5545(02)00012-1
Siddiqui, A. W., & Verma, M. (2015). A bi-objective approach to routing and scheduling maritime transportation of crude oil. *Transportation Research Part D: Transport and Environment, 37*, 65-78. doi:https://doi.org/10.1016/j.trd.2015.04.010
Silja Line. (2020). Cargo: Timetables 2020. Retrieved from https://www.tallinksilja.com/documents/10192/109489502/Cargo_Timetable_2020/5fe8b23d-3bdd-a81f-e696-4a2a74cceb38
Stock, G. N., Kasarda, J. D., & Greis, N. (2000). Enterprise Logistics and Supply Chain Structure: The Role of Fit. *Journal of Operations Management, 18*(5), 531-547. doi:10.1016/S0272-6963(00)00035-8
Sun, X., Hao, J., & Li, J. (2020). Multi-objective optimization of crude oil-supply portfolio based on interval prediction data. *Annals of Operations Research*. doi:https://doi.org/10.1007/s10479-020-03701-w
Sun, Y., & Lang, M. (2015). Bi-objective Optimization for Multi-modal Transportation Routing Planning Problem Based on Pareto Optimality. *Journal of Industrial Engineering and Management, 8*(4), 1195-1217. doi:http://dx.doi.org/10.3926/jiem.1562
Tohry, F.-Z. (2019). Grand sommet des Nouvelles routes de la soie. *L'Economiste(5502)*. Retrieved from https://www.leconomiste.com/article/1044216-grand-sommet-des-nouvelles-routes-de-la-soie
Tokcaer, S., & Özpeynirci, Ö. (2018). A bi-objective multimodal transportation planning problem with an application to a petrochemical ethylene manufacturer. *Maritime Economics & Logistics, 20*(1), 72-88. doi:10.1057/s41278-016-0001-4
Trans-Logistics LLC. (n.d.). Caspian ferry rates. Retrieved from https://www.translogisticllc.com/tariff/caspian-ferry-rates
UN/ECE. (2001). *Terminology on Combined Transport*. Paper presented at the United Nations (UN) & Economic Commission for Europe (ECE), New York and Geneva.
UN/ECE. (2019). Middle Corridor: Trans-Caspian International Transport Route. [PowerPoint slides]: UN/ECE.
UNCTAD. (2018). *Review of Maritime Transport 2018*. Retrieved from https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf
Vilko, J. P. P., & Hallikas, J. M. (2012). Risk assessment in multimodal supply chains. *International Journal of Production Economics, 140*(2), 586-595. doi:https://doi.org/10.1016/j.ijpe.2011.09.010
Woodburn, A., Browne, M., Piotrowska, M., & Allen, J. (2007). *Literature Review WM7: Scope for modal shift through fiscal, regulatory and organisational change*. Transport Studies Group University of Westminster and Institute for Transport Studies University of Leeds. Retrieved from

http://www.greenlogistics.org/SiteResources/e03d3ccc-eabe-4a86-b575-ef0e5d465343_WM7%20-%20Westminster%20-%20Modal%20Shift.pdf

Yin, C., Ke, Y., Yan, Y., Lu, Y., & Xu, X. (2020). Operation plan of China Railway Express at inland railway container center station. *International Journal of Transportation Science and Technology*. doi:https://doi.org/10.1016/j.ijtst.2020.05.001

Zhen, L., & Chang, D.-F. (2012). A bi-objective model for robust berth allocation scheduling. *Computers & Industrial Engineering, 63*(1), 262-273. doi:https://doi.org/10.1016/j.cie.2012.03.003

Zhu, L. (2019). Le mali adhère à l'initiative de la « route de la soie ». *Canard Déchainé*. Retrieved from https://www.canarddechaine.com/le-mali-adhere-a-linitiative-de-la-route-de-la-soie/

Ziegler. (2020). Phone enquiry. *20-07-2020* [Oral Source].

7. Appendices

Appendix 1: Dataset

1.1 Arcs dataset

Table 19: Arcs dataset with cost (USD), distance (Km) and speed (Km/h)

NODE1	**NODE2**	**MODE**	**USD**	**Km**	**Km/h**	**Route**		
Shanghai	Vladivostok	maritime	797	1801	13	TSR		
Vladivostok	Moscow	rail	979	6415	42	TSR		
China	Shanghai	rail	0	0	1	TSR	LSR	
Moscow	St-Petersburg	rail	1241	633	42	TSR		
Moscow	Krasnoye/Osinovka	rail	254	434	42	TSR		
Krasnoye/Osinovka	Brest/Terespol	rail	330	563	30	TSR		
Brest/Terespol	Warsaw	rail	112	187	42	TSR		
Alashankou/Dostyk	Petropavlov/Kokchetav	rail	755	2651	42	TSR		
Petropavlov/Kokchetav	Moscow	rail	208	732	42	TSR		
Erenhot/Zamyn-Uud	Sukhbaatar/Naushki	rail	547	862	36	TSR		
Sukhbaatar/Naushki	Moscow	rail	1383	4630	42	TSR		
China	Alashankou/Dostyk	rail	0	0	1	TSR	TC	SC
China	Khorgos/Altynkol	rail	0	0	1	TSR	TC	SC
China	Manzhouli/Zabajkalsk	rail	0	0	1	TSR		
China	Erenhot/Zamyn-Uud	rail	0	0	1	TSR		
Manzhouli/Zabajkalsk	Moscow	rail	1455	5111	42	TSR		
St-Petersburg	Vainikkala/Buslovskaya	rail	299	153	42	TSR		
Vainikkala/Buslovskaya	Kouvola	rail	169	87	50	TSR		
Kouvola	Helsinki	rail	243	124	50	TSR		
Hamburg	St-Petersburg	maritime	1047	2554	25	EUR		
St-Petersburg	Hamburg	maritime	1047	2554	25	EUR		

Gdansk	Warsaw	rail	193	284	23	EUR		
Istanbul	Hamburg	maritime	890	7616	21,16	EUR		
Aktau	Baku	maritime	630	558	23,25	TC		
Baku	Boyuk/Garbani	rail	538	503	24	TC	SC	
Boyuk/Garbani	Poti	rail	209	246	24	TC		
Poti	Istanbul	maritime	420	1143	11,90	TC		
Poti	Constanta	maritime	650	1080,47	18,01	TC		
Turkmenbashy	Baku	maritime	860	344,34	23,25	TC	SC	
Poti	Chornomorsk	maritime	504	1040,22	28,89	TC		
Almaty	Aktau	rail	1331	3258	40	TC	SC	
Alashankou/Dostyk	Astana	rail	220	1047	42	TC	SC	
Almaty	Astana	rail	204	972	42	TC	SC	TSR
Khorgos/Altynkol	Almaty	rail	208	293	42	TC	SC	
Astana	Almaty	rail	206	972	42	TC	SC	
Astana	Petropavlov/Kokchetav	rail	457	1605	42	TSR		
Almaty	Saryagash/Keles	rail	421	660	42	TC	SC	
Saryagash/Keles	Farap/Alat	rail	342	537	40	TC	SC	
Farap/Alat	Turkmenbashy	rail	578	907	40	TC	SC	
Farap/Alat	Serakhs/Sarakhs	rail	384	359	17	SC		
Serakhs/Sarakhs	Tehran	rail	950	888	17	SC		
Tehran	Kapikoy/Razi	rail	751	702	17	SC		
Kapikoy/Razi	Istanbul	rail	1431	1337	17	SC		
Boyuk/Garbani	Akhalkalaki/Turgozu	rail	239	223	17	SC		
Akhalkalaki/Turgozu	Kars	rail	120	112	17	SC		
Kars	Istanbul	rail	1260	1178	17	SC		
Istanbul	Kapikule/Andreevo	rail	412	236	17	SC		
Kapikule/Andreevo	Sofia	rail	471	270	17	SC		
Shanghai	Malacca Strait	maritime	0	4651,32	30	LSR		
Malacca Strait	Bab al-Mandab Strait	maritime	0	6449,34	30	LSR		
Bab al-Mandab Strait	Suez canal	maritime	0	2252,97	30	LSR		
Suez canal	Piraeus	maritime	1242	1197,03	22	LSR		
Suez canal	Strait of Gibraltar	maritime	0	3666,39	22	LSR		
Strait of Gibraltar	Rotterdam	maritime	900	2511,08	22	LSR		

Strait of Gibraltar	Gdansk	maritime	725	3613,66	23	LSR		
Strait of Gibraltar	Hamburg	maritime	612	2976,45	22	LSR		
Suez canal	Istanbul	maritime	1275	1678,87	22	LSR		
Strait of Gibraltar	St-Petersburg	maritime	796	4407,2	23	LSR		
Helsinki	Tallinn	maritime	138	81	27	EUR		
Tallinn	Riga	rail	547	280	30	EUR		
Riga	Kaunas	rail	426	229	30	EUR		
Kaunas	Vilnius	rail	100	92	30	EUR		
Kaunas	Klaipeda	rail	366	197	30	EUR		
Berlin	Duisburg	rail	1572	471	50	EUR		
Klaipeda	Kaunas	rail	134	197	30	EUR		
Kaunas	Warsaw	rail	213	353	30	EUR		
Warsaw	Berlin	rail	359	518	55	EUR		
Berlin	Hamburg	rail	177	256	55	EUR		
Hamburg	Berlin	rail	175	256	55	EUR		
Berlin	Warsaw	rail	354	518	55	EUR		
Warsaw	Kaunas	rail	245	353	30	EUR		
Riga	Tallinn	rail	547	280	30	EUR		
Tallinn	Helsinki	maritime	138	81	27	EUR		
Kaunas	Riga	rail	426	229	30	EUR		
Vilnius	Kaunas	rail	170	92	30	EUR		
Helsinki	Stockholm	maritime	204	406,8	22,92	EUR		
Stockholm	Malmo	rail	957	513	30	EUR		
Stockholm	Helsinki	maritime	204	406,8	22,92	EUR		
Malmo	Stockholm	rail	351	513	30	EUR		
Malmo	Copenhagen	rail	114	29	30	EUR		
Copenhagen	Malmo	rail	114	29	30	EUR		

Copenhagen	Hamburg	rail	200	289	50	EUR		
Hamburg	Copenhagen	rail	198	289	50	EUR		
Duisburg	Berlin	rail	601	471	50	EUR		
Berlin	Amsterdam	rail	1924	577	50	EUR		
Berlin	Rotterdam	rail	2042	612	50	EUR		
Rotterdam	Berlin	rail	780	612	50	EUR		
Amsterdam	Berlin	rail	395	577	50	EUR		
Rotterdam	Antwerp	rail	211	79	50	EUR		
Antwerp	Brussels	rail	111	42	50	EUR		
Duisburg	Brussels	rail	397	181	50	EUR		
Brussels	Antwerp	rail	111	42	50	EUR		
Antwerp	Rotterdam	rail	211	79	50	EUR		
Brussels	Duisburg	rail	484	181	50	EUR		
Brussels	Paris	rail	709	264	45	EUR		
Paris	Brussels	rail	709	264	45	EUR		
Brussels	Luxembourg	rail	522	188	45	EUR		
Luxembourg	Brussels	rail	412	188	45	EUR		
Brussels	London	rail	861	321	30	EUR		
London	Brussels	rail	861	321	30	EUR		
Paris	London	rail	922	344	30	EUR		
London	Paris	rail	922	344	30	EUR		
London	Felixstowe	rail	305	114	30	EUR		
Felixstowe	London	rail	305	114	30	EUR		
London	Liverpool	rail	770	287	30	EUR		
Liverpool	Dublin	maritime	330	214,7	26,84	EUR		
Luxembourg	Marseille	rail	1771	705	30	EUR		
Marseille	Luxembourg	rail	2895	705	30	EUR		

Le Havre	Paris	rail	474	177	6	EUR		
Paris	Le Havre	rail	474	177	6	EUR		
Paris	Madrid	rail	2827	1053	30	EUR		
Madrid	Paris	rail	4325	1053	30	EUR		
Madrid	Lisbon	rail	2064	503	30	EUR		
Lisbon	Madrid	rail	1263	503	30	EUR		
Piraeus	Thessaloniki	rail	239	304	30	EUR		
Thessaloniki	Sofia	rail	182	231	30	EUR		
Sofia	Bucharest	rail	515	296	30	EUR		
Bucharest	Budapest	rail	389	644	30	EUR		
Constanta	Bucharest	rail	356	204	30	EUR		
Tchop/Dobra	Budapest	rail	203	258	30	EUR		
Thessaloniki	Piraeus	rail	239	304	30	EUR		
Sofia	Thessaloniki	rail	189	231	30	EUR		
Bucharest	Sofia	rail	515	296	30	EUR		
Budapest	Bucharest	rail	394	644	30	EUR		
Budapest	Bratislava	rail	132	162	30	EUR		
Bratislava	Budapest	rail	127	162	30	EUR		
Bratislava	Vienna	rail	114	55	30	EUR		
Vienna	Bratislava	rail	114	55	30	EUR		
Tchop/Dobra	Prague	rail	411	593	30	EUR		
Prague	Tchop/Dobra	rail	406	593	30	EUR		
Prague	Munich	rail	245	300	50	EUR		
Vienna	Munich	rail	291	356	50	EUR		
Munich	Prague	rail	287	300	50	EUR		
Munich	Vienna	rail	341	356	50	EUR		
Munich	Paris	rail	2346	685	50	EUR		

Paris	Munich	rail	1838	685	50	EUR		
Warsaw	Bratislava	rail	364	532	30	EUR		
Bratislava	Warsaw	rail	369	532	30	EUR		
Vienna	Ljubljana	rail	227	278	30	EUR		
Vienna	Venice	rail	357	436	30	EUR		
Ljubljana	Vienna	rail	266	278	30	EUR		
Venice	Vienna	rail	357	436	30	EUR		
Ljubljana	Trieste	rail	114	73	30	EUR		
Trieste	Ljubljana	rail	114	73	30	EUR		
Venice	Roma	rail	990	394	30	EUR		
Roma	Venice	rail	990	394	30	EUR		
Ljubljana	Zagreb	rail	114	118	30	EUR		
Zagreb	Ljubljana	rail	114	118	30	EUR		
Zagreb	Budapest	rail	236	300	30	EUR		
Ljubljana	Budapest	rail	365	381	30	EUR		
Budapest	Zagreb	rail	245	300	30	EUR		
Budapest	Ljubljana	rail	311	381	30	EUR		
Trieste	Venice	rail	114	117	30	EUR		
Venice	Marseille	rail	1511	602	30	EUR		
Marseille	Madrid	rail	2052	817	30	EUR		
Venice	Trieste	rail	114	117	30	EUR		
Marseille	Venice	rail	1511	602	30	EUR		
Madrid	Marseille	rail	2052	817	30	EUR		
Roma	Munich	rail	1751	697	30	EUR		
Munich	Roma	rail	1751	697	30	EUR		
Munich	Hamburg	rail	782	613	30	EUR		
Hamburg	Munich	rail	419	613	30	EUR		

Chornomorsk	Tchop/Dobra	rail	410	679	30	EUR		
Budapest	Tchop/Dobra	rail	203	258	30	EUR		
Tchop/Dobra	Bratislava	rail	310	379	30	EUR		
Bratislava	Tchop/Dobra	rail	298	379	30	EUR		
Piraeus	Athens	rail	0	0	30	EUR		
Riga	Stockholm	maritime	470	462,5	25,69	EUR		
Stockholm	Riga	maritime	470	462,5	25,69	EUR		
Riga	Helsinki	maritime	396	389,3	21,043	EUR		
Helsinki	Riga	maritime	396	389,3	21,043	EUR		
Amsterdam	Rotterdam	rail	126	58	30	EUR		
Rotterdam	Amsterdam	rail	154	58	30	EUR		
Strait of Gibraltar	Klaipeda	maritime	776	4029,7	22	EUR		
Strait of Gibraltar	Felixstowe	maritime	715	2345,5	22	EUR		
Suez canal	Trieste	maritime	866	2569,5	22	EUR		
Prague	Vienna	rail	251	175	30	EUR		
Vienna	Prague	rail	251	178	30	EUR		
Suez canal	Marseille	maritime	735	2954	22	EUR		
Strait of Gibraltar	Le Havre	maritime	684	2121,3	22	EUR		
Strait of Gibraltar	Riga	maritime	980	4301	23	EUR		
Vladivostok	Moscow	road	16892	8446	31,25	TSR		
Moscow	St-Petersburg	road	1672	836	31,25	TSR		
Moscow	Krasnoye/Osinovka	road	950	475	31,25	TSR		
Krasnoye/Osinovka	Brest/Terespol	road	1212	606	31,25	TSR		
Brest/Terespol	Warsaw	road	414	207	31,25	TSR		
Alashankou/Dostyk	Petropavlov/Kokchetav	road	3502	1751	31,25	TSR		
Petropavlov/Kokchetav	Moscow	road	4982	2491	31,25	TSR		
Erenhot/Zamyn-Uud	Sukhbaatar/Naushki	road	2120	1060	31,25	TSR		

Sukhbaatar/Naushki	Moscow	road	11512	5756	31,25	TSR		
Manzhouli/Zabajkalsk	Moscow	road	13186	6593	31,25	TSR		
St-Petersburg	Vainikkala/Buslovskaya	road	414	207	31,25	TSR		
Vainikkala/Buslovskaya	Kouvola	road	226	113	31,25	TSR		
Kouvola	Helsinki	road	278	139	31,25	TSR		
Gdansk	Warsaw	road	836	418	31,25	EUR		
Baku	Boyuk/Garbani	road	1138	569	28,9	TC		
Boyuk/Garbani	Poti	road	774	387	28,9	TC		
Almaty	Aktau	road	5814	2907	28,9	TC		
Alashankou/Dostyk	Astana	road	3044	1522	28,9	TC		
Almaty	Astana	road	2438	1219	28,9	TC		
Khorgos/Altynkol	Almaty	road	716	358	28,9	TC		
Astana	Almaty	road	2438	1219	28,9	TC		
Astana	Petropavlov/Kokchetav	road	624	312	28,9	TSR		
Almaty	Saryagash/Keles	road	1594	797	28,9	TC		
Saryagash/Keles	Farap/Alat	road	1342	671	28,9	TC		
Farap/Alat	Turkmenbashy	road	2532	1266	28,9	TC		
Farap/Alat	Serakhs/Sarakhs	road	1086	543	28,9	SC		
Kapikoy/Razi	Istanbul	road	4796	2398	28,9	SC		
Boyuk/Garbani	Akhalkalaki/Turgozu	road	574	287	28,9	SC		
Akhalkalaki/Turgozu	Kars	road	312	156	28,9	SC		
Tallinn	Riga	road	622	311	37,5	EUR		
Riga	Kaunas	road	524	262	37,5	EUR		
Kaunas	Vilnius	road	204	102	37,5	EUR		
Kaunas	Klaipeda	road	428	214	37,5	EUR		
Berlin	Duisburg	road	1106	553	37,5	EUR		
Klaipeda	Kaunas	road	434	217	37,5	EUR		
Kaunas	Warsaw	road	892	446	37,5	EUR		
Warsaw	Berlin	road	1146	573	37,5	EUR		
Berlin	Hamburg	road	582	291	37,5	EUR		
Hamburg	Berlin	road	582	291	37,5	EUR		
Berlin	Warsaw	road	1152	576	37,5	EUR		

Warsaw	Kaunas	road	840	420	37,5	EUR		
Riga	Tallinn	road	622	311	37,5	EUR		
Kaunas	Riga	road	518	259	37,5	EUR		
Vilnius	Kaunas	road	204	102	37,5	EUR		
Stockholm	Malmo	road	1228	614	37,5	EUR		
Malmo	Stockholm	road	1228	614	37,5	EUR		
Malmo	Copenhagen	road	86	43	37,5	EUR		
Copenhagen	Malmo	road	86	43	37,5	EUR		
Copenhagen	Hamburg	road	576	288	37,5	EUR		
Hamburg	Copenhagen	road	576	288	37,5	EUR		
Duisburg	Berlin	road	1098	549	37,5	EUR		
Berlin	Amsterdam	road	1318	659	37,5	EUR		
Berlin	Rotterdam	road	1392	696	37,5	EUR		
Rotterdam	Berlin	road	1380	690	37,5	EUR		
Amsterdam	Berlin	road	1318	659	37,5	EUR		
Rotterdam	Antwerp	road	200	100	37,5	EUR		
Antwerp	Brussels	road	92	46	37,5	EUR		
Duisburg	Brussels	road	438	219	37,5	EUR		
Brussels	Antwerp	road	92	46	37,5	EUR		
Antwerp	Rotterdam	road	200	100	37,5	EUR		
Brussels	Duisburg	road	440	220	37,5	EUR		
Brussels	Paris	road	648	324	37,5	EUR		
Paris	Brussels	road	614	307	37,5	EUR		
Brussels	Luxembourg	road	438	219	37,5	EUR		
Luxembourg	Brussels	road	428	214	37,5	EUR		
London	Felixstowe	road	300	150	37,5	EUR		
Felixstowe	London	road	280	140	37,5	EUR		

London	Liverpool	road	682	341	37,5	EU R		
Luxembourg	Marseille	road	1658	829	37,5	EU R		
Marseille	Luxembourg	road	1658	829	37,5	EU R		
Le Havre	Paris	road	402	201	37,5	EU R		
Paris	Le Havre	road	402	201	37,5	EU R		
Paris	Madrid	road	2540	1270	37,5	EU R		
Madrid	Paris	road	2540	1270	37,5	EU R		
Madrid	Lisbon	road	1258	629	37,5	EU R		
Lisbon	Madrid	road	1258	629	37,5	EU R		
Piraeus	Thessaloniki	road	1020	510	37,5	EU R		
Thessaloniki	Sofia	road	848	424	37,5	EU R		
Sofia	Bucharest	road	772	386	37,5	EU R		
Bucharest	Budapest	road	1666	833	37,5	EU R		
Constanta	Bucharest	road	450	225	37,5	EU R		
Tchop/Dobra	Budapest	road	616	308	37,5	EU R		
Thessaloniki	Piraeus	road	1020	510	37,5	EU R		
Sofia	Thessaloniki	road	860	430	37,5	EU R		
Bucharest	Sofia	road	770	385	37,5	EU R		
Budapest	Bucharest	road	1670	835	37,5	EU R		
Budapest	Bratislava	road	404	202	37,5	EU R		
Bratislava	Budapest	road	404	202	37,5	EU R		
Bratislava	Vienna	road	110	55	37,5	EU R		
Vienna	Bratislava	road	134	67	37,5	EU R		
Tchop/Dobra	Prague	road	1718	859	37,5	EU R		
Prague	Tchop/Dobra	road	1718	859	37,5	EU R		
Prague	Munich	road	764	382	37,5	EU R		
Vienna	Munich	road	872	436	37,5	EU R		

Munich	Prague	road	766	383	37,5	EUR		
Munich	Vienna	road	712	356	37,5	EUR		
Munich	Paris	road	1660	830	37,5	EUR		
Paris	Munich	road	1664	832	37,5	EUR		
Warsaw	Bratislava	road	1354	677	37,5	EUR		
Bratislava	Warsaw	road	1348	674	37,5	EUR		
Vienna	Ljubljana	road	762	381	37,5	EUR		
Vienna	Venice	road	1244	622	37,5	EUR		
Ljubljana	Vienna	road	556	278	37,5	EUR		
Venice	Vienna	road	1244	622	37,5	EUR		
Ljubljana	Trieste	road	188	94	37,5	EUR		
Trieste	Ljubljana	road	190	95	37,5	EUR		
Venice	Roma	road	1056	528	37,5	EUR		
Roma	Venice	road	1060	530	37,5	EUR		
Ljubljana	Zagreb	road	278	139	37,5	EUR		
Zagreb	Ljubljana	road	282	141	37,5	EUR		
Zagreb	Budapest	road	682	341	37,5	EUR		
Ljubljana	Budapest	road	922	461	37,5	EUR		
Budapest	Zagreb	road	688	344	37,5	EUR		
Budapest	Ljubljana	road	922	461	37,5	EUR		
Trieste	Venice	road	342	171	37,5	EUR		
Venice	Marseille	road	1544	772	37,5	EUR		
Marseille	Madrid	road	1632	816	37,5	EUR		
Venice	Trieste	road	340	170	37,5	EUR		
Marseille	Venice	road	1542	771	37,5	EUR		
Madrid	Marseille	road	1632	816	37,5	EUR		
Roma	Munich	road	1838	919	37,5	EUR		

Munich	Roma	road	1834	917	37,5	EUR		
Munich	Hamburg	road	1652	826	37,5	EUR		
Hamburg	Munich	road	1556	778	37,5	EUR		
Chornomorsk	Tchop/Dobra	road	1818	909	37,5	EUR		
Budapest	Tchop/Dobra	road	616	308	37,5	EUR		
Tchop/Dobra	Bratislava	road	1070	535	37,5	EUR		
Bratislava	Tchop/Dobra	road	1070	535	37,5	EUR		
Amsterdam	Rotterdam	road	158	79	37,5	EUR		
Rotterdam	Amsterdam	road	156	78	37,5	EUR		
Prague	Vienna	road	502	251	37,5	EUR		
Vienna	Prague	road	664	332	37,5	EUR		
Vainikkala/Buslovskaya	Helsinki	road	514	257	37,5	EUR		

1.2 Nodes dataset

Table 20: Nodes dataset with cost (USD) and time spent at node (Hours)

NODE	MODE1	MODE2	USD	Hours
Akhalkalaki/Turgozu	rail	rail	446	53
Aktau	maritime	rail	557	64
Aktau	rail	rail	100	24
Aktau	maritime	maritime	250	35
Alashankou/Dostyk	rail	rail	446	53
Almaty	rail	rail	100	24
Amsterdam	rail	rail	100	24
Antwerp	rail	rail	100	24
Astana	rail	rail	100	24
Athens	rail	rail	0	1
Bab al-Mandab Strait	maritime	maritime	60	16
Baku	maritime	rail	557	64
Baku	rail	rail	100	24
Baku	maritime	maritime	250	35
Berlin	rail	rail	100	24
Boyuk/Garbani	rail	rail	296	48
Bratislava	rail	rail	100	24
Brest/Terespol	rail	rail	446	48
Brussels	rail	rail	100	24

Bucharest	rail	rail	100	24
Budapest	rail	rail	100	24
China	rail	rail	0	0
Chornomorsk	maritime	maritime	250	35
Chornomorsk	rail	rail	100	24
Chornomorsk	rail	maritime	407	40
Constanta	maritime	rail	407	40
Constanta	rail	rail	100	24
Constanta	maritime	maritime	250	35
Copenhagen	rail	rail	100	24
Dublin	maritime	maritime	250	35
Duisburg	rail	rail	100	24
Erenhot/Zamyn-Uud	rail	rail	446	53
Farap/Alat	rail	rail	296	48
Felixstowe	rail	rail	100	24
Felixstowe	rail	maritime	407	40
Felixstowe	maritime	maritime	250	35
Gdansk	rail	maritime	407	40
Gdansk	maritime	maritime	250	35
Gdansk	rail	rail	100	24
Hamburg	maritime	rail	407	40
Hamburg	rail	rail	100	24
Hamburg	maritime	maritime	250	35
Helsinki	rail	maritime	407	40
Helsinki	maritime	maritime	250	35
Helsinki	rail	rail	100	24
Istanbul	maritime	rail	407	40
Istanbul	rail	rail	100	24
Istanbul	maritime	maritime	250	35
Kapikoy/Razi	rail	rail	296	48
Kapikule/Andreevo	rail	rail	296	48
Kars	rail	rail	100	24
Kaunas	rail	rail	100	24
Khorgos/Altynkol	rail	rail	446	53
Klaipeda	rail	rail	100	24
Klaipeda	maritime	rail	407	40
Klaipeda	maritime	maritime	250	35
Kouvola	rail	rail	100	24
Krasnoye/Osinovka	rail	rail	296	48
Le Havre	rail	rail	100	24
Le Havre	maritime	rail	407	40
Le Havre	maritime	maritime	250	35
Lisbon	rail	rail	100	24
Liverpool	rail	maritime	407	40
Liverpool	maritime	maritime	250	35
Liverpool	rail	rail	100	24

Ljubljana	rail	rail	100	24
London	rail	rail	100	24
Luxembourg	rail	rail	100	24
Madrid	rail	rail	100	24
Malacca Strait	maritime	maritime	60	16
Malmo	rail	rail	100	24
Manzhouli/Zabajkalsk	rail	rail	446	53
Marseille	rail	rail	100	24
Marseille	maritime	rail	407	40
Marseille	maritime	maritime	250	35
Moscow	rail	rail	100	24
Munich	rail	rail	100	24
Paris	rail	rail	100	24
Petropavlov/Kokchetav	rail	rail	296	48
Piraeus	maritime	rail	407	40
Piraeus	rail	rail	100	24
Piraeus	maritime	maritime	250	35
Poti	rail	maritime	557	64
Poti	maritime	maritime	100	24
Poti	rail	rail	250	35
Prague	rail	rail	100	24
Riga	rail	maritime	407	40
Riga	maritime	maritime	250	35
Riga	rail	rail	100	24
Roma	rail	rail	100	24
Rotterdam	maritime	rail	407	40
Rotterdam	rail	rail	100	24
Rotterdam	maritime	maritime	250	35
Saryagash/Keles	rail	rail	296	48
Serakhs/Sarakhs	rail	rail	446	53
Shanghai	maritime	rail	557	64
Shanghai	rail	rail	100	24
Shanghai	maritime	maritime	250	35
St-Petersburg	rail	maritime	557	64
St-Petersburg	maritime	maritime	250	35
St-Petersburg	rail	rail	100	24
Sofia	rail	rail	100	24
Stockholm	maritime	rail	407	40
Stockholm	rail	rail	100	24
Stockholm	maritime	maritime	250	35
Strait of Gibraltar	maritime	maritime	60	16
Suez canal	maritime	maritime	60	16
Sukhbaatar/Naushki	rail	rail	446	53
Tallinn	maritime	rail	407	40
Tallinn	rail	rail	100	24
Tallinn	maritime	maritime	250	35

Tchop/Dobra	rail	rail	446	53
Tehran	rail	rail	100	24
Thessaloniki	rail	rail	100	24
Trieste	rail	rail	100	24
Trieste	maritime	rail	407	40
Trieste	maritime	maritime	250	35
Turkmenbashy	maritime	rail	557	64
Turkmenbashy	rail	rail	100	24
Turkmenbashy	maritime	maritime	250	35
Vainikkala/Buslovskaya	rail	rail	296	48
Venice	rail	rail	100	24
Vienna	rail	rail	100	24
Vilnius	rail	rail	100	24
Vladivostok	maritime	rail	407	40
Vladivostok	rail	rail	100	24
Vladivostok	maritime	maritime	250	35
Warsaw	rail	rail	100	24
Zagreb	rail	rail	100	24
Vladivostok	road	road	100	4
Moscow	road	road	100	4
St-Petersburg	road	maritime	450	40
St-Petersburg	road	road	100	4
Krasnoye/Osinovka	road	road	256	8
Brest/Terespol	road	road	256	8
Warsaw	road	road	100	4
Alashankou/Dostyk	road	road	256	8
Petropavlov/Kokchetav	road	road	256	8
Erenhot/Zamyn-Uud	road	road	256	8
Sukhbaatar/Naushki	road	road	256	8
Khorgos/Altynkol	road	road	256	8
Manzhouli/Zabajkalsk	road	road	256	8
Vainikkala/Buslovskaya	road	road	256	8
Kouvola	road	road	100	4
Helsinki	road	maritime	450	40
Helsinki	road	road	100	4
Hamburg	road	road	100	4
Gdansk	road	maritime	450	40
Gdansk	road	road	100	4
Istanbul	road	road	100	4
Aktau	road	road	100	4
Baku	road	road	100	4
Boyuk/Garbani	road	road	256	8
Poti	road	maritime	600	64
Poti	road	road	100	4
Constanta	road	road	100	4
Turkmenbashy	road	road	100	4

Chornomorsk	road	road	100	4
Almaty	road	road	100	4
Astana	road	road	100	4
Saryagash/Keles	road	road	256	8
Farap/Alat	road	road	256	8
Serakhs/Sarakhs	road	road	256	8
Kapikoy/Razi	road	road	256	8
Akhalkalaki/Turgozu	road	road	256	8
Kars	road	road	100	4
Kapikule/Andreevo	road	road	256	8
Sofia	road	road	100	4
Piraeus	road	road	100	4
Rotterdam	road	road	100	4
Tallinn	road	road	100	4
Riga	road	maritime	450	40
Riga	road	road	100	4
Kaunas	road	road	100	4
Vilnius	road	road	100	4
Klaipeda	road	maritime	450	40
Klaipeda	road	road	100	4
Berlin	road	road	100	4
Duisburg	road	road	100	4
Stockholm	road	road	100	4
Malmo	road	road	100	4
Copenhagen	road	road	100	4
Amsterdam	road	road	100	4
Antwerp	road	road	100	4
Brussels	road	road	100	4
Paris	road	road	100	4
Luxembourg	road	road	100	4
London	road	road	100	4
Felixstowe	road	maritime	450	40
Felixstowe	road	road	100	4
Liverpool	road	maritime	450	40
Liverpool	road	road	100	4
Marseille	road	maritime	450	40
Marseille	road	road	100	4
Le Havre	road	maritime	450	40
Le Havre	road	road	100	4
Madrid	road	road	100	4
Lisbon	road	road	100	4
Thessaloniki	road	road	100	4
Bucharest	road	road	100	4
Budapest	road	road	100	4
Tchop/Dobra	road	road	256	8
Bratislava	road	road	100	4

Vienna	road	road	100	4
Prague	road	road	100	4
Munich	road	road	100	4
Ljubljana	road	road	100	4
Venice	road	road	100	4
Trieste	road	maritime	450	40
Trieste	road	road	100	4
Roma	road	road	100	4
Zagreb	road	road	100	4
Vladivostok	maritime	road	450	40
Hamburg	maritime	road	450	40
Istanbul	maritime	road	450	40
Aktau	maritime	road	600	64
Baku	maritime	road	450	40
Constanta	maritime	road	450	40
Turkmenbashy	maritime	road	600	64
Chornomorsk	maritime	road	450	40
Piraeus	maritime	road	450	40
Rotterdam	maritime	road	450	40
Tallinn	maritime	road	450	40
Stockholm	maritime	road	450	40
Vladivostok	rail	road	257	29
Moscow	rail	road	257	29
St-Petersburg	rail	road	257	29
Krasnoye/Osinovka	rail	road	453	53
Brest/Terespol	rail	road	453	53
Warsaw	rail	road	257	29
Alashankou/Dostyk	rail	road	453	53
Petropavlov/Kokchetav	rail	road	453	53
Erenhot/Zamyn-Uud	rail	road	453	53
Sukhbaatar/Naushki	rail	road	453	53
Khorgos/Altynkol	rail	road	453	53
Manzhouli/Zabajkalsk	rail	road	453	53
Vainikkala/Buslovskaya	rail	road	453	53
Kouvola	rail	road	257	29
Helsinki	rail	road	257	29
Hamburg	rail	road	257	29
Gdansk	rail	road	257	29
Istanbul	rail	road	257	29
Aktau	rail	road	257	29
Baku	rail	road	257	29
Boyuk/Garbani	rail	road	453	53
Poti	rail	road	257	29
Constanta	rail	road	257	29
Turkmenbashy	rail	road	257	29
Chornomorsk	rail	road	257	29

Almaty	rail	road	257	29
Astana	rail	road	257	29
Saryagash/Keles	rail	road	453	53
Farap/Alat	rail	road	453	53
Serakhs/Sarakhs	rail	road	453	53
Kapikoy/Razi	rail	road	453	53
Akhalkalaki/Turgozu	rail	road	453	53
Kars	rail	road	257	29
Kapikule/Andreevo	rail	road	453	53
Sofia	rail	road	257	29
Piraeus	rail	road	257	29
Rotterdam	rail	road	257	29
Tallinn	rail	road	257	29
Riga	rail	road	257	29
Kaunas	rail	road	257	29
Vilnius	rail	road	257	29
Klaipeda	rail	road	257	29
Berlin	rail	road	257	29
Duisburg	rail	road	257	29
Stockholm	rail	road	257	29
Malmo	rail	road	257	29
Copenhagen	rail	road	257	29
Amsterdam	rail	road	257	29
Antwerp	rail	road	257	29
Brussels	rail	road	257	29
Paris	rail	road	257	29
Luxembourg	rail	road	257	29
London	rail	road	257	29
Felixstowe	rail	road	257	29
Liverpool	rail	road	257	29
Marseille	rail	road	257	29
Le Havre	rail	road	257	29
Madrid	rail	road	257	29
Lisbon	rail	road	257	29
Thessaloniki	rail	road	257	29
Bucharest	rail	road	257	29
Budapest	rail	road	257	29
Tchop/Dobra	rail	road	453	53
Bratislava	rail	road	257	29
Vienna	rail	road	257	29
Prague	rail	road	257	29
Munich	rail	road	257	29
Ljubljana	rail	road	257	29
Venice	rail	road	257	29
Trieste	rail	road	257	29
Roma	rail	road	257	29

Zagreb	rail	road	257	29

1.3 Speed sources

Table 21: Speed per region, route or country.

Region	Mode	Speed (km/h)	Calculations and estimates based on
Europe	Road	37.5	European Court of Auditors (2016)
CAREC	Road	28.9	Asian Development Bank (2019)
Kazakhstan	Road	23.5	Davydenko et al. (2012)
Azerbaijan	Road	31.25	Asian Development Bank (2019)
Georgia	Road	31.25	Asian Development Bank (2019)
Uzbekistan	Road	31.25	Asian Development Bank (2019)
Turkmenistan	Road	31.25	Asian Development Bank (2019)
Mongolia	Road	31.25	Asian Development Bank (2019)
Europe	Rail	30	European Court of Auditors (2016)
TEN T corridor 1	Rail	50	European Court of Auditors (2016)
Germany	Rail	50	Yin et al. (2020)
Belgium	Rail	45	Yin et al. (2020)
Trans-Caspian Route	Rail	40	Jakóbowski et al. (2018)
Southern Route	Rail	17	Jakóbowski et al. (2018)
Trans-Siberian Railway	Rail	42	Jakóbowski et al. (2018)
Macedonia, Serbia	Rail	35	Jakóbowski et al. (2018)
Belarus	Rail	30	Scientific and Research Institute of Motor Transport (2016)
Finland	Rail	50	Finnish Transport Agency (2020)
Poland	Rail	23	Scientific and Research Institute of Motor Transport (2016)
Caspian Sea	Maritime	23.25	Neise (2018)
North and Baltic Sea	Maritime	25	Freightlink (2020)
Mediterranean Sea	Maritime	22	Neise (2018)
Other sea	Maritime	30	Herrera Rodriguez et al. (2018)

1.4 Arcs sources

Table 22: Sources on which are based the value of the arcs dataset.

NODE1	NODE2	MODE	Cost	Distance	Speed
Shanghai	Vladivostok	maritime	SeaRates.com (2020)	SeaRates.com (2020)	SeaRates.com (2020)
Vladivostok	Moscow	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
China	Shanghai	rail	Assumption	Assumption	Assumption
Moscow	St-Petersburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)

Moscow	Krasnoye/Osinovka	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Krasnoye/Osinovka	Brest/Terespol	rail	SeaRates.com (2020)	SeaRates.com (2020)	Scientific and Research Institute of Motor Transport (2016)
Brest/Terespol	Warsaw	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Alashankou/Dostyk	Petropavlov/Kokchetav	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Petropavlov/Kokchetav	Moscow	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Erenhot/Zamyn-Uud	Sukhbaatar/Naushki	rail	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Sukhbaatar/Naushki	Moscow	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
China	Alashankou/Dostyk	rail	Assumption	Assumption	Assumption
China	Khorgos/Altynkol	rail	Assumption	Assumption	Assumption
China	Manzhouli/Zabajkalsk	rail	Assumption	Assumption	Assumption
China	Erenhot/Zamyn-Uud	rail	Assumption	Assumption	Assumption
Manzhouli/Zabajkalsk	Moscow	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
St-Petersburg	Vainikkala/Buslovskaya	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Vainikkala/Buslovskaya	Kouvola	rail	SeaRates.com (2020)	SeaRates.com (2020)	Finnish Transport Agency (2020)
Kouvola	Helsinki	rail	SeaRates.com (2020)	SeaRates.com (2020)	Finnish Transport Agency (2020)
Hamburg	St-Petersburg	maritime	Neise (2018)	SeaRates.com (2020)	Freightlink (2020)
St-Petersburg	Hamburg	maritime	Freightlink (2020)	SeaRates.com (2020)	Freightlink (2020)
Gdansk	Warsaw	rail	SeaRates.com (2020)	SeaRates.com (2020)	Scientific and Research Institute of Motor Transport (2016)
Istanbul	Hamburg	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Aktau	Baku	maritime	Neise (2018)	SeaRates.com (2020)	Neise (2018)
Baku	Boyuk/Garbani	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Boyuk/Garbani	Poti	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Poti	Istanbul	maritime	Neise (2018)	SeaRates.com (2020)	Neise (2018)
Poti	Constanta	maritime	UN/ECE (2019)	SeaRates.com (2020)	UN/ECE (2019)
Turkmenbashy	Baku	maritime	UN/ECE (2019)	SeaRates.com (2020)	Neise (2018)
Poti	Chornomorsk	maritime	UN/ECE (2019)	SeaRates.com (2020)	UN/ECE (2019)
Almaty	Aktau	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Alashankou/Dostyk	Astana	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Almaty	Astana	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)

Khorgos/Altynkol	Almaty	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Astana	Almaty	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Astana	Petropavlov/Kokchetav	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Almaty	Saryagash/Keles	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Saryagash/Keles	Farap/Alat	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Farap/Alat	Turkmenbashy	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Farap/Alat	Serakhs/Sarakhs	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Serakhs/Sarakhs	Tehran	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Tehran	Kapikoy/Razi	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Kapikoy/Razi	Istanbul	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Boyuk/Garbani	Akhalkalaki/Turgozu	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Akhalkalaki/Turgozu	Kars	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Kars	Istanbul	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Istanbul	Kapikule/Andreevo	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Kapikule/Andreevo	Sofia	rail	SeaRates.com (2020)	SeaRates.com (2020)	Jakóbowski et al. (2018)
Shanghai	Malacca Strait	maritime	Assumption	SeaRates.com (2020)	Herrera Rodriguez et al. (2018)
Malacca Strait	Bab al-Mandab Strait	maritime	Assumption	SeaRates.com (2020)	Herrera Rodriguez et al. (2018)
Bab al-Mandab Strait	Suez canal	maritime	Assumption	SeaRates.com (2020)	Herrera Rodriguez et al. (2018)
Suez canal	Piraeus	maritime	Freightos.com (2020)	SeaRates.com (2020)	Neise (2018)
Suez canal	Strait of Gibraltar	maritime	Assumption	SeaRates.com (2020)	Neise (2018)
Strait of Gibraltar	Rotterdam	maritime	Freightos.com (2020)	SeaRates.com (2020)	Neise (2018)
Strait of Gibraltar	Gdansk	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018); Freightlink (2020)
Strait of Gibraltar	Hamburg	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Suez canal	Istanbul	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Strait of Gibraltar	St-Petersburg	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018); Freightlink (2020)
Helsinki	Tallinn	maritime	Freightlink (2020)	SeaRates.com (2020)	silja line
Tallinn	Riga	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Riga	Kaunas	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Vilnius	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Kaunas	Klaipeda	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Duisburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Klaipeda	Kaunas	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Warsaw	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Warsaw	Berlin	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Berlin	Hamburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Hamburg	Berlin	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Berlin	Warsaw	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Warsaw	Kaunas	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Riga	Tallinn	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tallinn	Helsinki	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Kaunas	Riga	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vilnius	Kaunas	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Helsinki	Stockholm	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Stockholm	Malmo	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Stockholm	Helsinki	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Malmo	Stockholm	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Malmo	Copenhagen	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Copenhagen	Malmo	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Copenhagen	Hamburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Hamburg	Copenhagen	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Duisburg	Berlin	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Berlin	Amsterdam	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Berlin	Rotterdam	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Rotterdam	Berlin	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Amsterdam	Berlin	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Rotterdam	Antwerp	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Antwerp	Brussels	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Duisburg	Brussels	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)

Brussels	Antwerp	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Antwerp	Rotterdam	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Brussels	Duisburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Brussels	Paris	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Paris	Brussels	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Brussels	Luxembourg	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Luxembourg	Brussels	rail	SeaRates.com (2020)	SeaRates.com (2020)	Yin et al. (2020)
Brussels	London	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Brussels	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	London	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Paris	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Felixstowe	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Felixstowe	London	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Liverpool	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Liverpool	Dublin	maritime	Freightlink (2020)	P&O Ferries (2020)	P&O Ferries (2020)
Luxembourg	Marseille	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Luxembourg	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Le Havre	Paris	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Le Havre	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Madrid	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Paris	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Lisbon	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Lisbon	Madrid	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Piraeus	Thessaloniki	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Thessaloniki	Sofia	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Sofia	Bucharest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bucharest	Budapest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Constanta	Bucharest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Budapest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Thessaloniki	Piraeus	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Sofia	Thessaloniki	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bucharest	Sofia	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Bucharest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Bratislava	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Budapest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Vienna	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Bratislava	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Prague	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Prague	Tchop/Dobra	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Prague	Munich	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Vienna	Munich	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Munich	Prague	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Munich	Vienna	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Munich	Paris	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Paris	Munich	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016); Yin et al. (2020)
Warsaw	Bratislava	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Warsaw	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Ljubljana	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Venice	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Vienna	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Vienna	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Trieste	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Trieste	Ljubljana	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Roma	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Roma	Venice	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Zagreb	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Zagreb	Ljubljana	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Zagreb	Budapest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Ljubljana	Budapest	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Zagreb	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Ljubljana	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Trieste	Venice	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Marseille	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Madrid	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Trieste	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Venice	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Marseille	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Roma	Munich	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Roma	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Hamburg	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Hamburg	Munich	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Chornomorsk	Tchop/Dobra	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Tchop/Dobra	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Bratislava	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Tchop/Dobra	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Piraeus	Athens	rail	Assumption	Assumption	European Court of Auditors (2016)
Riga	Stockholm	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Stockholm	Riga	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Riga	Helsinki	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Helsinki	Riga	maritime	Freightlink (2020)	SeaRates.com (2020)	Silja Line (2020)
Amsterdam	Rotterdam	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Rotterdam	Amsterdam	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Strait of Gibraltar	Klaipeda	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Strait of Gibraltar	Felixstowe	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Suez canal	Trieste	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Prague	Vienna	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Prague	rail	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Suez canal	Marseille	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)

Strait of Gibraltar	Le Havre	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018)
Strait of Gibraltar	Riga	maritime	SeaRates.com (2020)	SeaRates.com (2020)	Neise (2018); Freightlink (2020)
Vladivostok	Moscow	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Moscow	St-Petersburg	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Moscow	Krasnoye/Osinovka	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Krasnoye/Osinovka	Brest/Terespol	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Brest/Terespol	Warsaw	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Alashankou/Dostyk	Petropavlov/Kokchetav	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Petropavlov/Kokchetav	Moscow	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Erenhot/Zamyn-Uud	Sukhbaatar/Naushki	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Sukhbaatar/Naushki	Moscow	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Manzhouli/Zabajkalsk	Moscow	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
St-Petersburg	Vainikkala/Buslovskaya	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Vainikkala/Buslovskaya	Kouvola	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Kouvola	Helsinki	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Gdansk	Warsaw	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Baku	Boyuk/Garbani	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Boyuk/Garbani	Poti	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Almaty	Aktau	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Alashankou/Dostyk	Astana	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Almaty	Astana	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Khorgos/Altynkol	Almaty	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Astana	Almaty	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Astana	Petropavlov/Kokchetav	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Almaty	Saryagash/Keles	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Saryagash/Keles	Farap/Alat	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Farap/Alat	Turkmenbashy	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Farap/Alat	Serakhs/Sarakhs	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Kapikoy/Razi	Istanbul	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)

Boyuk/Garbani	Akhalkalaki/Turgozu	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Akhalkalaki/Turgozu	Kars	road	SeaRates.com (2020)	SeaRates.com (2020)	Asian Development Bank (2019)
Tallinn	Riga	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Riga	Kaunas	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Vilnius	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Klaipeda	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Duisburg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Klaipeda	Kaunas	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Warsaw	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Warsaw	Berlin	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Hamburg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Hamburg	Berlin	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Warsaw	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Warsaw	Kaunas	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Riga	Tallinn	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Kaunas	Riga	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vilnius	Kaunas	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Stockholm	Malmo	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Malmo	Stockholm	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Malmo	Copenhagen	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Copenhagen	Malmo	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Copenhagen	Hamburg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Hamburg	Copenhagen	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Duisburg	Berlin	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Amsterdam	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Berlin	Rotterdam	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Rotterdam	Berlin	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Amsterdam	Berlin	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Rotterdam	Antwerp	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Antwerp	Brussels	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Duisburg	Brussels	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Brussels	Antwerp	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Antwerp	Rotterdam	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Brussels	Duisburg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Brussels	Paris	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Brussels	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Brussels	Luxembourg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Luxembourg	Brussels	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Felixstowe	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Felixstowe	London	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
London	Liverpool	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Luxembourg	Marseille	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Luxembourg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Le Havre	Paris	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Le Havre	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Madrid	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Paris	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Lisbon	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Lisbon	Madrid	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Piraeus	Thessaloniki	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Thessaloniki	Sofia	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Sofia	Bucharest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bucharest	Budapest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Constanta	Bucharest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Budapest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Thessaloniki	Piraeus	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Sofia	Thessaloniki	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bucharest	Sofia	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Budapest	Bucharest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Bratislava	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Budapest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Vienna	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Bratislava	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Prague	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Prague	Tchop/Dobra	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Prague	Munich	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Munich	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Prague	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Vienna	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Paris	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Paris	Munich	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Warsaw	Bratislava	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Warsaw	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Ljubljana	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Venice	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Vienna	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Vienna	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Trieste	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Trieste	Ljubljana	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Roma	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Roma	Venice	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Zagreb	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Zagreb	Ljubljana	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Zagreb	Budapest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Ljubljana	Budapest	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Zagreb	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Ljubljana	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

Trieste	Venice	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Marseille	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Madrid	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Venice	Trieste	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Marseille	Venice	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Madrid	Marseille	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Roma	Munich	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Roma	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Munich	Hamburg	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Hamburg	Munich	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Chornomorsk	Tchop/Dobra	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Budapest	Tchop/Dobra	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Tchop/Dobra	Bratislava	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Bratislava	Tchop/Dobra	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Amsterdam	Rotterdam	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Rotterdam	Amsterdam	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Prague	Vienna	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vienna	Prague	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)
Vainikkala/Buslovskaya	Helsinki	road	SeaRates.com (2020)	SeaRates.com (2020)	European Court of Auditors (2016)

1.5 Estimates of node parameters

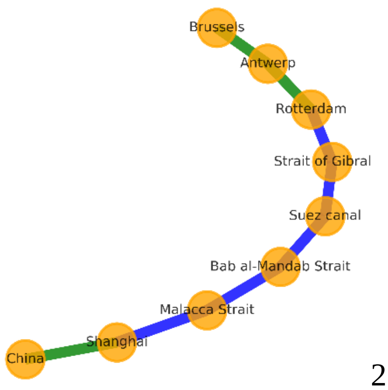
		Cost [USD/TEU]	Time [hrs]	Sources from which estimates are derived
Transhipment				
maritime	rail	157	5	Davydenko et al. (2012) European Commission (2017)
rail	road	157	5	Davydenko et al. (2012) European Commission (2017) Ziegler (2020) Neise (2018)
maritime	road	200	5	Davydenko et al. (2012) European Commission (2017) Ziegler (2020) Neise (2018)
Border crossing	port	150	24	Jinno (2018)

				de Soyres et al. (2018) SeaRates.com (2020) Ziegler (2020)
Border crossing	BCP rail	196	24	Asian Development Bank (2019) Ziegler (2020)
Border crossing	BCP road	156	6	Asian Development Bank (2019) Ziegler (2020)
Change of gauge	station	150	4	Davydenko et al. (2012) ESCAP (2018) Schramm and Zhang (2018)
Transit	strait	60	16	Doceul and Tabarly (2018) Massard (2007)
Terminal handling	port	250	35	Couper (2019) UNCTAD (2018) SeaRates.com (2020) Freightos.com (2020) Neise (2018) Inland Transport Committee (2018) Ziegler (2020)
Terminal handling	road	100	4	European Commission (2017) Ziegler (2020)
Terminal handling	station	100	24	Yin et al. (2020) Ziegler (2020) Neise (2018) Asian Development Bank (2019) Inland Transport Committee (2018)

Appendix 2: Pareto set and Analysis

2.1 Mapping of the solutions of Table 5

2.1.1 Brussels



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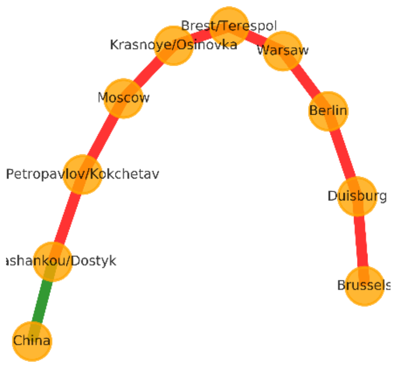
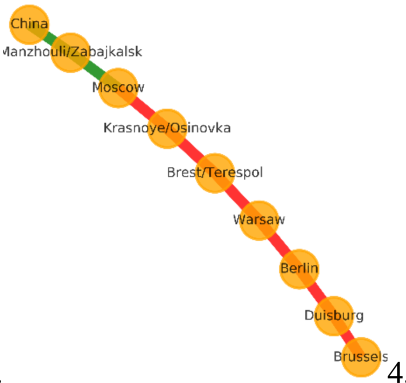
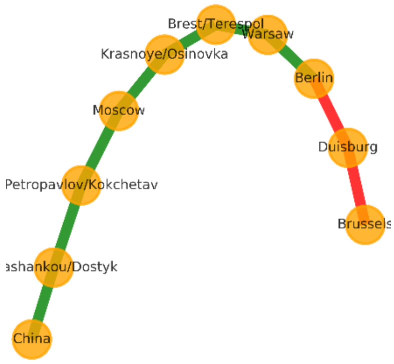


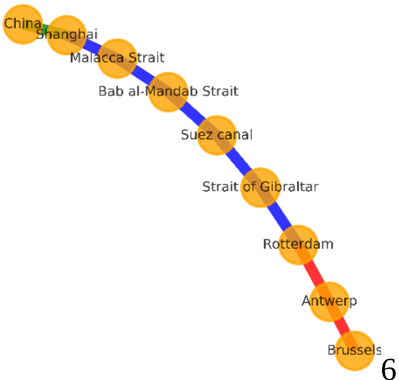
2.


China
Manzhouli/Zabajkalsk
Moscow
Krasnoye/Osinovka
Brest/Terespol
Warsaw
Berlin
Duisburg
Brussels

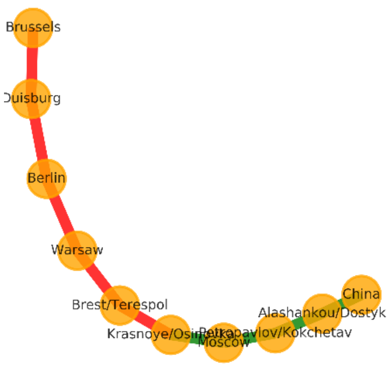
3.


Brest/Terespol
Warsaw
Krasnoye/Osinovka
Berlin
Moscow
Duisburg
Petropavlov/Kokchetav
Brussels
ashankou/Dostyk
China

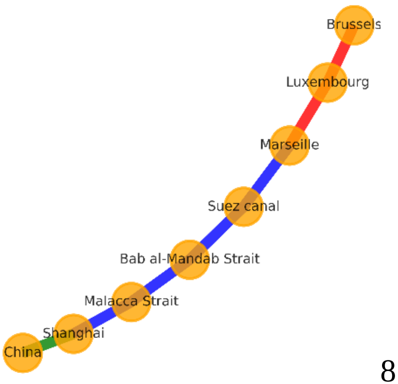
4.


China
Shanghai
Malacca Strait
Bab al-Mandab Strait
Suez canal
Strait of Gibraltar
Rotterdam
Antwerp
Brussels

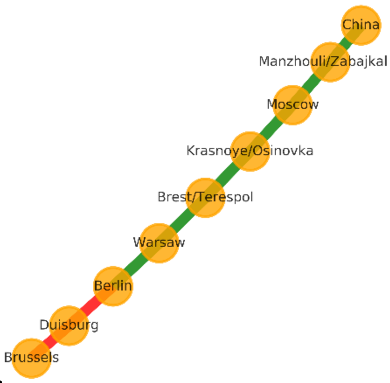
5.


Brussels
Duisburg
Berlin
Warsaw
Brest/Terespol
China
Alashankou/Dostyk
Petropavlov/Kokchetav
Moscow

6.


Brussels
Luxembourg
Marseille
Suez canal
Bab al-Mandab Strait
Malacca Strait
Shanghai
China

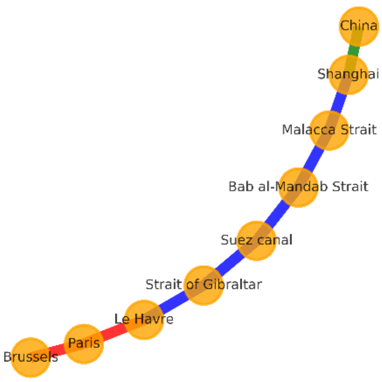
7.


China
Manzhouli/Zabajkal
Moscow
Krasnoye/Osinovka
Brest/Terespol
Warsaw
Berlin
Duisburg
Brussels

8.


China
Manzhouli/Zabajkalsk
Moscow
Krasnoye/Osinovka
Brest/Terespol
Warsaw
Berlin
Duisburg
Brussels

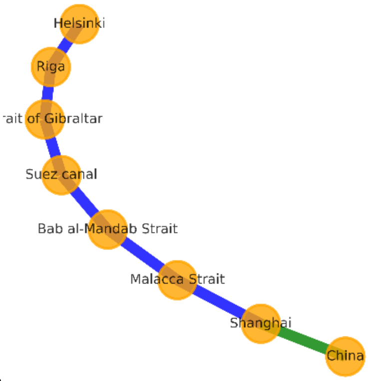
9.


China
Shanghai
Malacca Strait
Bab al-Mandab Strait
Suez canal
Strait of Gibraltar
Le Havre
Paris
Brussels

10.

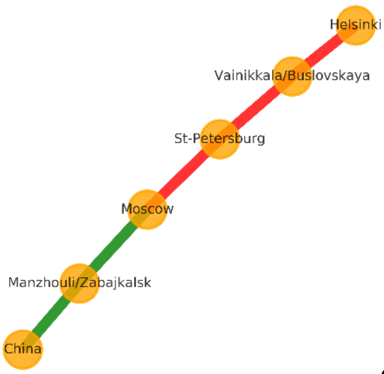
2.1.2 Helsinki

1.



2.

3.



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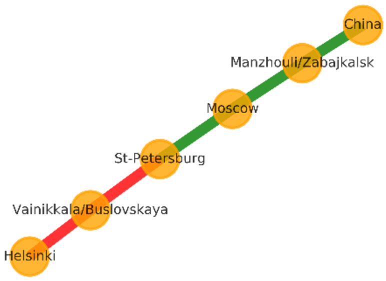

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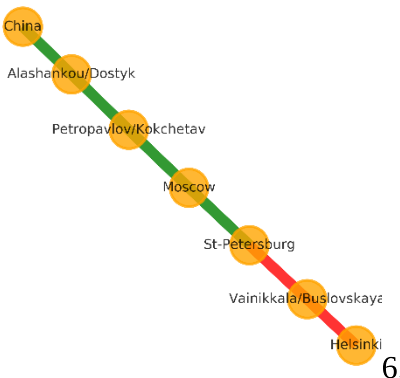

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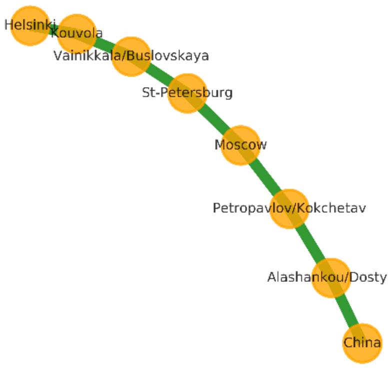
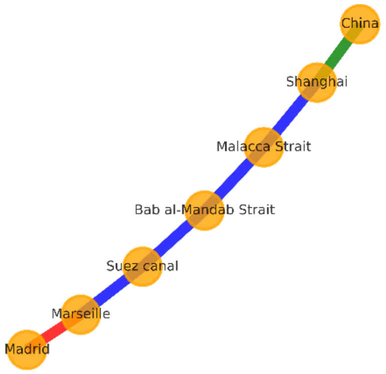


2.1.3 Madrid



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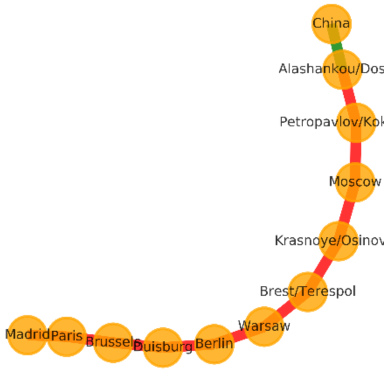
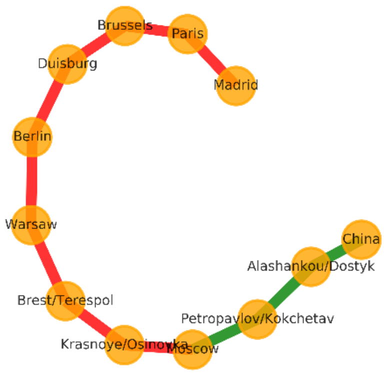
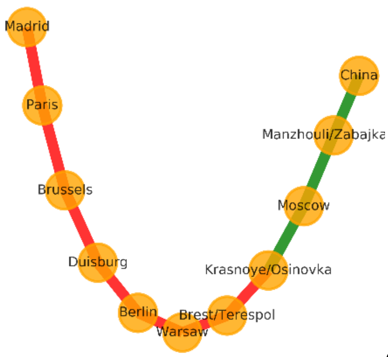


2.

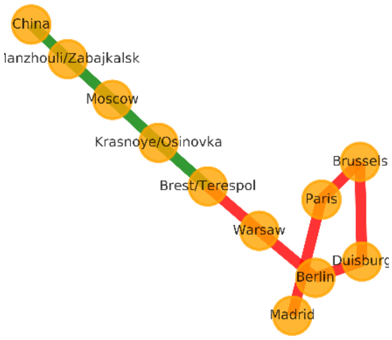
3.



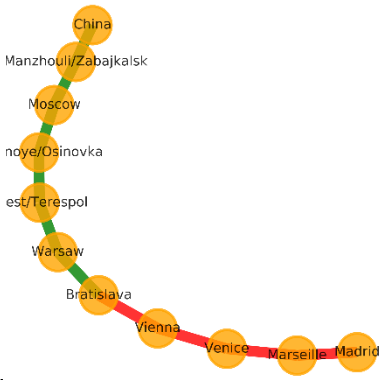
4.



5.



6.



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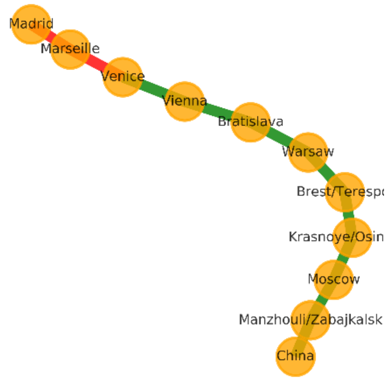

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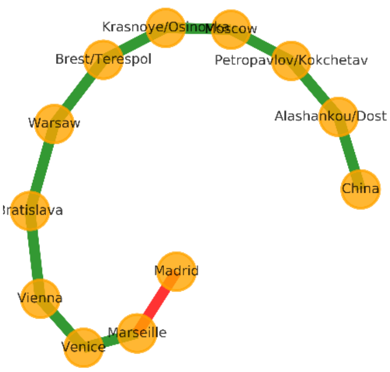

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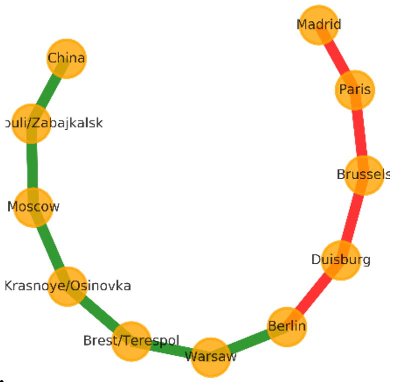
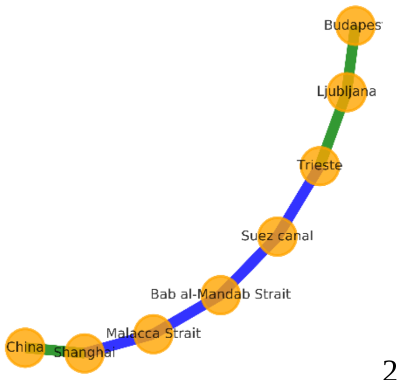


10.

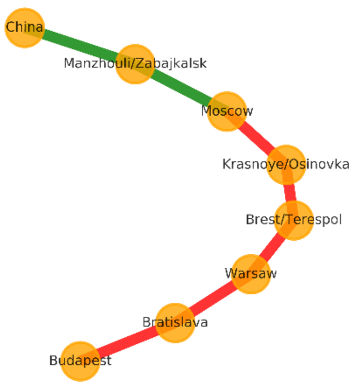
2.1.4 Budapest



1.

2.

3.



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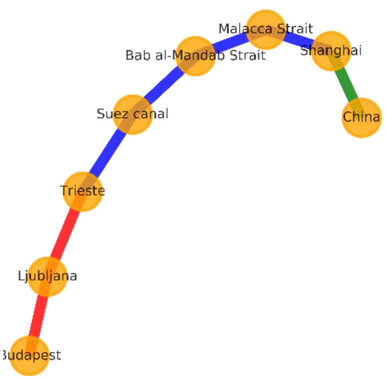

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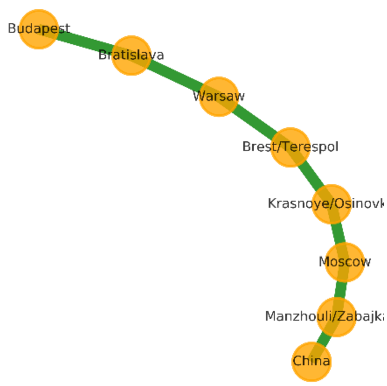
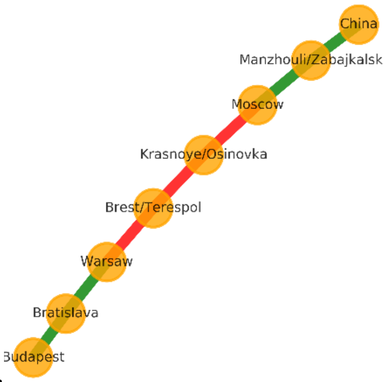
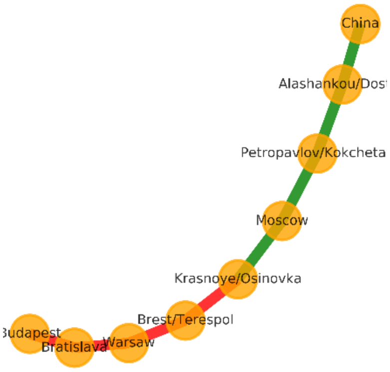


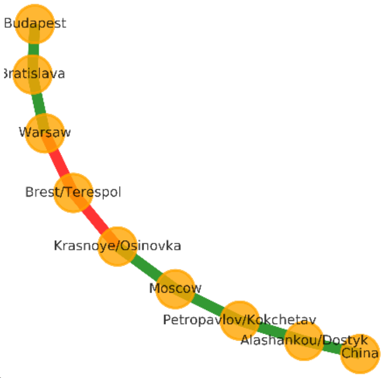
6.


China
Manzhouli/Zabajkalsk
Moscow
Krasnoye/Osinovka
Brest/Terespol
Warsaw
Bratislava
Budapest

7.


China
Alashankou/Dos
Petropavlov/Kokcheta
Moscow
Krasnoye/Osinovka
Brest/Terespol
Budapest
Bratislava
Warsaw

8.


Budapest
Bratislava
Warsaw
Brest/Terespol
Krasnoye/Osinovka
Moscow
Petropavlov/Kokchetav
Alashankou/Dostyk
China

9.

Appendix 3: EU regions

3.1 Northern cities

Table 23: proportion of arcs using each mode of transportation and belonging to each BRI route for each pareto solution and weight of the solution in the total set of optimizations for Northern EU capitals.

% of	No.	Obj1	Obj2	3	4	5	6	7	8	9	10
count on nwsa solutions	Helsinki	2	1	2	1	4	1				
	Stockholm	3	1	2	1	4	1	1	1	1	1
	Copenhagen	2	1	4	4	1	1	1	1	1	
	Warsaw	2	1	3	5	1	1	1	1		
	Riga	2	1	3	2	3	1				
	Tallinn	2	1	2	1	4	1	1	1	1	1
	Vilnius	2	1	3	1	4	1	1	1	1	
count on 29 solutions	Helsinki	3	1	9	1	4	11				
	Stockholm	3	1	8	1	4	1	8	1	1	1
	Copenhagen	3	1	9	10	1	2	1	1	1	
	Warsaw	3	1	9	12	1	1	1	1		
	Riga	3	1	8	4	12	1				
	Tallinn	2	1	9	1	4	2	1	7	1	1
	Vilnius	2	1	9	1	11	2	1	1	1	
TSR	Helsinki	14%	83%	80%	80%	83%	100%				
	Stockholm	14%	71%	67%	67%	71%	86%	88%	11%	11%	71%
	Copenhagen	14%	67%	63%	67%	63%	63%	10%	63%	63%	
	Warsaw	14%	100%	100%	100%	100%	11%	100%	100%		
	Riga	17%	75%	71%	71%	75%	75%				
	Tallinn	14%	71%	67%	67%	71%	88%	86%	67%	14%	8%
	Vilnius	13%	75%	71%	75%	75%	75%	9%	13%	71%	
LSR	Helsinki	71%	0%	0%	0%	0%	0%				
	Stockholm	71%	0%	0%	0%	0%	0%	0%	67%	67%	0%
	Copenhagen	86%	0%	0%	0%	0%	0%	40%	0%	0%	
	Warsaw	86%	0%	0%	0%	0%	44%	0%	0%		
	Riga	83%	0%	0%	0%	0%	0%				
	Tallinn	71%	0%	0%	0%	0%	0%	0%	0%	71%	33%
	Vilnius	63%	0%	0%	0%	0%	0%	36%	63%	0%	
SC	Helsinki	0%	17%	0%	0%	17%	14%				
	Stockholm	0%	14%	0%	0%	14%	0%	13%	0%	0%	14%
	Copenhagen	0%	11%	0%	11%	0%	0%	0%	0%	0%	
	Warsaw	0%	17%	0%	17%	17%	0%	0%	17%		
	Riga	0%	13%	0%	14%	13%	13%				
	Tallinn	0%	14%	0%	0%	14%	13%	0%	11%	0%	0%
	Vilnius	0%	13%	0%	13%	13%	13%	0%	0%	0%	
TC	Helsinki	0%	17%	0%	0%	17%	14%				
	Stockholm	0%	14%	0%	0%	14%	0%	13%	0%	0%	14%
	Copenhagen	0%	11%	0%	11%	0%	0%	0%	0%	0%	
	Warsaw	0%	17%	0%	17%	17%	0%	0%	17%		
	Riga	0%	13%	0%	14%	13%	13%				
	Tallinn	0%	14%	0%	0%	14%	13%	0%	11%	0%	0%
	Vilnius	0%	13%	0%	13%	13%	13%	0%	0%	0%	
rail	Helsinki	14%	17%	40%	60%	67%	100%				
	Stockholm	14%	14%	33%	50%	57%	86%	88%	22%	11%	43%
	Copenhagen	29%	11%	25%	100%	63%	100%	60%	75%	38%	
	Warsaw	29%	17%	40%	100%	67%	56%	100%	50%		
	Riga	17%	13%	29%	57%	100%	38%				
	Tallinn	29%	14%	33%	50%	57%	88%	86%	100%	14%	67%
	Vilnius	38%	13%	29%	38%	100%	50%	64%	13%	100%	
road	Helsinki	0%	83%	60%	40%	33%	0%				
	Stockholm	0%	71%	50%	33%	29%	0%	0%	22%	33%	43%
	Copenhagen	0%	89%	75%	0%	38%	0%	0%	25%	63%	
	Warsaw	0%	83%	60%	0%	33%	0%	0%	50%		
	Riga	0%	88%	71%	29%	0%	63%				
	Tallinn	0%	71%	50%	33%	29%	0%	0%	0%	14%	0%
	Vilnius	0%	88%	71%	63%	0%	50%	0%	25%	0%	
ship	Helsinki	86%	0%	0%	0%	0%	0%				
	Stockholm	86%	14%	17%	17%	14%	14%	13%	56%	56%	14%
	Copenhagen	71%	0%	0%	0%	0%	0%	40%	0%	0%	
	Warsaw	71%	0%	0%	0%	0%	44%	0%	0%		
	Riga	83%	0%	0%	14%	0%	0%				
	Tallinn	71%	14%	17%	17%	14%	13%	14%	0%	71%	33%
	Vilnius	63%	0%	0%	0%	0%	0%	36%	63%	0%	

3.2 Western cities

Table 24: proportion of arcs using each mode of transportation and belonging to each BRI route for each pareto solution and weight of the solution in the total set of optimizations for Western EU capitals.

% of	No.	Obj1	Obj2	3	4	5	6	7	8	9	10	11	12
count on nwsa solutions	Berlin	2	1	3	5	1	1	1	1	1			
	Amsterdam	3	1	4	3	1	1	1	1				
	Paris	3	1	4	1	2	1	1	1	1	1		
	Brussels	1	1	4	3	2	1	1	1	1	1		
	London	3	1	4	1	2	1	1	1	1	1	1	1
	Dublin	3	1	4	1	2	1	1	1	1	1		
count on 29 solutions	Berlin	2	1	9	12	1	1	1	1	1			
	Amsterdam	5	1	9	10	1	1	1	1				
	Paris	4	1	9	1	3	1	1	6	2	1		
	Brussels	1	1	9	9	2	1	3	1	1	1		
	London	3	1	9	1	2	1	1	6	1	2	1	1
	Dublin	5	1	8	2	2	1	1	6	2	1		
TSR	Berlin	14%	86%	83%	86%	86%	10%	14%	83%	83%			
	Amsterdam	14%	75%	71%	75%	75%	10%	71%	71%				
	Paris	14%	60%	56%	60%	60%	60%	56%	60%	13%	56%		
	Brussels	13%	67%	63%	67%	13%	67%	14%	13%	63%	63%		
	London	14%	60%	56%	60%	60%	60%	60%	60%	13%	14%	13%	56%
	Dublin	11%	50%	45%	50%	50%	50%	50%	50%	10%	45%		
LSR	Berlin	86%	0%	0%	0%	0%	40%	86%	0%	0%			
	Amsterdam	86%	0%	0%	0%	0%	40%	0%	0%				
	Paris	71%	0%	0%	0%	0%	0%	0%	0%	50%	0%		
	Brussels	75%	0%	0%	0%	75%	0%	57%	63%	0%	0%		
	London	71%	0%	0%	0%	0%	0%	0%	0%	50%	71%	50%	0%
	Dublin	56%	0%	0%	0%	0%	0%	0%	0%	40%	0%		
SC	Berlin	0%	14%	0%	14%	14%	0%	0%	0%	0%			
	Amsterdam	0%	13%	0%	13%	13%	0%	0%	0%				
	Paris	0%	10%	0%	10%	10%	10%	0%	10%	0%	0%		
	Brussels	0%	11%	0%	11%	0%	11%	0%	0%	0%	0%		
	London	0%	10%	0%	10%	10%	10%	10%	10%	0%	0%	0%	0%
	Dublin	0%	8%	0%	8%	8%	8%	8%	8%	0%	0%		
TC	Berlin	0%	14%	0%	14%	14%	0%	0%	0%	0%			
	Amsterdam	0%	13%	0%	13%	13%	0%	0%	0%				
	Paris	0%	10%	0%	10%	10%	10%	0%	10%	0%	0%		
	Brussels	0%	11%	0%	11%	0%	11%	0%	0%	0%	0%		
	London	0%	10%	0%	10%	10%	10%	10%	10%	0%	0%	0%	0%
	Dublin	0%	8%	0%	8%	8%	8%	8%	8%	0%	0%		
rail	Berlin	29%	14%	33%	100%	71%	60%	29%	100%	67%			
	Amsterdam	29%	13%	29%	88%	50%	10%	100%	43%				
	Paris	14%	10%	22%	30%	70%	40%	67%	90%	13%	44%		
	Brussels	38%	11%	25%	78%	13%	44%	14%	13%	75%	38%		
	London	29%	20%	33%	40%	80%	50%	70%	90%	38%	14%	25%	56%
	Dublin	11%	25%	36%	42%	75%	50%	67%	83%	30%	55%		
road	Berlin	0%	86%	67%	0%	29%	0%	0%	0%	33%			
	Amsterdam	0%	88%	71%	13%	50%	50%	0%	57%				
	Paris	14%	90%	78%	70%	30%	60%	33%	10%	38%	56%		
	Brussels	0%	89%	75%	22%	25%	56%	29%	25%	25%	63%		
	London	0%	80%	67%	60%	20%	50%	30%	10%	13%	14%	25%	44%
	Dublin	22%	67%	55%	50%	17%	42%	25%	8%	20%	36%		
ship	Berlin	71%	0%	0%	0%	0%	40%	71%	0%	0%			
	Amsterdam	71%	0%	0%	0%	0%	40%	0%	0%				
	Paris	71%	0%	0%	0%	0%	0%	0%	0%	50%	0%		
	Brussels	63%	0%	0%	0%	63%	0%	57%	63%	0%	0%		
	London	71%	0%	0%	0%	0%	0%	0%	0%	50%	71%	50%	0%
	Dublin	67%	8%	9%	8%	8%	8%	8%	8%	50%	9%		

3.3 Southern cities

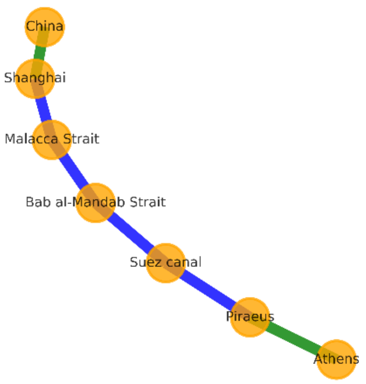
Table 25: proportion of arcs using each mode of transportation and belonging to each BRI route for each pareto solution and weight of the solution in the total set of optimizations for Southern EU capitals.

% of	No.	Obj1	Obj2	3	4	5	6	7	8	9	10	11	12	13
count on nwsa solutions	Madrid	4	1	5	1	1	1	1	1	1	1			
	Lisbon	4	1	5	1	1	1	1	1	1	1			
	Roma	3	1	5	2	1	1	1	1	1	1	1		
	Zagreb	2	1	5	3	1	1	1	1	1				
	Athens	4	1	5	1	1	1	1	1	1	1	1	1	1
	Ljubljana	2	1	5	3	1	1	1	1	1	1			
count on 29 solutions	Madrid	6	1	9	1	2	1	1	2	5	1			
	Lisbon	6	1	9	1	2	1	1	2	5	1			
	Roma	3	1	10	8	1	1	1	1	1	1	1		
	Zagreb	2	1	10	9	2	1	2	1	1				
	Athens	5	1	9	2	1	1	1	1	2	1	3	1	1
	Ljubljana	3	1	10	9	1	1	1	1	1	1			
TSR	Madrid	16,67%	54,55%	50,00%	54,55%	50,00%	50,00%	50,00%	50,00%	54,55%	50,00%			
	Lisbon	14,29%	50,00%	45,45%	50,00%	45,45%	45,45%	45,45%	33,33%	50,00%	45,45%			
	Roma	14,29%	60,00%	55,56%	60,00%	55,56%	55,56%	60,00%	14,29%	55,56%	55,56%	60,00%		
	Zagreb	14,29%	66,67%	62,50%	66,67%	62,50%	66,67%	62,50%	14,29%	66,67%				
	Athens	16,67%	46,15%	41,67%	41,67%	46,15%	41,67%	46,15%	46,15%	41,67%	41,67%	46,15%	46,15%	41,67%
	Ljubljana	16,67%	66,67%	62,50%	66,67%	62,50%	66,67%	66,67%	62,50%	62,50%	66,67%			
LSR	Madrid	66,67%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			
	Lisbon	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			
	Roma	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%	0,00%		
	Zagreb	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%				
	Athens	83,33%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Ljubljana	66,67%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			
SC	Madrid	0,00%	9,09%	0,00%	9,09%	0,00%	0,00%	0,00%	0,00%	9,09%	0,00%			
	Lisbon	0,00%	8,33%	0,00%	8,33%	0,00%	0,00%	0,00%	0,00%	8,33%	0,00%			
	Roma	0,00%	10,00%	0,00%	10,00%	0,00%	0,00%	10,00%	0,00%	0,00%	0,00%	10,00%		
	Zagreb	0,00%	11,11%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	11,11%				
	Athens	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%
	Ljubljana	0,00%	11,11%	0,00%	11,11%	0,00%	11,11%	11,11%	0,00%	0,00%	11,11%			
TC	Madrid	0,00%	9,09%	0,00%	9,09%	0,00%	0,00%	0,00%	0,00%	9,09%	0,00%			
	Lisbon	0,00%	8,33%	0,00%	8,33%	0,00%	0,00%	0,00%	0,00%	8,33%	0,00%			
	Roma	0,00%	10,00%	0,00%	10,00%	0,00%	0,00%	10,00%	0,00%	0,00%	0,00%	10,00%		
	Zagreb	0,00%	11,11%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	11,11%				
	Athens	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%
	Ljubljana	0,00%	11,11%	0,00%	11,11%	0,00%	11,11%	11,11%	0,00%	0,00%	11,11%			
rail	Madrid	16,67%	9,09%	20,00%	27,27%	30,00%	40,00%	60,00%	80,00%	90,91%	60,00%			
	Lisbon	14,29%	8,33%	18,18%	25,00%	27,27%	36,36%	54,55%	66,67%	83,33%	54,55%			
	Roma	42,86%	10,00%	22,22%	100,00%	33,33%	66,67%	70,00%	14,29%	100,00%	66,67%	50,00%		
	Zagreb	42,86%	11,11%	25,00%	100,00%	37,50%	66,67%	100,00%	14,29%	66,67%				
	Athens	33,33%	15,38%	25,00%	33,33%	46,15%	58,33%	69,23%	76,92%	83,33%	100,00%	100,00%	61,54%	41,67%
	Ljubljana	33,33%	11,11%	25,00%	100,00%	37,50%	66,67%	77,78%	100,00%	62,50%	44,44%			
road	Madrid	16,67%	90,91%	80,00%	72,73%	70,00%	60,00%	40,00%	20,00%	9,09%	40,00%			
	Lisbon	28,57%	91,67%	81,82%	75,00%	72,73%	63,64%	45,45%	33,33%	16,67%	45,45%			
	Roma	0,00%	90,00%	77,78%	0,00%	66,67%	33,33%	30,00%	28,57%	0,00%	33,33%	50,00%		
	Zagreb	0,00%	88,89%	75,00%	0,00%	62,50%	33,33%	0,00%	28,57%	33,33%				
	Athens	0,00%	84,62%	75,00%	66,67%	53,85%	41,67%	30,77%	23,08%	16,67%	0,00%	0,00%	38,46%	58,33%
	Ljubljana	0,00%	88,89%	75,00%	0,00%	62,50%	33,33%	22,22%	0,00%	37,50%	55,56%			
ship	Madrid	66,67%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			
	Lisbon	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			
	Roma	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%	0,00%		
	Zagreb	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%				
	Athens	66,67%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Ljubljana	66,67%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%			

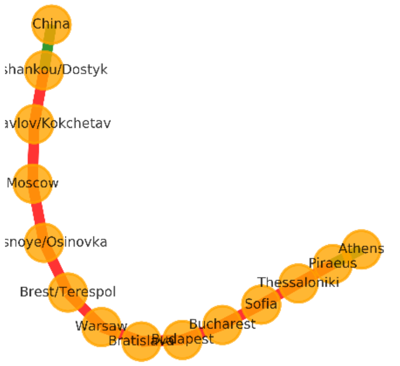
3.3.1 Pareto set of Southern EU capitals

	Madrid		Lisbon		Roma		Zagreb		Athens		Ljubljana	
	OBJ1	**OBJ2**	**OBJ1**	**OBJ2**	**OBJ1**	**OBJ2**	**OBJ1**	**OBJ2**	**OBJ1**	**OBJ2**	**OBJ1**	**OBJ2**
1	3554	753	4912	774	3214	755	2338	744	2387	652	2124	716
2	18759	356	20117	377	16545	324	15127	303	19316	392	14907	300
3	<u>11624</u>	<u>359</u>	<u>12982</u>	<u>380</u>	<u>9410</u>	<u>327</u>	<u>7992</u>	<u>306</u>	<u>12181</u>	<u>395</u>	<u>7772</u>	<u>303</u>
4	11428	366	12786	387	5468	478	4279	440	11400	411	4248	436
5	10968	394	12326	415	8754	362	7336	341	10533	435	7116	338
6	10126	434	11484	455	7628	409	6243	378	**9198**	**467**	6212	374
7	**8990**	**471**	**10348**	**492**	6574	446	**4475**	**433**	8725	493	4936	421
8	8107	510	9465	530	3551	737	2621	724	7735	513	**4444**	**429**
9	7878	536	9236	557	5664	471	6146	405	7275	541	5896	401
10	9187	466	10545	487	**6770**	**439**			5967	569	7198	334
11			4912	377	8418	376			5771	575		
12			20117	774					9002	473		
13									10729	428		
Utopia	**3554**	**356**	**4912**	**377**	**3214**	**324**	**2338**	**303**	**2387**	**392**	**2124**	**300**
Nadir	**18759**	**753**	**20117**	**774**	**16545**	**755**	**15127**	**744**	**19316**	**652**	**14907**	**716**

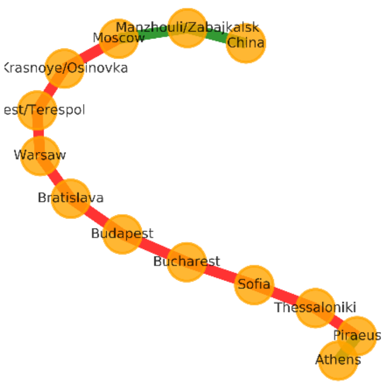
3.3.2 Mapping of Pareto set for Athens



1.

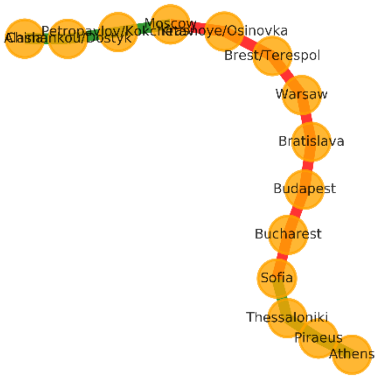


2.

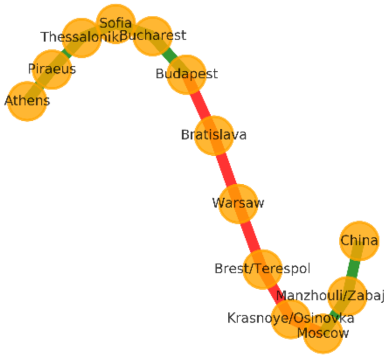


3.

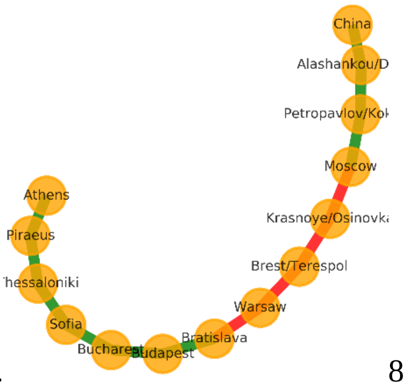
4.



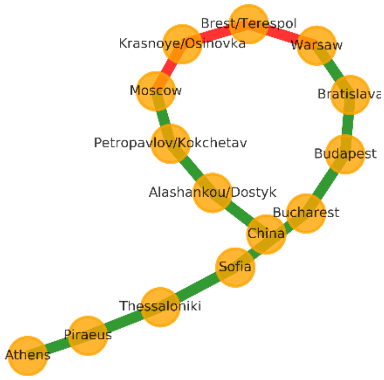
5.



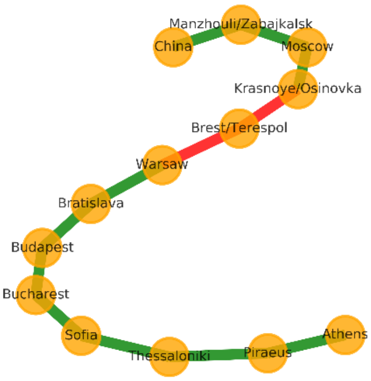
6.



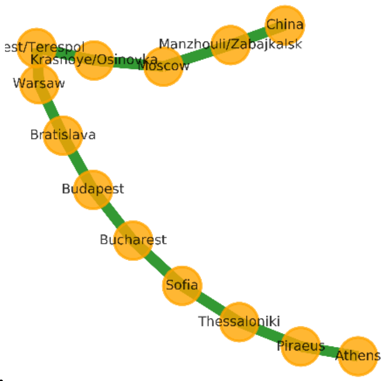
7.



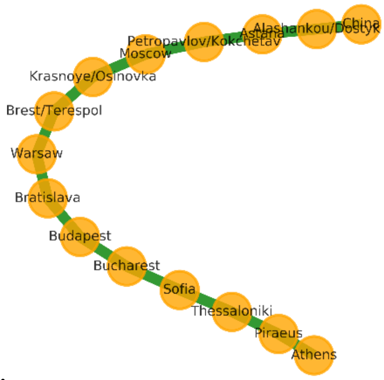
8.



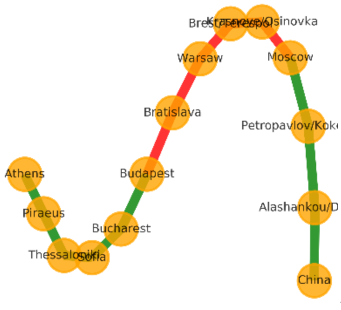
9.



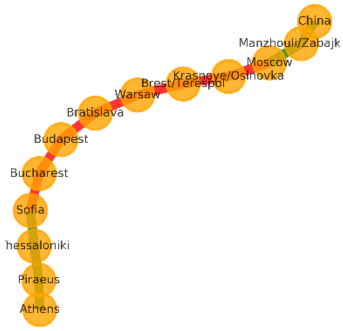
10.



11.



12.



13.

3.4 Eastern cities

Table 26: proportion of arcs using each mode of transportation and belonging to each BRI route for each pareto solution and weight of the solution in the total set of optimizations for Eastern EU capitals.

% of	No.	Obj1	Obj2	3	4	5	6	7	8	9	10	11	12
count on nwsa solutions	Budapest	2	1	4	4	1	1	1	1	1			
	Bucharest	2	1	3	1	4	1	1	1	1	1		
	Sofia	3	1	5	2	1	1	1	1	1	1		
	Bratislava	1	1	3	5	1	1	1	1				
	Prague	1	1	3	1	4	1	1	1	1	1	1	1
	Vienna	2	1	4	4	1	1	1	1	1			
count on 29 solutions	Budapest	2	1	10	11	1	1	1	1	1			
	Bucharest	2	1	8	2	10	1	1	2	1	1		
	Sofia	4	1	10	7	1	1	2	1	1	1		
	Bratislava	1	1	9	11	4	1	1	1				
	Prague	1	1	8	2	8	3	1	1	1	1	1	1
	Vienna	2	1	10	11	1	1	1	1	1			
TSR	Budapest	14,29%	75,00%	71,43%	75,00%	75,00%	75,00%	14,29%	71,43%	71,43%			
	Bucharest	12,50%	66,67%	62,50%	62,50%	66,67%	62,50%	66,67%	12,50%	62,50%	62,50%		
	Sofia	14,29%	60,00%	55,56%	60,00%	60,00%	55,56%	60,00%	60,00%	55,56%	60,00%		
	Bratislava	12,50%	85,71%	83,33%	85,71%	12,50%	85,71%	83,33%	83,33%				
	Prague	12,50%	66,67%	62,50%	66,67%	66,67%	12,50%	62,50%	62,50%	12,50%	12,50%	62,50%	66,67%
	Vienna	14,29%	75,00%	71,43%	75,00%	75,00%	75,00%	14,29%	71,43%	75,00%			
LSR	Budapest	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%			
	Bucharest	50,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	62,50%	0,00%	0,00%		
	Sofia	71,43%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%		
	Bratislava	75,00%	0,00%	0,00%	0,00%	50,00%	0,00%	0,00%	0,00%				
	Prague	75,00%	0,00%	0,00%	0,00%	0,00%	50,00%	0,00%	0,00%	50,00%	50,00%	0,00%	0,00%
	Vienna	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%			
SC	Budapest	0,00%	12,50%	0,00%	12,50%	12,50%	12,50%	0,00%	0,00%	0,00%			
	Bucharest	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%		
	Sofia	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%		
	Bratislava	0,00%	14,29%	0,00%	14,29%	0,00%	14,29%	0,00%	0,00%				
	Prague	0,00%	11,11%	0,00%	11,11%	11,11%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	11,11%
	Vienna	0,00%	12,50%	0,00%	12,50%	12,50%	12,50%	0,00%	0,00%	12,50%			
TC	Budapest	0,00%	12,50%	0,00%	12,50%	12,50%	12,50%	0,00%	0,00%	0,00%			
	Bucharest	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%		
	Sofia	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%		
	Bratislava	0,00%	14,29%	0,00%	14,29%	0,00%	14,29%	0,00%	0,00%				
	Prague	0,00%	11,11%	0,00%	11,11%	11,11%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	11,11%
	Vienna	0,00%	12,50%	0,00%	12,50%	12,50%	12,50%	0,00%	0,00%	12,50%			
rail	Budapest	42,86%	12,50%	28,57%	100,00%	50,00%	75,00%	14,29%	100,00%	57,14%			
	Bucharest	50,00%	11,11%	25,00%	37,50%	100,00%	50,00%	66,67%	50,00%	100,00%	62,50%		
	Sofia	42,86%	10,00%	22,22%	100,00%	40,00%	55,56%	70,00%	80,00%	100,00%	0,00%		
	Bratislava	37,50%	14,29%	33,33%	100,00%	50,00%	71,43%	100,00%	50,00%				
	Prague	37,50%	11,11%	25,00%	33,33%	100,00%	50,00%	62,50%	100,00%	25,00%	12,50%	75,00%	66,67%
	Vienna	42,86%	12,50%	28,57%	100,00%	50,00%	62,50%	14,29%	100,00%	62,50%			
road	Budapest	0,00%	87,50%	71,43%	0,00%	50,00%	25,00%	28,57%	0,00%	42,86%			
	Bucharest	0,00%	88,89%	75,00%	62,50%	0,00%	50,00%	33,33%	0,00%	0,00%	37,50%		
	Sofia	0,00%	90,00%	77,78%	0,00%	60,00%	44,44%	30,00%	20,00%	0,00%	100,00%		
	Bratislava	0,00%	85,71%	66,67%	0,00%	0,00%	28,57%	0,00%	50,00%				
	Prague	0,00%	88,89%	75,00%	66,67%	0,00%	0,00%	37,50%	0,00%	25,00%	37,50%	25,00%	33,33%
	Vienna	0,00%	87,50%	71,43%	0,00%	50,00%	37,50%	28,57%	0,00%	37,50%			
ship	Budapest	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%			
	Bucharest	50,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	50,00%	0,00%	0,00%		
	Sofia	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%		
	Bratislava	62,50%	0,00%	0,00%	0,00%	50,00%	0,00%	0,00%	0,00%				
	Prague	62,50%	0,00%	0,00%	0,00%	0,00%	50,00%	0,00%	0,00%	50,00%	50,00%	0,00%	0,00%
	Vienna	57,14%	0,00%	0,00%	0,00%	0,00%	0,00%	57,14%	0,00%	0,00%			

3.5 South-Eastern cities

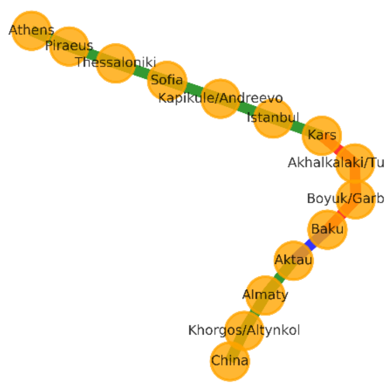
3.5.1 Increase in speed along SC

Table 27: proportion of arcs belonging to SC and TC for each pareto solution and weight of the solution in the total set of optimizations for South-Eastern capitals.

Sofia	weight	4	1	10	7	1	1	2	1	1	1					
0	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
0	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
Sofia	weight	4	1	4	2	4	7	1	1	2	1	1	1			
50	SC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	0,00%	10,00%	18,18%	0,00%			
50	TC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	0,00%	10,00%	18,18%	0,00%			
Sofia	weight	4	1	4	3	3	7	1	2	2	1	1				
100	SC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	0,00%	0,00%	10,00%	18,18%				
100	TC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	0,00%	0,00%	10,00%	18,18%				
Sofia	weight	4	1	5	3	3	7	1	1	1	1	1	1			
200	SC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	18,18%	18,18%	0,00%	18,18%	0,00%	0,00%			
200	TC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	18,18%	18,18%	0,00%	18,18%	0,00%	0,00%			
Sofia	weight	4	1	5	1	2	7	2	1	1	1	1	1	1	1	
400	SC	0,00%	18,18%	18,18%	18,18%	90,00%	10,00%	0,00%	18,18%	18,18%	0,00%	25,00%	0,00%	0,00%	100,00%	
400	TC	0,00%	18,18%	18,18%	18,18%	50,00%	10,00%	0,00%	18,18%	18,18%	0,00%	25,00%	0,00%	0,00%	40,00%	
Athens	weight	5	1	9	2	1	1	1	1	2	1	3	1	1		
0	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
0	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
Athens	weight	5	1	4	3	3	2	1	1	1	1	1	1	3	1	1
50	SC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	14,29%	0,00%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	0,00%
50	TC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	14,29%	0,00%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	0,00%
Athens	weight	5	1	4	5	2	1	1	1	1	1	1	3	1	1	1
100	SC	0,00%	14,29%	14,29%	14,29%	0,00%	7,69%	0,00%	7,69%	0,00%	14,29%	8,33%	7,69%	0,00%	0,00%	14,29%
100	TC	0,00%	14,29%	14,29%	14,29%	0,00%	7,69%	0,00%	7,69%	0,00%	14,29%	8,33%	7,69%	0,00%	0,00%	14,29%
Athens	weight	5	1	5	4	2	1	1	1	1	1	1	3	1	1	1
200	SC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	7,69%	7,69%	14,29%	14,29%	14,29%	7,69%	0,00%	0,00%	14,29%
200	TC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	7,69%	7,69%	14,29%	14,29%	14,29%	7,69%	0,00%	0,00%	14,29%
Athens	weight	5	1	5	3	2	2	1	1	1	1	1	3	1	1	1
400	SC	0,00%	14,29%	14,29%	14,29%	69,23%	14,29%	0,00%	7,69%	14,29%	14,29%	14,29%	7,69%	0,00%	0,00%	0,00%
400	TC	0,00%	14,29%	14,29%	14,29%	38,46%	14,29%	0,00%	7,69%	14,29%	14,29%	14,29%	7,69%	0,00%	0,00%	0,00%
Bucharest	weight	2	1	8	2	10	1	1	2	1	1					
0	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
0	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
Bucharest	weight	2	1	4	3	1	1	9	2	1	1	2	1	1		
50	SC	0,00%	20,00%	20,00%	20,00%	0,00%	0,00%	11,11%	20,00%	11,11%	20,00%	0,00%	11,11%	20,00%		
50	TC	0,00%	20,00%	20,00%	20,00%	0,00%	0,00%	11,11%	20,00%	11,11%	20,00%	0,00%	11,11%	20,00%		
Bucharest	weight	2	1	4	4	1	9	2	1	1	2	1	1			
100	SC	0,00%	20,00%	20,00%	20,00%	0,00%	11,11%	20,00%	11,11%	20,00%	0,00%	11,11%	20,00%			
100	TC	0,00%	20,00%	20,00%	20,00%	0,00%	11,11%	20,00%	11,11%	20,00%	0,00%	11,11%	20,00%			
Bucharest	weight	2	1	4	4	1	9	1	1	1	2	1	1	1		
200	SC	0,00%	20,00%	20,00%	20,00%	0,00%	11,11%	11,11%	0,00%	20,00%	0,00%	11,11%	20,00%	20,00%		
200	TC	0,00%	20,00%	20,00%	20,00%	0,00%	11,11%	11,11%	0,00%	20,00%	0,00%	11,11%	20,00%	20,00%		
Bucharest	weight	2	1	4	4	2	9	1	1	2	2	1				
400	SC	0,00%	20,00%	20,00%	20,00%	20,00%	11,11%	11,11%	0,00%	11,11%	0,00%	20,00%				
400	TC	0,00%	20,00%	20,00%	20,00%	20,00%	11,11%	11,11%	0,00%	11,11%	0,00%	20,00%				

Athens: from 0% to 200% speed increase, no solutions takes SC or TC routes.

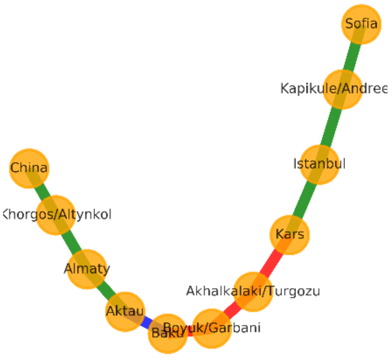
With 400% speed increase: 1 solution in the Pareto set:



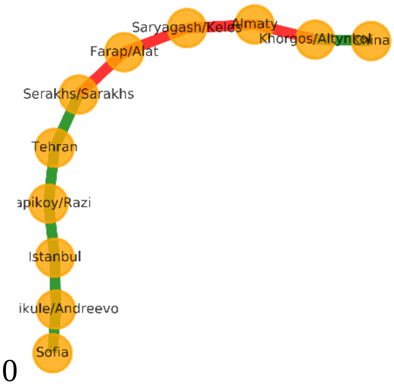
NWSA 60% weight on obj1

Sofia: from 0%to 200% increase, no solutions takes SC or TC routes.

With 400% increase: 2 solutions in the Pareto set.



NWSA 40% weight on obj1



ECM c/obj1: 11510

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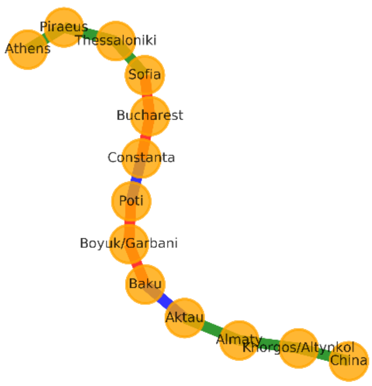
Bucharest: from 0% to 400% no solution takes SC or TC routes

3.5.2 Increase in speed along TC

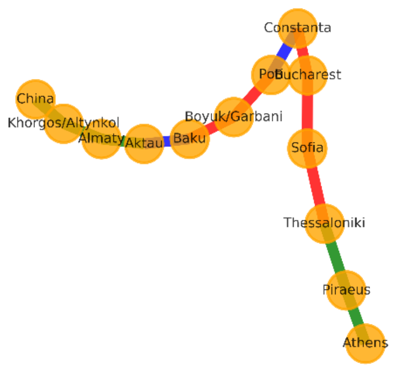
Table 28: proportion of arcs belonging to SC and TC for each pareto solution and weight of the solution in the total set of optimizations for South-Eastern capitals.

Sofia	weight	4	1	10	7	1	1	2	1	1	1					
0	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
0	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
Sofia	weight	4	1	7	7	1	1	1	1	1	1	1	2	1		
50	SC	0,00%	18,18%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%	0,00%	18,18%	0,18181818		
50	TC	0,00%	18,18%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%	0,00%	18,18%	0,18181818		
Sofia	weight	4	1	4	6	7	1	1	1	1	1	1	1			
100	SC	0,00%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	10,00%	10,00%	0,00%	0,00%	0			
100	TC	0,00%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	10,00%	10,00%	0,00%	0,00%	0			
Sofia	weight	4	1	4	2	4	7	1	1	2	1	1	1			
200	SC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	0,00%	10,00%	18,18%	0,00%			
200	TC	0,00%	18,18%	18,18%	18,18%	0,00%	10,00%	10,00%	10,00%	0,00%	10,00%	18,18%	0,00%			
Sofia	weight	4	1	5	3	1	7	2	1	2	1	1	1			
400	SC	0,00%	18,18%	18,18%	18,18%	44,44%	10,00%	0,00%	0,00%	0,00%	0,00%	18,18%	44,44%			
400	TC	0,00%	18,18%	18,18%	18,18%	77,78%	10,00%	0,00%	0,00%	0,00%	0,00%	18,18%	77,78%			
Athens	weight	5	1	9	2	1	1	1	1	2	1	3	1	1		
0	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
0	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
Athens	weight	5	1	7	2	1	1	1	1	2	1	3	1	1	1	1
50	SC	0,00%	14,29%	0,00%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	0,00%	14,29%	14,29%
50	TC	0,00%	14,29%	0,00%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	0,00%	14,29%	14,29%
Athens	weight	5	1	3	6	1	1	2	1	1	1	2	1	3	1	
100	SC	0,00%	14,29%	14,29%	0,00%	0,00%	7,69%	0,00%	7,69%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	
100	TC	0,00%	14,29%	14,29%	0,00%	0,00%	7,69%	0,00%	7,69%	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	
Athens	weight	5	1	4	3	3	2	1	1	1	1	1	1	3	1	1
200	SC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	14,29%	0,00%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	0,00%
200	TC	0,00%	14,29%	14,29%	14,29%	0,00%	0,00%	14,29%	0,00%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	0,00%
Athens	weight	5	1	5	4	1	1	1	1	1	1	1	3	1	1	1
400	SC	0,00%	14,29%	14,29%	14,29%	33,33%	7,69%	33,33%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	33,33%	0,00%
400	TC	0,00%	14,29%	14,29%	14,29%	58,33%	7,69%	58,33%	7,69%	0,00%	14,29%	14,29%	7,69%	0,00%	58,33%	0,00%
Bucharest	weight	2	1	8	2	10	1	1	2	1	1					
0	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
0	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
Bucharest	weight	2	1	5	2	10	1	1	2	1	1	1	2			
50	SC	0,00%	20,00%	0,00%	0,00%	11,11%	11,11%	11,11%	0,00%	11,11%	0,00%	20,00%	20,00%			
50	TC	0,00%	20,00%	0,00%	0,00%	11,11%	11,11%	11,11%	0,00%	11,11%	0,00%	20,00%	20,00%			
Bucharest	weight	2	1	5	2	9	1	1	1	2	1	1	3			
100	SC	0,00%	20,00%	0,00%	0,00%	11,11%	11,11%	11,11%	0,00%	0,00%	11,11%	0,00%	20,00%			
100	TC	0,00%	20,00%	0,00%	0,00%	11,11%	11,11%	11,11%	0,00%	0,00%	11,11%	0,00%	20,00%			
Bucharest	weight	2	1	4	3	1	1	9	2	1	1	2	1	1		
200	SC	0,00%	20,00%	20,00%	20,00%	0,00%	0,00%	11,11%	20,00%	11,11%	12,50%	0,00%	11,11%	20,00%		
200	TC	0,00%	20,00%	20,00%	20,00%	0,00%	0,00%	11,11%	20,00%	11,11%	12,50%	0,00%	11,11%	20,00%		
Bucharest	weight	2	1	4	4	1	9	1	1	1	2	1	1	1		
400	SC	0,00%	20,00%	20,00%	20,00%	50,00%	11,11%	11,11%	0,00%	20,00%	0,00%	11,11%	0,2	0,2		
400	TC	0,00%	20,00%	20,00%	20,00%	87,50%	11,11%	11,11%	0,00%	20,00%	0,00%	11,11%	0,2	0,2		

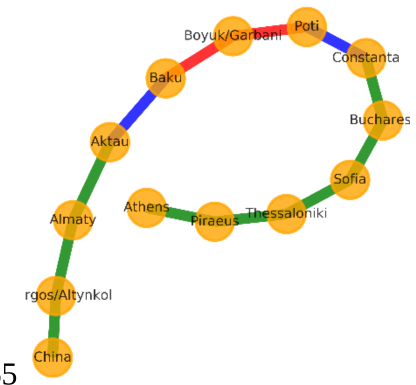
Athens: from 400% increase, there are 3 solutions.



NWSA 60% on obj1:

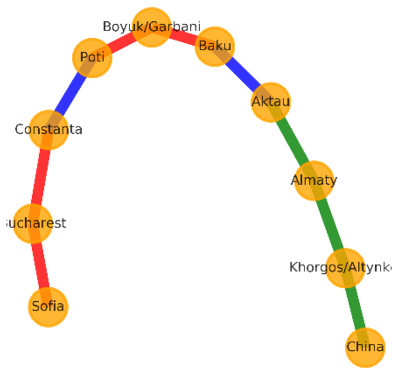


ECM c/obj2 448

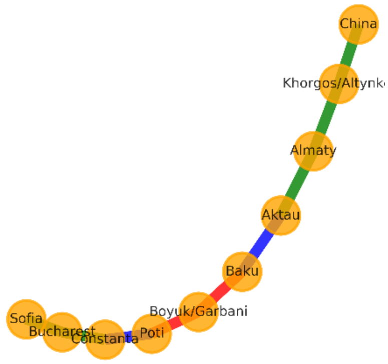


ECM c/obj1 9265

Sofia: from 400% increase, there are 2 solutions.

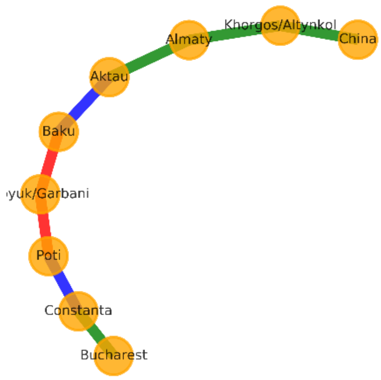


NWSA 50% on obj1



ECM c/obj1 8642

Bucharest: from 400% increase, there is 1 solution.



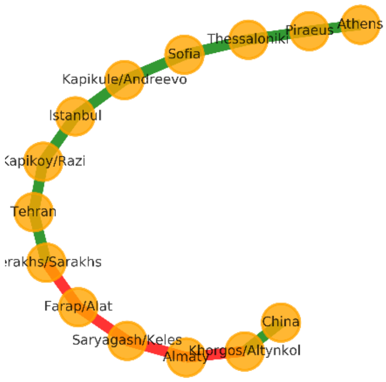
NWSA 40% on obj1

3.5.3 Decrease in cost along SC

Table 29: proportion of arcs belonging to SC and TC for each pareto solution and weight of the solution in the total set of optimizations for South-Eastern capitals.

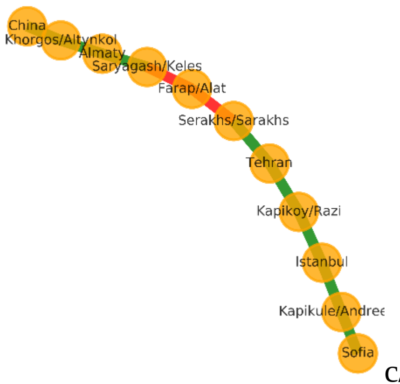
Sofia	weight	4	1	10	7	1	1	2	1	1	1					
0	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
0	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
Sofia	weight	4	1	10	2	1	1	2	1	5	1	1				
50	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
50	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
Sofia	weight	3	1	10	2	1	1	2	1	3	1	2	1	1		
70	SC	0,00%	10,00%	0,00%	10,00%	18,18%	0,00%	10,00%	10,00%	18,18%	100,00%	100,00%	0,00%	0,00%		
70	TC	0,00%	10,00%	0,00%	10,00%	18,18%	0,00%	10,00%	10,00%	18,18%	40,00%	40,00%	0,00%	0,00%		
Sofia	weight	1	1	10	6	1	1	1	1	1	1	1	1	1	1	1
90	SC	28,57%	10,00%	0,00%	100,00%	0,00%	0,00%	0,00%	10,00%	18,18%	100,00%	0,00%	90,00%	0,00%	10,00%	0
90	TC	0,00%	10,00%	0,00%	40,00%	0,00%	0,00%	0,00%	10,00%	18,18%	40,00%	0,00%	50,00%	0,00%	10,00%	0
Athens	weight	5	1	9	2	1	1	1	1	2	1	3	1	1		
0	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
0	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
Athens	weight	5	1	9	2	1	1	1	1	2	1	2	1	1	1	
50	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
50	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
Athens	weight	5	1	9	2	1	1	1	1	2	1	2	1	1	1	
70	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
70	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
Athens	weight	4	1	9	2	1	1	1	1	2	1	2	1	1	1	1
90	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	76,92%	7,69%	7,69%	0,00%
90	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	30,77%	7,69%	7,69%	0,00%
Bucharest	weight	2	1	8	2	10	1	1	2	1	1					
0	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
0	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
Bucharest	weight	2	1	8	2	5	1	1	6	1	1	1				
50	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
50	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
Bucharest	weight	2	1	8	2	5	1	1	6	1	1	1				
70	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
70	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
Bucharest	weight	2	1	8	2	4	4	1	1	2	1	1	1	1		
90	SC	0,00%	11,11%	0,00%	0,00%	11,11%	20,00%	0,00%	11,11%	90,91%	90,91%	0,00%	0,00%	0,00%		
90	TC	0,00%	11,11%	0,00%	0,00%	11,11%	20,00%	0,00%	11,11%	36,36%	36,36%	0,00%	0,00%	0,00%		

Athens: 1 solution when cost reduced by 90 %



ECM c/obj1 4079

Sofia: 2 solutions when cost reduced by 70%

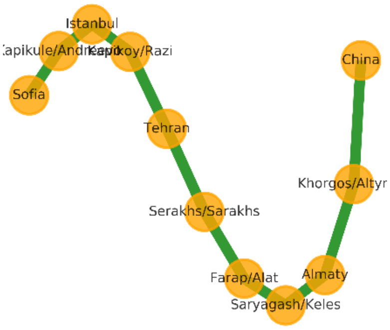


ECM c/obj2 621

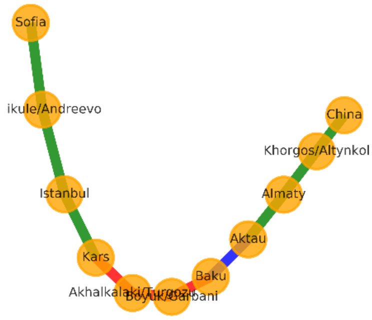
c/obj2 657

3 solutions when cost reduced by 90%

NWSA 60% on obj1

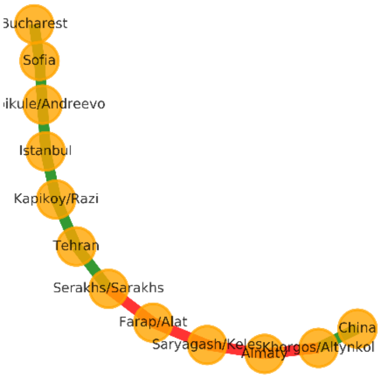


ECM c/obj2 670

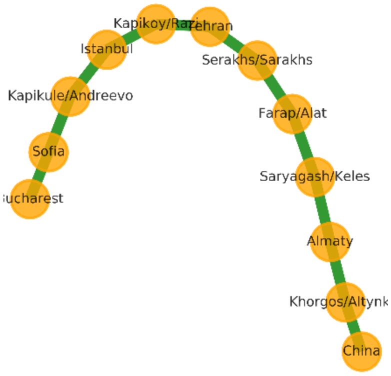


c/obj1 4221

Bucharest: 2 solutions when cost reduced by 90%



ECM c/obj2 605



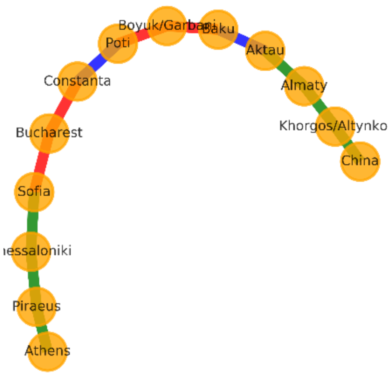
c/obj2 702

3.5.4 Decrease in cost along TC

Table 30: proportion of arcs belonging to SC and TC for each pareto solution and weight of the solution in the total set of optimizations for South-Eastern capitals.

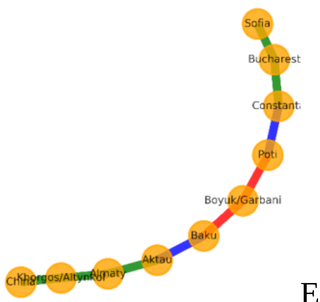
Sofia	weight	4	1	10	7	1	1	2	1	1	1					
0	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
0	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	0,00%	0,00%					
Sofia	weight	4	1	10	2	1	1	2	1	5	1	1				
50	SC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
50	TC	0,00%	10,00%	0,00%	10,00%	10,00%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
Sofia	weight	4	1	10	2	1	1	2	1	5	1	1				
70	SC	0,00%	10,00%	0,00%	10,00%	18,18%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
70	TC	0,00%	10,00%	0,00%	10,00%	18,18%	0,00%	10,00%	10,00%	18,18%	0,00%	0,00%				
Sofia	weight	2	1	10	2	4	1	1	2	1	1	2	1	1		
90	SC	0,00%	10,00%	0,00%	10,00%	44,44%	18,18%	0,00%	10,00%	10,00%	18,18%	44,44%	0,00%	0,00%		
90	TC	0,00%	10,00%	0,00%	10,00%	77,78%	18,18%	0,00%	10,00%	10,00%	18,18%	77,78%	0,00%	0,00%		
Athens	weight	5	1	9	2	1	1	1	1	2	1	3	1	1		
0	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
0	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	7,69%	7,69%	0,00%		
Athens	weight	5	1	9	2	1	1	1	1	2	1	2	1	1	1	
50	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
50	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
Athens	weight	5	1	9	2	1	1	1	1	2	1	2	1	1	1	
70	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
70	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	7,69%	7,69%	0,00%	
Athens	weight	5	1	9	2	1	1	1	1	2	1	1	1	1	1	1
90	SC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	33,33%	7,69%	7,69%	0,00%
90	TC	0,00%	7,69%	0,00%	0,00%	7,69%	0,00%	7,69%	7,69%	0,00%	0,00%	14,29%	58,33%	7,69%	7,69%	0,00%
Bucharest	weight	2	1	8	2	10	1	1	2	1	1					
0	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
0	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	0,00%	0,00%	0,00%					
Bucharest	weight	2	1	8	2	5	1	1	6	1	1	1				
50	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
50	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
Bucharest	weight	2	1	8	2	5	1	1	6	1	1	1				
70	SC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
70	TC	0,00%	11,11%	0,00%	0,00%	11,11%	0,00%	11,11%	20,00%	0,00%	0,00%	0,00%				
Bucharest	weight	1	1	8	2	3	5	1	1	3	1	1	1	1		
90	SC	0,00%	11,11%	0,00%	0,00%	11,11%	50,00%	0,00%	11,11%	50,00%	0,00%	20,00%	0,00%	0,00%		
90	TC	0,00%	11,11%	0,00%	0,00%	11,11%	87,50%	0,00%	11,11%	87,50%	0,00%	20,00%	0,00%	0,00%		

Athens: 1 solution when cost reduced by 90 %

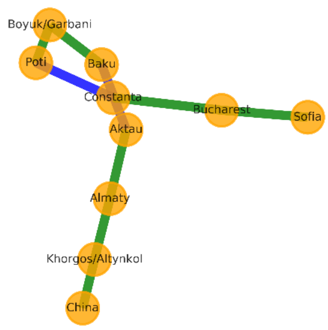


ECM c/obj2 626

Sofia: 2 solutions when cost reduced by 90%

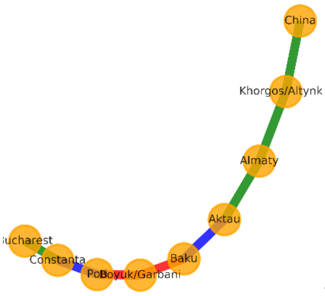


NWSA 80% on obj1

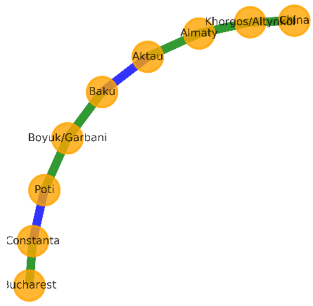


ECM c/obj2 621

Bucharest: 2 solutions when cost reduced by 90%



NWSA 70% on obj1



ECM c/obj2 605

3.6 Hubs

Table 31: For a destination, number of solutions that contain a particular hub.

East	**Bucharest**	**Sofia**	**Budapest**	**Prague**	**Vienna**	**Bratislava**
Warsaw	8	9	7	8	7	7
Bratislava	8	9	7	8	7	0
Budapest	9	8	0	0	0	0
Vienna	0	0	0	11	0	1
Ljubljana	1	0	2	3	2	1
Trieste	1	0	2	3	2	1
Bucharest	0	8	0	0	0	0
Piraeus	1	1	0	0	0	0
Thessaloniki	1	1	0	0	0	0
Sofia	1	0	0	0	0	0
Hamburg	0	0	0	1	0	0
Munich	0	0	0	1	0	0
Gdansk	0	0	0	0	0	1
South	**Madrid**	**Lisbon**	**Roma**	**Zagreb**	**Athens**	**Ljubljana**
Warsaw	9	9	9	7	12	9
Bratislava	3	3	9	7	12	9
Vienna	3	3	9	0	0	9
Budapest	0	0	0	7	12	0
Venice	3	3	11	0	0	0
Piraeus	0	0	0	0	13	0
Berlin	6	6	0	0	0	0
Brussels	6	6	0	0	0	0
Sofia	0	0	0	0	12	0
Bucharest	0	0	0	0	12	0
Paris	6	6	0	0	0	0
Duisburg	6	6	0	0	0	0
Thessaloniki	0	0	0	0	12	0
Madrid	0	10	0	0	0	0
Marseille	4	4	0	0	0	0
Trieste	0	0	2	2	0	1
Ljubljana	0	0	0	2	0	0

West	**Berlin**	**Amsterdam**	**Paris**	**Brussels**	**London**	**Dublin**
Warsaw	7	6	8	6	8	8
Berlin	0	6	7	6	8	8
Brussels	0	0	7	6	8	8
Madrid	0	1	8	0	10	9
Lisbon	0	0	0	0	0	10
Zagreb	0	0	0	0	0	10
Sofia	0	1	1	1	2	1
Budapest	0	1	1	1	2	1
Bucharest	1	2	0	2	0	0
Bratislava	0	1	0	2	0	0
Prague	0	0	0	0	2	1
Dublin	1	0	1	0	0	0
London	1	0	1	0	0	0
Paris	0	0	1	1	0	0
Luxembourg	0	0	0	1	0	0
Amsterdam	1	0	0	0	0	0
Vilnius	1	0	0	0	0	0
Riga	1	0	0	0	0	0
Tallinn	0	0	1	0	0	0

North	**Helsinki**	**Stockholm**	**Copenhagen**	**Warsaw**	**Riga**	**Tallinn**	**Vilnius**
Warsaw	0	0	7	0	4	2	7
Kaunas	0	0	0	0	4	2	9
Helsinki	0	7	0	0	1	6	0
Hamburg	0	2	9	0	0	0	0
Berlin	0	0	7	0	0	0	0
Riga	1	1	0	0	0	4	0
Kouvola	1	2	0	0	0	2	0
Vienna	0	0	1	1	0	1	1
Ljubljana	0	0	1	1	0	1	1
Trieste	0	0	1	1	0	1	1
Bratislava	0	0	0	1	0	1	1
Copenhagen	0	2	0	0	0	0	0
Klaipeda	0	0	0	0	0	0	2
Malmo	0	2	0	0	0	0	0
Munich	0	0	1	0	0	0	0
Gdansk	0	0	0	1	0	0	0

Appendix 4: Assessment grid

Master thesis assessment grid

Student's last name and first name: ……………………………………………………………….

	--	-	+	++	Remarks
Competence No. 7 "Project management"					
Timeliness (defense in June)					
Initiative capability and degree of student autonomy					
Competence No. 2 "Knowledge and reasoning"					
Innovative aspect (managerial and / or scientific originality)					
Ability to mobilize concepts and relevant literature to address the problem					
Competence No. 3 "A scientific and systematic approach"					
Clarity of presentation of the problem and / or hypotheses					
Scientific rigor of the methods used					
Balance, articulation and overall consistency of the work					
Quality and relevance of references					
Relevance of conclusions and managerial implications					
Competence No. 1 "Corporate citizenship"					
Ability to produce a societal reflection (intellectual independence, critical and reflective view of managerial practices)					
Competence No. 8 " Communication and interpersonal skills "					
Synthesis ability					
Compliance with the formal rules of presentation					
Quality of writing text (style, spelling, syntax)					
Competence No. 9 "Personal and professional development"					
Total investment of the student					
Appreciation of this master thesis before the oral defense	**/ 20**				
Competence No. 8 " Communication and interpersonal skills "					
Oral synthesis ability					
Compliance with the formal rules of oral presentation					
Appreciation of the oral defense					
Global appreciation of the master thesis	**/ 20**				

This grid is indicative of the competencies expected in the master thesis.
Source:https://www.uclouvain.be/cps/ucl/doc/iag/images/competency_en.pdf
The weights between the criteria, however, are left to the discretion of the jury.

Check one of four boxes of the scale with reference to the following assessment code. - - = Absent or poorly realized criterion (a "weak point" of this thesis); - = Badly or insufficiently realized criterion; + = Well done criterion; + + = Very well done criterion (a "highlight" of this thesis that makes recommended reading).

Each member of the jury gives this page to the thesis promoter who keeps them for any subsequent feedback.

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