Interreg
EUROPEAN UNION
Danube Transnational Programme
DIONYSUS

Integrating Danube Region into Smart & Sustainable Multi-modal & Intermodal Transport Chains

Concept for Container Liner Services

Version Final

Date: 29/06/2021

Final

DIONYSUS_Report_final_2.0

Project co-funded by European Union Funds (ERDF, IPA, ENI)

Document History

Version	**Date**	**Authorised**
0.1	18/06/2021	FTTE
Final	29/06/2021	FTTE

Contributing Authors

Name	**Organisation**	**Email**
Vladislav Maraš Aleksandar Radonjić Danijela Pjevčević Slobodan Mitrović	FTTE	v.maras@sf.bg.ac.rs a.radonjic@sf.bg.ac.rs danijela@sf.bg.ac.rs cobaja@sf.bg.ac.rs
Silviu Meterna	PDR	pdr.office.2020@gmail.com
RAFAEL Robert	PDM	Rafael@prodanube.eu
Cristiana Dima	MPAC	CDima@constantza-port.ro
Karin Voglsam	EHOO	k.voglsam@ennshafen.at
Igor Barna	VPas	igor.barna@vpas.sk
Monika Thury	HFIP	popeiproject@gmail.com
Srdja Ljesević	PGA	srdja.ljesevic@aul.gov.rs
Cristian Dobritoiu	MT	cristian.dobritoiu@mt.ro
Serban Cucu	AAOPFR	aserbancucu@gmail.com
Victor Ceban	UTM	victor.ceban@tran.utm.md
PP experts (assigned Communication experts)	All DIONYSUS partners	

Table of Contents

1 Table of Figures

2 Table of Tables

3 Abbreviations

Abbreviation	Explanation
BRP	Bulgarian River Shipping
CND tool	Container Network Development tool
COB	Container-on-barge
EaP	Eastern Partnership
IWT	Inland Waterway Transport
MILP	Mixed integer linear programming
MSC	Mediterranean Shipping Company
Ro-Ro	Roll-on/Roll-off
TEN-T	Trans-European Transport Network
TEU	Twenty-feet Equivalent Units
WTO	World Trade Organization

4 Introduction

4.1 Project objectives and WPT1 overview

The project's overarching goal is to facilitate DR's integration into multimodal and intermodal freight and passenger transport systems. In this context, Danube ports must be seen as key elements of the extensive DR transport system (which consists of a range of corridors, each with specific characteristics in terms of scale, trade, transport modes used, price and service quality), which are essential to help achieve this overarching goal.

WPT1 aims to provide a substantial knowledge basis regarding ongoing and future transport corridor developments in the Danube region as well as regarding their potential connections to transport corridors and networks in the Black Sea region. The analyses and assessments carried out in this work package shall identify gaps in corridor planning and transport infrastructure of the DR.

To achieve this, four activities have been planned. Activity A.T1.1 will identify and label gaps that are relevant for a better functioning transport system and for a higher share of waterborne transport considering the enabling role of ports. It will include:

- the assessment of the TEN-T Core as well as Comprehensive network sections and nodes (T.T1.1.1),
- a status quo analysis of the DR infrastructure (T.T1.1.2),
- an analysis of on-going and planned corridor projects for selected sections and nodes (T.T1.1.3),
- traffic flows analysis at DR transport corridor level involving all transport modes (T.T1.1.4).

Activity A.T1.2 investigates the current market situation and identifies alternative cargo volumes in growing markets. It will encompass:

- definition of trade flows and economic development scenarios (T.T1.2.1),
- analysis and forecasts of the main cargo flows for all modes of transport (T.T1.2.2),
- identification and quantification of the cargo flows that represent a potential for IWT (T.T1.2.3),
- evaluation of the high impact of available fairway depth on transport efficiency and competitiveness (T.T1.2.4)
- analysis of the prospects of containerized cargo development on the Danube (T.T1.2.5)
- investigation of the development of transport of passengers on the Danube waterway with a special focus on river cruise passengers (T.T1.2.6).

Activity A.T1.3 will investigate new cargo opportunities for Danube IWT that the transport of containers may offer. It will be done through the following tasks:

- analysis of the market framework conditions, as well as failed past operations (T.T1.3.1),
- studying potential routes and modelling of the potential services (T.T1.3.2),
- organization of the three stakeholder meetings that will identify potential partners for such a service as well as to inquire into the necessary market and regulatory pre-conditions (T.T1.3.4),
- based on the market analysis and the stakeholder feedback, elaboration of the recommendations for the conditions to set-up a successful service (T.T1.3.4),
- performing support activities for the implementation of these recommendations as well as undertaking preparatory measures to raise a container liner service on the Danube River (T.T1.3.5).

Activity A.T1.4 will analyze potential new cargo flows due to connections of the Danube waterway with transport corridors in the adjoining Black Sea region. It is especially related to the Middle Corridor comprising Georgia, Azerbaijan, Kazakhstan and reaching out to western provinces in China, as well as Connections via the Black Sea linking the Danube seaports with destinations in the Russian Federation as well as in Turkey. This will be achieved through:

- analysis of the socio-economic benefits and costs of increased cargo flows on the Danube waterway (T.T1.4.1),
- elaboration of the strategic concept for the promotion of Danube waterway transport in the European transport policy framework and towards the transport & logistics markets (T.T1.4.2),
- development of an Action plan detailing the measures to connect the Danube corridor with EU Eastern Partnership (EaP) corridors, the Russian Federation and Turkey (T.T1.4.4).

4.2 Objectives of Deliverable D.T1.3.2

This report assesses potential routes and services and introduces a tool for modelling of the container liner services according to vessel concepts and market requirements. Comprehensive analysis of the market framework conditions for container transport on the Danube, as well as investigation of the previously failed container transport services is given in the D.T1.3.1. Inputs for the elaboration of these concepts for Container Liner Service is based on previous concepts as well as being derived from stakeholder consultations. The first stakeholder workshop validated the conceptual work leading to further improvements in the concepts. The concepts are structured to provide a sound knowledge basis for companies that are interested in container transport or in the operation of container liner services. This research enables us to identify opportunities and potential threats for container liner services which are considered as a pre-condition to develop container transport on the Danube.

As the main outcome of this task, we have developed an online tool for optimal routing of a barge container ship on an inland waterway. It is based on the MILP model and aims to maximize the profit of the shipping company, while, at the same time, defines upstream and downstream calling sequence and number of loaded and empty containers transported between any two ports. The tool is titled Container Network Development or CND tool and is available at the http://dionysus.sf.bg.ac.rs/. CNDTool is made for any user and is free of charge.

5 Development of container barge networks – decision making level

5.1 Introduction

As with other modes of business, liner shipping companies, including barge operators, make decisions at the strategic, tactical, and operational planning levels (Schmidt & Wilhelm, 2000). These planning levels differ according to the time periods to which the decisions are made (short-term, medium-term and long-term). The most significant issues that shipping companies face and the decisions that, in this regard, are made at each of these three levels of planning are the following (Karsten, 2015; Maraš, 2017):

- Strategic planning level
  - Markets to be served;
  - Fleet size and mix or composition of the fleet;
  - Joining or formation of alliances;
  - Network design;

- Tactical planning level
  - Scheduling and routing of ships;
  - Fleet deployment;
  - Sailing speed optimisation;
  - Pricing;
  - Bunker refueling plan;
  - Environmental routing;
  - Empty containers management;

- Operational planning level
  - Cargo routing;
  - Container stowage plan;
  - Revenue management;
  - Disruption management and vessel schedule recovery;
  - Adaptation of the bunker refueling plan;
  - Berth scheduling;
  - Crane allocation;
  - Container stacking.

Decisions made at one level of planning have a major impact on decisions that will be made at other levels. Strategic decisions mostly relate to the adoption of general policies and business directions and represent a framework for decision-making at the tactical and operational planning levels. The available carrying capacities of inland waterway ships on different barge container liner services depend on decisions made at the tactical level, which, also, sets limitations that need to be taken into account in decision-making processes at the operational level. For example, the decision on the transport route of each container, from the port of loading to the port of unloading, clearly depends on the available capacities on barge ships navigating on different barge container liner services (tactical planning level) within the established container barge network (strategic planning level). In the opposite direction, the data on costs and revenues on each liner service represent the input data in the decision-making processes at the tactical and strategic level of planning.

5.2 Container barge network development – strategic planning level

The strategic planning level involves solving problems and making decisions that have long-term effects. They usually refer to a time period of 2 to 5 years and define the scope of decisions made at the tactical level of planning. These decisions are made usually once to two times a year. However, strategic decisions are very important for the success of a barge liner shipping company, because they usually define its further development directions and business areas that require large investments. Some of the usual decisions made at the strategic level in liner shipping include (Karsten, 2015):

- determining the market that will be served through established container liner services;
- defining the number of ships and the structure of the fleet that the shipping company will engage at various routes or services (either by owing or chartering ships);
- designing a network of container shipping liner services (network design);
- establishing or joining shipping conferences and alliances - cooperation with other shipping companies.

This deliverable deals with the possibilities of establishing container barge liner service on the Danube River. The decisions relating to this aspect clearly belong to the network designing domain. Therefore, we will develop a model that aims to facilitate decision-making processes at the strategic planning level, which relate to the establishment of a container barge network on the Danube.

Problems of planning the network of barge container liner services can be considered from three levels:

- problems of routing and scheduling barge ships on each liner service;
- problems of deploying ships on barge liner services and determining the frequency of services on each service;
- sailing speed optimization.

Routing and scheduling problems include determination of the calling ports on the barge liner service, the schedule for ships to call ports, as well as the days of the week on which ships will arrive and leave each port included in the service. After the liner service is defined, the ships maintain the established routes and schedule during a certain pre-defined period of time.

Different authors observe certain processes of planning container liner service networks through decision-making at the tactical level of planning. This especially refers to the problems of determining the schedule, i.e. the time of arrival of ships in ports on the route or service (scheduling), fleet deployment, as well as determining the optimal sailing speed (Guericke, 2014; Carsten, et al., 2015). Mulder & Dekker, 2016 classify the entire process of planning a liner service network at the tactical level of planning. Such differences in approaches clearly indicate that it is not possible to fully distribute the problems and decisions made by a liner shipping company by planning levels, i.e. some of these decisions, according to their characteristics, can be classified into two levels of planning.

The values of freight rates and the container transport demands may have a seasonal character, which, among other things, including hydro-meteorological conditions, impose the need for the constant redefining of established container liner services. Liner shipping companies are expected to perform revision of established services at least twice a year. The revision implies seasonal (the season usually lasts from 3 to 6 months) adjustment, i.e. reconfiguration of the entire container barge network of liner services or routes. The adjustment of the network is done on the basis of seasonal data on the changes in the demand in previous years, forecasting changes in the level of the demand, the experience of decision makers and experts, as well as adopted management policies at the level of barge shipping company.

6 Causes and conditions of the development of container barge networks – Outcome of the D.T1.3.1

6.1 Favourable and unfavourable conditions and recommendations for launching container liner services on Danube

D.T1.3.1 presents a theoretical and practical analysis of the causes and conditions of the development of container barge networks. In this research, we particularly emphasise the possibilities of establishing container transportation on the Danube River. Main findings, in terms of favourable and unfavourable conditions, as well as recommendations for the modelling and launching container liner service on the Danube River are given below.

Favourable conditions:

- **the Danube River enables the connection of economic potentials in the hinterland of a number of capitals and other strongest industrial regions in the Southeast Europe (**Belgrade, Budapest, Bratislava and Vienna; City of Bucharest is in the immediate vicinity, i.e. 60 km away from the Port of Giurgiu; Ennshafen Port is situated in Austria's strongest industrial region (the Container Terminal has a capacity with 450,000 TEU's; 2 industrial parks with more than 60 companies settled there; directly in the port area over 2.500 employees)**);**
- **the Danube River provides good enough conditions for the development of container barge transport from the connection with other river basins point of view** (Rhine River, through the Main-Danube Canal and the Main River; Sava River, Tisza River, etc);
- **annual container traffic in the Port of Constanta clearly indicates a significant, but untapped potential for the establishment of regular container barge lines on the Danube;**
- **from the distance of transport perspective,** as one of the factors of competitiveness**, the Danube River offers favorable conditions for development of container barge transport;**
- **the most important economic regions in Serbia** are the areas near the cities of Belgrade and Novi Sad – **proximity of the Danube River**; **container handling equipment is available in the ports of Belgrade and Pančevo**;
- **location of the port of Belgrade** at the mouth of the Sava River, or near the mouth of the Tisza River, as well as between the ports of Smederevo and Novi Sad, **is an extremely strong argument for choosing this port as a hub port, in the possible future establishment of "hub-and-spoke" system on the Danube;**
- there is possible **connection between Zagreb**, as the most important economic center in Croatia, **and the Danube River**;
- **port of Budapest is capable to handle container ships** (in most cases, the equipment is used to transship empty containers).

Unfavourable conditions:

- **container transit times, between the Port of Constanta and the ports in e.g. Serbia or Hungary are significantly higher than containers delivery times from the ports of Rijeka, Koper or Bar, using road or rail transport** (7 to 11 days, or 4 to 8 days compared to 1 day);
- the level of development and suitability of **available infrastructure** in the most ports on the Danube River to the needs of transshipment and transport of containers on the Danube is **another significant group of obstacles** to the development of this type of transport;
- **the structure of the cargo** that is currently most often **transported on the Danube** cannot be considered favourable for the development of container barge transport;
- **current level of economic activity in the hinterland area** on Danube is an obstacle for generation of sufficient volumes of container flows which would justify the establishment of container liner services;
- potential shippers are most **often insufficiently informed about the advantages of inland waterway transport** and they have **preferences toward road and rail transport**;
- possibilities of shipping containers from **The Port of Constanta to Bucharest**, using barge transport (via Giurgiu Port or Oltenita) has very **strong competition of road transport** (Bucharest and Constanta are connected with a 200 km highway);
- in Bulgaria, the most developed economic areas are the capital city of Sofia **with its surroundings, as well as the city of Ruse**; freight flows to Sofia, both in export and import direction, go through the ports of **Burgas and Varna**;
- concerning Serbia, the import and export of containers is mainly done through the **port of Rijeka, but also through the ports of Koper and Bar**;
- import and export activities **in Croatia** are mainly realized **through the Port of Rijeka**;
- most **import-export processes to or from Hungary** takes place through the **ports of Hamburg, Rotterdam and Antwerp**;
- **non-favourable hydro-meteorological conditions**, with emphasis on **low water level**, are usually taken as the main reason for non-successful attempts to establish container liner services on Danube;
- **low water levels** increase barge **freight rates** and undermine **service reliability**, two major factors shaping competition with other transport modes;
- **low water level**, on a certain part of the waterway, can lead to the need to move **barges one by one** (to dismantle the pushed convoys in order to enable the passage through a given section and formation, after the passage of the sector, of pushed tows) – transit time, of any type of cargo, may increase significantly;
- lower **water level** may lead to increased shipping traffic, as barges have to reduce the cargo load per sailing to reduce vessel draft and thus **make more roundtrips** to carry the same amount of freight

- **Danube flows through both the EU and non-EU countries** – this may cause **administrative and political obstacles**, which can, significantly, reduce the competitiveness of container barge transport compared to its rail and road alternative;
- **custom clearance procedure** in Serbia and Hungary may take up to three days - the fixed costs of the ship due to the delay of three days greatly burden the costs of transporting full containers on the routes on the Danube River;

Recommendations for the modelling and establishing container liner services on the Danube:

- **Port of Constanta**, should be a starting and ending port of call on all potential container liner services;
- Some of the **ports of call of the container liner service** (based on the previous experiences) should be Giurgiu, Ruse, Svistov, Smederevo, Belgrade, Novi Sad, Budapest, Ennshafen port, Deggendorf, Passau;
- **the analysis of the potential demand** for container barge transport on the Danube should incorporate the **cargo flows of the Danube countries in the import and export direction** and **selection of those that could be transferred from other transport modes to river transport**;
- the starting point for establishing a new barge service is usually the presence of **one or a few launching customers**, which guarantee a minimum (threshold) transport volume to start operations and hence limit exploitation risk;
- the establishment of container liner services, with a **high frequency (frequency of the service** should typically be **one to two round trips per week**), would be a necessary step towards the transfer of existing container flows in the Danube region, to a certain extent, to the Danube;
- container demand should relate to the container **transport over long, but also short distances** (experience on the Rhine indicate that containers are transported from the port of Rotterdam or Antwerp, by IWT, to locations in the hinterland, which are only about 50 km away);
- development of container barge transport is stimulated by **building up container terminals** in the hinterland;
- In that initial phase, where volumes are still small, **simple and rather inexpensive terminal equipment** may be chosen, for instance a reach stacker (possibly second-hand) or a general-purpose crane that is mixed used for both container and general cargo transshipment;
- use of the **combined pushed convoys**, consisting of standard push barges for the transport of bulk or liquid cargo and push barge for the transport of containers, may lead to good business results;
- one of the possible directions of action is the necessity of investing in **green ships with low draft**, in order to reduce the impact of low water levels - **subsidy programs from EU funds** could be very important for enabling such a development;
- process of establishing inland waterway container services must also take into account the possibility of **interruptions or limitations in navigation** (due to unfavorable hydro-meteorological conditions, i.e. low or high water level, fog, ice level, ice drift, wind, etc) and provide for appropriate solutions;
- development of container transport networks on inland waterways should be based on the establishment of some types of the **"hub-and-spoke" concept**

- the processes of **transporting empty containers by barge ships** should be particularly emphasized;
- container liner service operator should **sign collaborative agreements with major shipping container lines** (like MSC and China Shipping Container Lines) in order to increase the attractiveness and competitiveness of container barge transport on the Danube;
- **integration of river and maritime shipping companies, terminal operators, road or rail carriers, freight forwarders** is a basic precondition for a more significant development of inland waterway transport, and especially container barge transport;
- establishment of container liner service services implies **cooperation and joint action of market players and decision makers**;
- in the initial stages, **transport and port authorities** should be in charge of the integration of all participants.

6.2 Existing situation and further development steps

It is possible to distinguish several phases in the historical growth pattern of the European container barge network. These phases are the following (Notteboom and Konings, 2004; Notteboom, 2006; Frémont et al, 2009; Notteboom et. al.,2020):

- First phase (the pioneering phase mid-1968 till early 1970s);
- Second phase (mid 1970s till mid 1980s);
- Third phase (mid 1980s till mid 1990s);
- Fourth phase (from mid 1990s till 2007);
- Fifth phase (from 2007).

Each of the phases has its distinctive characteristics related to:

- terminal development;
- barge service design;
- container volumes;
- market organization.

This section describes the existing situation on the Danube based on the characteristics of the growth pattern phases of the European container barge network. In addition, we indicate possible directions for the development of container barge transport, i.e. what should be done to move to the next development phase of container transport on the Danube.

After analysing the phases in the historical growth pattern of the European container barge network, described in D.T1.3.1, we can see that existing situation on the Danube mostly corresponds to the first phase characteristics, given below:

- terminals:
  - establishment of first container terminals;
  - development of specialized terminals;
- services:

  - transport at irregular intervals;
  - usage of conventional barges;
  - primarily transport of grouped empty containers (in the immediate vicinity of the users);
  - barge transport unattractive to deep-sea carriers and shippers;
  - service offered by barge operators do not include transshipment and pre- and end-hauls by trucks;
- Container volumes:
  - low volumes;
- Market organization:
  - features only few pioneering barge operators in the market.

It can be noticed that even the characteristics of the first phase have not yet been fully achieved on the Danube. However, in order to accelerate the development of barge container transport on the Danube, the next steps in this process should be aimed at achieving the characteristics related to both the second and the third phase of this growth pattern. These characteristics, which can be also taken as an action plan for the development of container liner services on the Danube, are given in Table 1.

Table 1 Action plan for the development of container barge service on the Danube

Network elements	Distinctive characteristics	Comment
Terminals	new terminals to be set up within the perimeter of existing ports, or at new locations along the main navigation route	
	initiative for setting up inland waterway terminals should also come from the Danube carriers	
Services	scheduled container liner services by barge to be developed gradually	operators may divide the Danube into three navigation stretches, namely the Lower Danube, the Middle Danube and the Upper Danube
	Jointly operated and frequent liner services to each of the three navigation areas on the Danube	line-bundling services with typically five inland ports of call per loop
	complemented by a limited number of direct point-to-point shuttles	barge services are threatened by rail services; as a response, more and more waterway services are to be established; such services should consist of point-to-point services between the port and the largest urban area in the hinterland; it lowers costs and improves the reliability, frequency and transit time of services

	to achieve guaranteed punctuality - barge transport will gain in competitiveness	Once punctuality could be guaranteed by fixed departure schedules for each navigation area, with exceptions only occurring in case of problems with water levels, barge transport will quickly gain in competitiveness
Container volumes	annual transport volume on the Rhine to grow	
Market organization	the market is expected to be dominated by a few carriers / alliances operational collaboration agreements - raise the level of service and prevent destructive competition partners to streamline their sailing schedules participating parties to maintain its own commercial identity and freedom limited degree of central planning	existing barge carriers to initiate joint liner services on the different navigation areas of the Danube so as to offer a high frequency of departures from the seaports to the lower Rhine

7 Modelling of the container liner services on the Danube

In this section, we consider the barge container ship routing problem with the aim of maximizing the shipping company profit while picking up and delivering containers (both loaded and empty) along the inland waterway. We present a mixed integer linear programming (MILP) formulation for this problem. Our approach is based on the development of a mathematical programming model that can be applied to give recommendations about establishing a container liner service on any inland waterway. We specifically analyze the possibilities of applying this model in an attempt to facilitate decision-making processes related to the establishment of this service on the Danube.

7.1 Description of the container barge liner service modelling logic

The problem considered in this paper consists of finding the route for a given barge container ship as to maximize the profit of the shipping company. The solution of this problem defines upstream and downstream calling sequence and number of loaded and empty containers transported between any two ports while achieving maximum profit of the shipping company. The first port (a sea port, located at a river mouth) is always included in a solution, while the remaining n−1 ports in either direction (upstream or downstream) may or may not appear in the optimal (and even any feasible) solution.

Our approach is based on the perspective that a barge shipping company on Danube would like to design a liner service, i.e. sequence of calling ports with a given schedule. Such service has to be defined under the following assumptions, which are typically considered in the barge container ship routing:

- a predetermined ordering of ports for the outbound-inbound trips is given;
- the port calling sequence must start at and return to the first port, i.e. sea port located at a river mouth (usually, the Port of Constanta in case of Danube river);
- at the last visited port (furthest called port upstream), the ship changes sailing direction. In our case, this port is not known in advance and it is up to the model to make recommendation in terms of the last visited port in the upstream direction;
- the ship does not have to visit the same ports in upstream and downstream directions;
- the model assumes a weekly known cargo demand for all port pairs;
- all the container demand emanating from a port may not be selected for transport even if that port is included in the route or service;
- repositioning of empty containers between the ports in allowed.

We have analyzed a number of mathematical programming models, which can be found in the literature, and which relate to barge container shipping. Some of these models are contained in the following papers:

1. Maraš, V., (2008), “Determining Optimal Transport Routes of Inland Waterway Container Ships”, in Transportation Research Record, No. 2062, Transportation Research Board of the National Academies, Washington, D.C., pp. 50-58.
2. Maraš, V., “Routing of container ships on inland waterways”, Faculty of Transport and Traffic Engineering, University of Belgrade, February 07, 2012.

3. Maraš, V., Lazić, J., Davidović, T., Mladenović, N. (2013). "Routing of barge container ships by mixed-integer programming heuristics", Applied Soft Computing, Vol. 13, Number 8, pp. 3515-3528.
4. Alfandari, L., Davidović, T., Furini, F., Ljubić, I., Maraš, V., Martin, S. (2019). Tighter MIP Models for Barge Container Ship Routing, OMEGA: International journal of management science, Vol. 82, pp. 38-54.

However, a model proposed in the Alfandari et. al., 2019 significantly outperforms all other existing approaches available in the literature. It is particularly related to the computational time. In addition, it is also the first approach for the barge container shipping that simultaneously searches for the optimal route, while taking into account empty container balancing and repositioning, optimizing the turnaround time and therefore the size of the fleet and search for the final port of call in the upstream direction. Therefore, in the next section, we will introduce the model given in the Alfandari et. al., 2019.

7.2 Adopted model

The selected model is intended to determine:

- The turnaround time of the route, expressed in weeks (which also represents the size of the fleet);
- The last port of call of the route in the upstream direction;
- The sequence of ports to be called in the upstream direction;
- The sequence of ports to be called in the downstream direction;
- The numbers of full and empty containers to be shipped between any two ports;
- The numbers of empty containers leased or stored at any port on the route.

The model asks to maximise the profit, which is calculated as the difference between the revenue for shipping full containers and the port call costs, cargo-handling costs, bunker and capital costs. In order to be able to give realistic results, the model is structured to respect the following constraints:

- The route must start at Port 1 (Port of Constanta in our case);
- The total turnaround time (which includes travelling and handling time in ports) must be between pre-defined min and max numbers of weeks;
- At each port in the route, if the total inflow of full and empty containers (counting the flow both in upstream and downstream direction) is not equal to the total outflow, the difference should be balanced by either leasing or storing containers at that port;
- Empty containers can be transported on the ships;
- Full containers can be transported either in the upstream or downstream direction.

7.2.1 Input parameters

This section contains explanation of the input parameters, which are used in the model. These parameters are the following:

- $N = \{1, \ldots, n\}$: ordered set of n ports, where 1 is the starting port and n is the last port that can be visited in the upstream direction;

- $D_{ij} \in Z_+$: weekly expected number of full containers available to be transported between ports i and j [TEU/week];
- $C \in Z_+$: carrying capacity of the ship [TEU];
- $P_{ij} \in R_+$: freight rate per container from port i to port j, $i, j \in N$ [€/TEU];
- F_i : entry cost per call at port i, $i \in N$ [€];
- $L_i^f\left(U_i^f\right)$: loading (unloading) cost per full container at port i, $i \in N$ [€/TEU];
- $L_i^e(U_i^e)$: loading (unloading) cost per empty container at port i, $i \in N$ [€/TEU];
- $L_i(S_i)$: short-term leasing (storage) cost per empty container at port i, $i \in N$ [€/TEU];
- $T_i^l(T_i^u)$: average loading (unloading) time per full container at port i, $i \in N$ [h/TEU];
- $\tilde{T}_i^l\left(\tilde{T}_i^u\right)$: average loading (unloading) time per empty container at port i, $i \in N$ [h/TEU];
- $T_i^a\left(T_i^d\right)$: stand-by time for arrival (departure) port i, $i \in N$ [h];
- w_{min} : minimum allowed turnaround time [weeks];
- w_{max} : maximum allowed turnaround time [weeks];
- C_I : cost per time for keeping the ship idle at the initial port [€/h];
- H_I : maximum allowed idle time at the initial port [h];
- T_I : total sailing time to go from Port 1 to port i, and to go back to port 1, for each $i \in N$ [h];
- T_i^w: total waiting time for crossing borders and locks along the route from Port 1 to port i, in both directions, for each $i \in N$ (T_i^w: is counted in T_I) [h].

7.2.2 Container barge liner service model

The following variables are included in the model:

- χ_i – binary variables which are set to one iff port *i* is the last visited port, $i \in N$,
- x_i – binary variables which are set to one iff port *i* is called, $i \in \bar{N}$,
- z_{ij} – the number of full containers shipped from *i* to *j*, $(i, j) \in A^f$,
- y_{ij} – the number of empty containers shipped from *i* to *j*, $(i, j) \in A^e$,
- s_i – the number of empty containers stored at port i, $i \in N$,
- l_i – the number of empty containers leased at port i, $i \in N$,
- w – the turnaround time in weeks (which is also the size of the fleet),
- h – the number of idle hours the ship remains waiting at the starting port.

In the DAG G^f, for a given $S \subset \bar{N}$, let $\delta_f^+(S) = \left\{(i,j) \in A^f : i \in S, j \notin S\right\}$ denote the set of outgoing arcs from *S*, and similarly $\delta_f^-(S) = \left\{(i,j) \in A^f : i \notin S, j \in S\right\}$ the set of incoming arcs. For each node $i' \in \bar{N}$, with $A_{i'}^f$ we denote the arc-cut between the predecessors of i'(including i') and all its successors:

$$A_{i'}^f = \left\{(i,j) \in A^f : i \leq i', j > i'\right\} \tag{1}$$

with the corresponding notation $A_{i'}^e$ for empty containers. By summing up the number of all containers shipped through $A_{i'}^f$ and $A_{i'}^e$, we obtain the load of the ship between ports i' and $i' + 1$. Obviously, for each

$1 \leq i' < 2n - 1$, we must ensure that the total load does not exceed capacity *C*. We also use the following simplified compact notations:

$$\sum_j (z_{ij} + y_{ij}) \equiv \sum_{(i,j)\in\delta_f^+(i)} z_{ij} + \sum_{(i,j)\in\delta_e^+(i)} y_{ij}$$

$$\sum_j (z_{ji} + ji) \equiv \sum_{(j,i)\in\delta_f^-(i)} z_{ji} + \sum_{(j,i)\in\delta_e^-(i)} y_{ji}$$

The objective function is given in (2) and it maximizes the difference between the net profit ($\bar{P}$) obtained for shipping the full containers, and the remaining cost that is composed of the cost for loading and unloading empty containers, cost for entering the ports (they are calculated twice if the same port is visited in the upstream and downstream direction) and cost for balancing containers at each port. The last three terms correspond to the fuel cost, the charter cost and the cost for idle hours.

$$\max \begin{array}{l} \sum_{(i,j)\in A^f} \bar{P}_{ij} z_{ij} - \sum_{(i,j)\in A^e} \bar{C}_{ij} y_{ij} - \sum_{i\in\bar{N}} F_i x_i + \sum_{i\in N\setminus\{n\}} F_i \chi_i \\ - \sum_{i\in N} (S_i s_i + L_i l_i) - \sum_{i\in N} K_i \chi_i - wccW - C_l h \end{array} \tag{2}$$

Next expressions relate to the family of imposed constraints. Constraint (3) ensures that exactly one port is chosen as the last visited port, whereas constraints (4) and (5) ensure that this port is called (both in the upstream and downstream direction). Constraint (6) ensure that all ports after the last visited one cannot be called in each direction.

$$\sum_{i\in N} \chi_i = 1 \tag{3}$$

$$\chi_i \leq x_i, \qquad i \in N \tag{4}$$

$$\chi_i \leq x_{2n-1}, \qquad i \in N \tag{5}$$

$$x_i + x_j \leq 1, \qquad i \in N\setminus\{n\}, i < j < 2n - 1 \tag{6}$$

Constraints (7) and (8) guarantee that full containers can be shipped from port *i* to port *j* only if both ports *i* and *j* are called. In addition, they impose the number of shipped containers not to exceed the demand $\bar{D}_{ij}$.

$$z_{ij} \leq \bar{D}_{ij} x_i, \qquad (i,j) \in A^f \tag{7}$$

$$z_{ij} \leq \bar{D}_{ij} x_j, \qquad (i,j) \in A^f \tag{8}$$

Constraints (9) and (10) state that the complete ship load to be delivered at (or shipped from, respectively) port *i* cannot exceed ship capacity *C*, and in addition, nothing can be transported to/from a port, if the port is not called.

$$\sum_j (z_{ij} + y_{ij}) \leq Cx_i, \qquad i \in \bar{N} \tag{9}$$

$$\sum_j (z_{ji} + y_{ji}) \leq Cx_i, \qquad i \in \bar{N} \tag{10}$$

Inequalities (11) are the capacity constraints associated to the maximal capacity of the ship *C*: they ensure that the load of the ship (concerning both empty and full containers) between each node $i'$and $i' + 1$ does not exceed *C*.

$$\sum_{(i,j)\in A^f_{i'}} z_{ij} + \sum_{(i,j)\in A^e_{i'}} y_{ij} \leq C \qquad i' \in \bar{N}\backslash\{\bar{1}\} \tag{11}$$

Balancing of empty containers is given by constraints (12), where we again use the notation $\bar{\imath} = 2n - i$. For a given port $i \in N$, we calculate the difference of all containers loaded at *i* (either in the upstream and downstream direction) and containers unloaded at *i* (again, either upstream or downstream). If this difference is positive, the shipping company has to lease as many containers in port *i*, otherwise, it will need to store them. By minimization of $S_i s_i + L_i l_i$ in the objective function, at optimality we necessarily have for each *i* either $l_i \geq 0$ and $s_i = 0$ or $s_i \geq 0$ and $l_i = 0$, but not $l_i > 0$ and $s_i > 0$.

$$\sum_j (z_{ij} + y_{ij}) - \sum_j (z_{ji} + y_{ji}) + \sum_j (z_{\bar{\imath}j} + y_{\bar{\imath}j}) - \sum_j (z_{j\bar{\imath}} + y_{j\bar{\imath}}) \leq l_i - s_i \qquad i \in N \tag{12}$$

Finally, we compute the turnaround time *w* and the number of idle hours *h* with constraint (13) together with the minimisation of associated costs in the objective. The bounds on variables *w* and *h* are given in constraints (14)-(15).

$$168w - h \leq \sum_{i\in N} T_i \chi_i + \sum_{(i,j)\in A^f} \bar{T}_{ij} z_{ij} + \sum_{(i,j)\in A^e} \bar{T}^e_{ij} y_{ij} + \sum_{i\in \bar{N}} \bar{T}_i \chi_i - \sum_{i\in N\backslash\{n\}} \bar{T}_i \chi_i \leq 168w \tag{13}$$

$$w_{min} \leq w \leq w_{max} \tag{14}$$

$$h \leq H_i \tag{15}$$

The nature of decision variables is defined by (16)-(20).

$$s_i, l_i \geq 0 \qquad i \in N \tag{16}$$

$$x_i \in \{0,1\} \qquad i \in \bar{N} \tag{17}$$

$$w, h \in Z_+ \tag{18}$$

$$z_{ij} \in Z_+ \qquad (i,j) \in A^f \tag{19}$$

$$y_{ij} \in Z_+ \qquad (i,j) \in A^e \tag{20}$$

This model integrates the optimisation of the turnaround time along with the design of the shipping route.

7.3 Input data

This sub-section introduces the input data, which refer to numerous examples, aiming to determine the optimal liner services of container vessels on inland waterways. The proposed model can be used to assist in making such strategic decisions on any inland waterway. However, since the goal of the DIONYSUS project is to facilitate Danube Region's integration into multimodal and intermodal freight transport systems, all the examples considered relate to the Danube River.

Web site https://www.danubecommission.org/dc/en/danube-navigation/ports-on-the-danube/ contains indications about existence of container handling capabilities in the Danubean ports. Based on this source, most of the ports, included in our elaboration own, to a more or less extent, container handling equipment. Elaborated ports are the following:

- Romania – Contstantza, Giurgiu, Drobeta Turnu Severin;
- Bulgaria –Vidin, Ruse;
- Serbia – Smederevo, Pančevo, Belgrade, Novi Sad;
- Croatia – Vukovar;
- Hungary – Baja, Dunaújváros, Budapest;
- Slovakia – Komarno, Bratislava;
- Austrian public ports – Vienna, Ennshafen port, Krems, Linz;
- Germany – Passau, Deggendorf, Straubing, Regensburg.

This list of ports is indicative, containing ports which are selected based on the attempt to understand the potential of introducing container liner services on the Lower, Middle and Upper Danube. Just as the model can be used to elaborate the described issues on any inland waterway, so very easily the above list of ports can be changed, according to user needs. In any case, the user is the one who selects which ports, from the offered ones, will be taken into account, that is, there is no obligation to consider all given ports. It is enough to select a few ports and the model, i.e. the developed online tool – CND tool, will suggest the optimal container liner service.

The input data, which refer to all included ports, i.e. port-related data consists of two groups. The first group is made of data on distances between ports, locking time between every two ports, as well as boarding times. These data sets are defined on the basis of generally known values (e.g. distances), as well as taken from various studies and sources, such as COLD, 2006; Konings, 2009; EHOO, 2018; Port of Constanta, 2019. Therefore, this data cannot be changed.

The second group of port-related data, which is necessary for the functioning of the proposed model and CND-online tool, consists of:

- Time-related data
  - Average loading time per full container at each port [h/TEU];
  - Average unloading time per full container at each port [h/TEU];
  - Average loading time per empty container at each port [h/TEU];
  - Average unloading time per empty container at each port [h/TEU];

- Stand-by time for arrival at each port [h];
- Stand-by time for departure at each port [h];

- Cost-related data
  - Loading cost per full container at each port [EUR/TEU];
  - Unloading cost per full container at each port [EUR/TEU];
  - Loading cost per empty container at each port [EUR/TEU];
  - Unloading cost per empty container at each port [EUR/TEU];
  - Entry cost per call at each port [EUR];
  - Short-term storage cost per empty container at each port [EUR/TEU];
  - Short-term leasing cost per empty container at each port [EUR/TEU].

Various sources were used to collect time and cost-related data for some of the considered ports. However, as not all of these ports have the necessary container handling equipment, most of the data is assumed. Either taken from the existing sources or assumed, all ports are given default values of the port-related data. On the other side, each user has the option to change these default values, if they think that the data do not correspond to real values.

Users also define ship-related data, i.e. data on the ship that would be used for container transport on the liner service to be established. This data include:

- Ship name;
- Upstream Speed (km/h);
- Downstream Speed (km/h);
- Specific Fuel Consumption (t/kWh);
- Specific Lubricant Consumption (t/kWh);
- Engine Power (kW);
- Weekly Charter Costs (EUR/week);
- Carrying Capacity (TEU);
- Cost per time for keeping the ship idle [EUR/h].

Given the current situation regarding the transport of containers on the Danube, data on container traffic between ports, as well as on the values of freight rates cannot be obtained from real and relevant sources. Therefore, there are no values, which refer to these parameters, which could be used as default values. Since this is the case, it is necessary to use the assumed values. The assumed demand values should be obtained on the basis of assessment of container flows and analysis of potentials of cargo containerization between any two ports. Deliverable D.T1.2.5 “Report on containerization demands on the Danube Region” deals with cargo flows, which could be containerized and then transported on the waterway in the Danube Region. Outcomes of this report should be used to determine the required input values in our tool. For this reason, users have the opportunity to define themselves the expected weekly number of full containers available to be transported between selected ports, as well as the values of expected freight rates. This approach allows users to analyze the impact of different values of both demands and freight rates on the establishment of container liner services on the Danube.

One of the most important features of any container liner service relates to total turnaround time. Our model, as well as the CND online tool, has been developed in a way to allow the user to elaborate the impact of different values of total turnaround time on the cost-effectiveness of maintaining a container liner service on the Danube. For this reason, the user is expected to define the minimum and maximum value of the turnaround time, and the model, i.e. CND tool, will determine and suggest the optimal value of this indicator.

The model also allows for considering the impact of fuel and lubricant prices on the establishment of a container liner service on the Danube. Therefore, the user is in charge to provide the values of these parameters himself.

The aim of the proposed model is to enable each user to receive recommendations on the possibility of establishing a container liner service on the Danube River. Each user has the option of selecting the ports to consider, providing the appropriate time and cost-related data about selected ports, defining the basic characteristics of the ship that would be employed in container liner service, setting the expected demands and freight rates between ports, determining values of preferred turnaround times, as well as values of fuel and lubricant prices. Thus, by simply changing the values of these parameters, the user can get an indication of the cost-effectiveness of introducing or maintaining a container liner service on the Danube under various scenarios. In other words, the user can increase or decrease the values of each of these parameters and thus analyze the impact of such changes on the justification of the introduction or maintaining such services. The following cases can be taken as examples:

- Analysis of the impact of increasing the maximum turn-around time from two to three weeks;
- Analysis of the impact of increasing freight rates by 10%;
- Analysis of the impact of reducing the price of fuel by 5%;
- Analysis of the impact of increasing loading / unloading costs in several ports by 15%.

These are only arbitrarily chosen options, whereby the user can change the value of any parameter, in any direction, by any percentage, according to his own needs.

7.4 CND Tool – Solution method

7.4.1 Introduction

CND Tool is a custom coded interactive calculation software that is technically consisted of the PHP based frontend, MySQL based custom database, as well as Python based calculation engine with MILP (Mixed Integer Linear Programming) intelligence. It is designed to operate within class of Linux based server operating systems. This tool is created with intention to operate either in real hardware or in virtualized CPU multithread environment. Just like any other software solution, it has also minimal hardware requirements, which should be satisfied in order to operate with expected performance.

Main features of this tool are:

- multiuser activity support – each user has its review of earlier activities (sessions)
- set of selected ports' parameters autoload – within each new session
- very efficient Python based mixed integer linear programming engine
- included option to delete unnecessary sessions.

7.4.2 CND Tool – Engine and Database description

CND Tool is consisted of three engines (Session engine, Data Entry & Review Engine and Python Calculation Engine) and the CND Database. The block diagram of this tool is presented in the Figure 1.

7.4.2.1 Session Engine

Session engine contain registration, login and session management modules. Registration module provides simple saving scheme that consists of only username and password data in order to keep privacy of participants. It also contain possibility to register name, surname and email address if needed (only with participant consent, if such an option is activated). Its filter prevents participant's registration with same usernames. Login modules uses the same scheme for user authentication. After successful authentication, this module passes part of entered credentials to Session module in order to generate list of sessions associated to the corresponding participant. As a result, the participant is in position to choose between opening a new session and editing data in a previously recorded session. The response is furtherly exchanged as a session-id flag between Session engine and Data Entry & Review Engine in order to keep consistency on recorded Session and other data in CND Database. The CND Database structure is graphically presented in Figure 2. User authentication data upon registration is stored in "users" table, while all registered sessions are stored in "activity" table of the database.

Session list also offers participant option to delete selected previously recorded session by clicking on the Delete Session button. Click on this button will open the data review page, where all submitted data is shown, offering possibility to cancel this operation by clicking to the corresponding button in order to be back to the session list page.

7.4.2.2 Data Entry & Review Engine

Data Entry & Review Engine is designed with the aim to generate user interface that would be used by the participant to enter new or edit recorded dataset related to following entities:

- General-dataset;
- Ports' selection dataset;
- Selected ports' parameters;
- Ship parameters;
- Data related to
    - expected weekly number of full containers available to be transported between selected ports;
    - freight rate per container between selected ports.

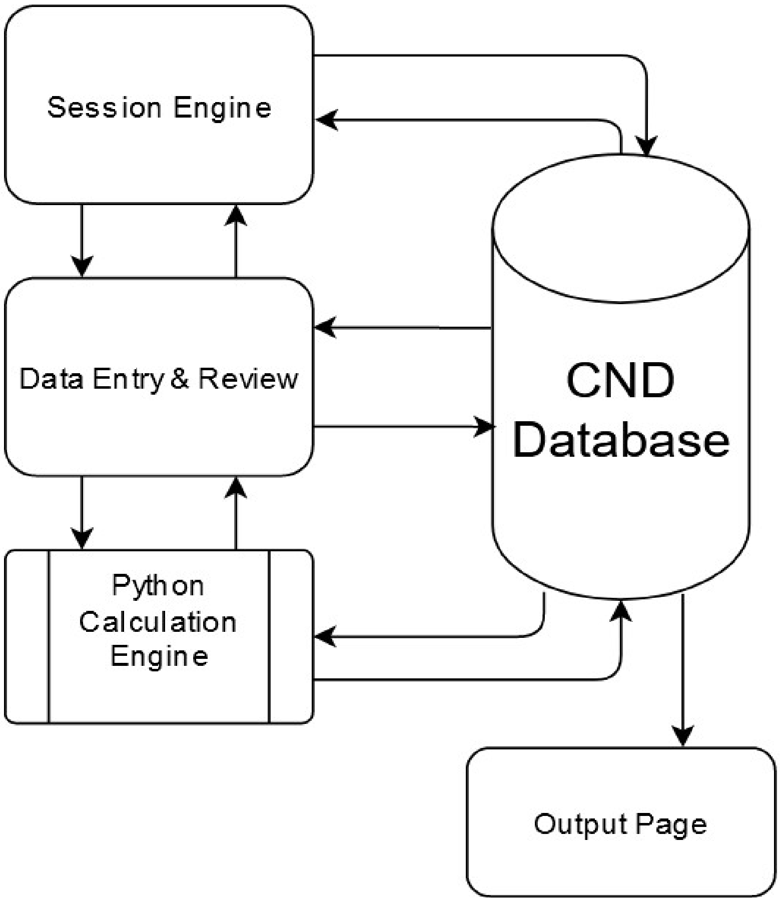


Figure 1. CND tool block diagram

This Engine mostly communicates to both, the participant and the CND Database through the generated user interface. On the other hand, its communication to other two engines is limited to session data exchange only. The Engine is consisted of three modules:

- New-session data entry Module
- Existing Session data review and edit Module
- Process Router Module.

New-session data entry Module is designed with the aim to iteratively guide participant through new data entry process. The entry sequences correspond to the set of entities listed above. Each new entry sequence is activated after submission of previous one. This is realized by generating submit button below each corresponding table/cells-set. General-dataset entity comprise four different elements: Fuel price, Lubricant price, Minimal allowed turnaround time and Maximal allowed turnaround time.

The dataset elements are stored in the “generaladata” table of the CND Database. Ports-dataset is created with the purpose of selection of such ports, which parameters would be used later in the calculation process. In this Module (that could be activated by selecting “New Session” option) list of ports is loaded from the “ports” table of the CND Database. Selection of some ports is directly related to the dimensioning process of another table – selected ports' parameters table (SPP table). SPP table consists list of 13 parameters, which are specific for each selected port and the number of columns directly corresponds to the number of selected ports.

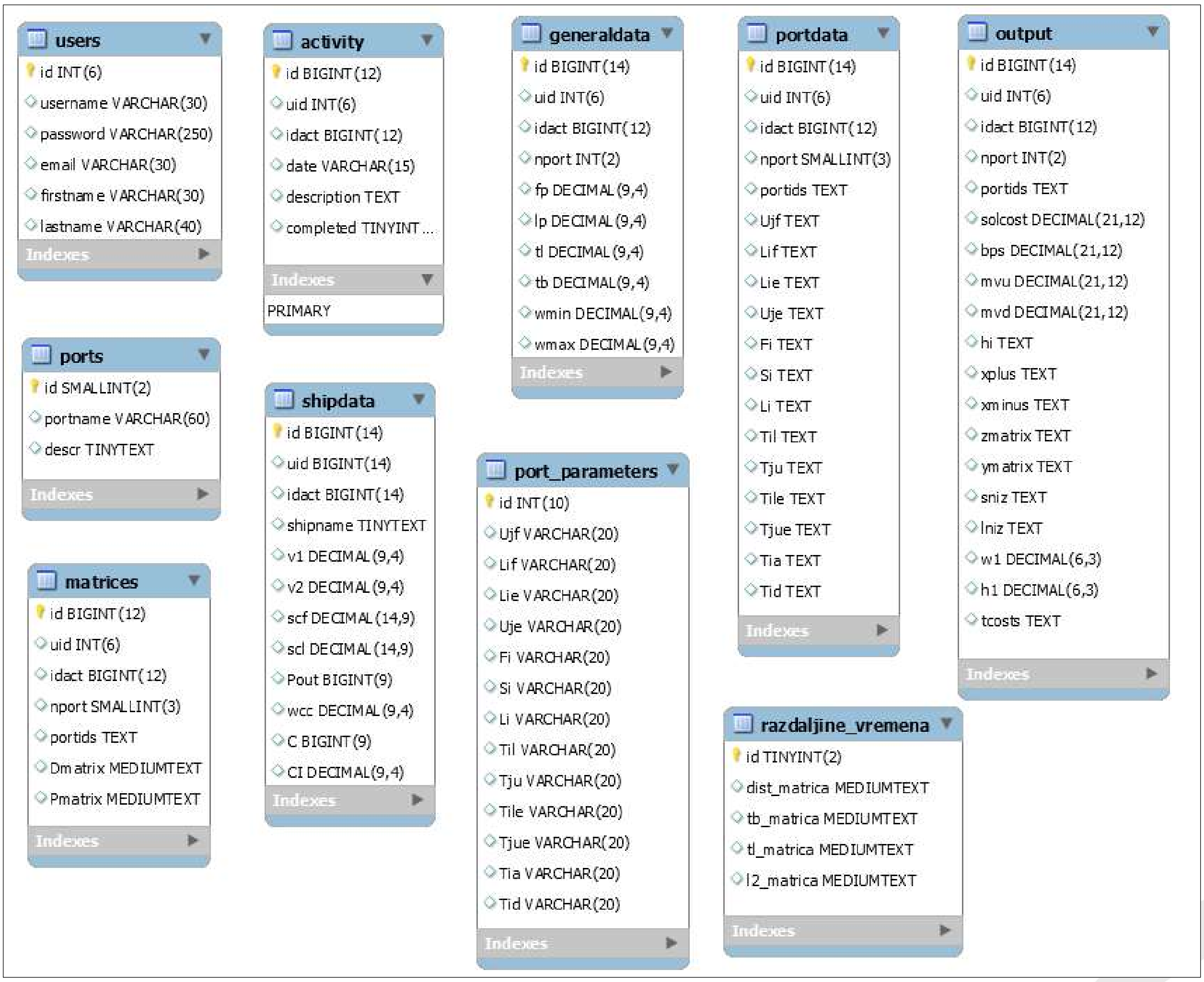


Figure 2. CND Database basic structure – tables and corresponding columns

These parameters are: Unloading cost per full container at each port, Loading cost per full container at each port, Loading cost per empty container at each port, Unloading cost per empty container at each port, Entry cost per call at each port, Short-term storage cost per empty container at each port, Short-term leasing cost per empty container at each port, Average loading time per full container at each port, Average unloading time per full container at each port, Average loading time per empty container at each port, Average unloading time per empty container at each port, Stand-by time for arrival at each port, as well as Stand-by time for departure at each port.

Total number of cells, which have to be submitted increases by 13 with each new adding of another port. Considering the fact that total number of cells, which are required to be submitted, could be huge – a new feature is introduced: selected ports' parameters autoload. This feature is technically realized by generating a special query that automatically "pulls" data from the CND database table "port parameters" and loads them to the corresponding cells of SPP table. Participant could modify these cells later and all submitted data is stored in “portdata” table of the same database. In this way, the sequence related to Selected ports’ parameters entry is completed.

Next sequence is related to Ship parameters. It generates a set of nine cells, which correspond to following ship parameters: *Ship name*, *Upstream Speed*, *Downstream Speed*, Specific Fuel Consumption, *Specific Lubricant Consumption*, *Engine Power*, Weekly Charter Costs, Carrying Capacity, as well as *Cost per time for keeping the ship idle* at the initial port. Submitted cells’ values are stored in “shipdata” table of the CND database.

The last sequence is related to data, whose submission is realized through generation of two matrices:

- expected weekly number of full containers available to be transported between selected ports
- freight rate per container between selected ports.

Size of both matrices corresponds to the number of selected ports. Considering structure, the first matrix is not symmetric unlike the second one. So, the second matrix is configured for data submission in the upper half (above diagonal). After clicking on the submit button, the engine will reallocate copies of entered data to corresponding cells (below diagonal) in order to keep rule of symmetric matrix. Further, submitted data of both matrices will be stored to the table “matrices” of the CND Database.

Existing Session data review and edit Module is similar to New-session data entry Module, regarding the way that tables, cell-sets and matrices are generated by Engine. However, unlike New-session data entry Module, all data is directly loaded from the corresponding tables of the CND Database with the respect of user-id and the id of the active session. This reflects in the inability to change the structure of selected ports, but all other data could be edited and saved at the end of the generated page. After editing data, records in corresponding tables are updated after click on Submit button.

Process Router Module is a backend module that routes session from module to module according participant demands. It is also responsible for keeping track on session flow, from the moment of session start until its end.

7.4.2.3 Python Calculation Engine

When participant completes data entry/edit by clicking the Save button, it gets an option to call the Optimization process, by clicking the Calculate button afterwards. In this way, the Python Calculation Engine will be activated. First, this engine gets necessary session data generated by Process Router Module, which is further used in order to load corresponding data from the tables of the CND Database. Upon load, this Engine activates set of Python modules, which operation is explained in more detail in sub-section 7.4.2.4. When Calculation process is completed, corresponding Python module generates the flag that is used by this Engine in order to store obtained data in the “output” table of the CND Database.

7.4.2.4 Operation of Python modules

In order to solve mixed integer linear programming CNDTool, Coin-or branch and cut (CBC) solver is used. CBC solver is called through the Python-MIP package. Python-MIP package provides tools for modeling and solving Mixed-Integer Linear Programming Problems (MILPs) in Python. Python-MIP module was written in modern, typed Python and works with the fast just-in-time Python compiler Pypy.

There is two layers in Python-MIP module: modelling layer and calling layer. Modelling layer is used for writing model constraints and objective functions, while calling layer is used for calling and starting CBC solver.

In the modelling layer, models can be written very concisely, as in high-level mathematical programming languages. It is responsible for accurate mapping of model constraints and objective functions as written text to usable programming code. Calling layer is responsible for starting CBC solver, getting optimal and feasible solutions and for printing final solutions.

Python-MIP makes easier the development of high-performance MIP solver for project application by providing a tight integration with the branch-and-cut algorithms of the supported CBC solver. Strong formulations with an exponential number of constraints are handled by the inclusion of Cut Generators and Lazy Constraints from CBC solver. Although heuristics can be integrated for providing initial feasible solutions to the MIP solver, they are not applied in the first step.

Python is a scripting language and lets programmers to enter other software platforms as it is CBC solver. However, in order to amplify the possibilities of the final solution, python scripts are written in a manner to enable many more functions that are in connection with the final solutions. The scripts are written so that each script represents one class.

Classes provide a means of bundling data from the PHP code and functionality together. Every class creates a new type of object, allowing new instances of that type to be made. For example, there are three main classes in the tool: one for gathering data, one for writing models and one for issuing final solutions .Each class instance have attributes attached to it for maintaining its state. In order to accept all modifications from the input data class instances also have methods for modifying its state. Classes are parts of the dynamic nature of Python: they are created at runtime, and can be modified further after creation.

7.4.2.5 Output page

Recorded data are further loaded by Output page that will generate appropriate report and offer possibility to enter the short comment on obtained calculation results. It will also set the completed flag to the active session and offer back to another data review or back to session list.

8 Selected case studies

This section is intended to describe the possibilities of the model and the CND tool through presentation of various examples. It should be pointed out that port-related data, ship-related data, expected weekly demands and freight rates, as well as fuel and lubricant prices are assumed. Therefore, this example serves for the illustrative purposes as each user can easily modify the input data according to the real values that the user might have at disposal. Processes of changes of the input data are described in the sub-section 7.3 Input data, as well as in the Annex of this Report.

8.1 Example 1 – Input data

The first step relates to provision of the fuel and lubricant prices, given in EUR/t, as well as to the indication of preferences in terms of the minimum and maximum turn-around times of the container liner service. A user can enter any values according to the needs and expected characteristics of the service. Figure 3 gives the values of the general data in our example.

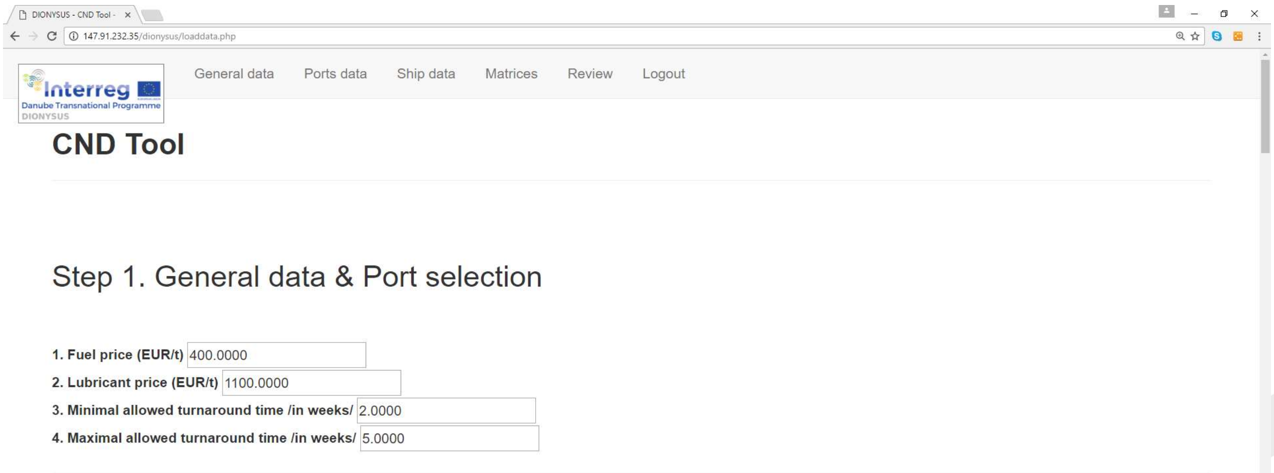
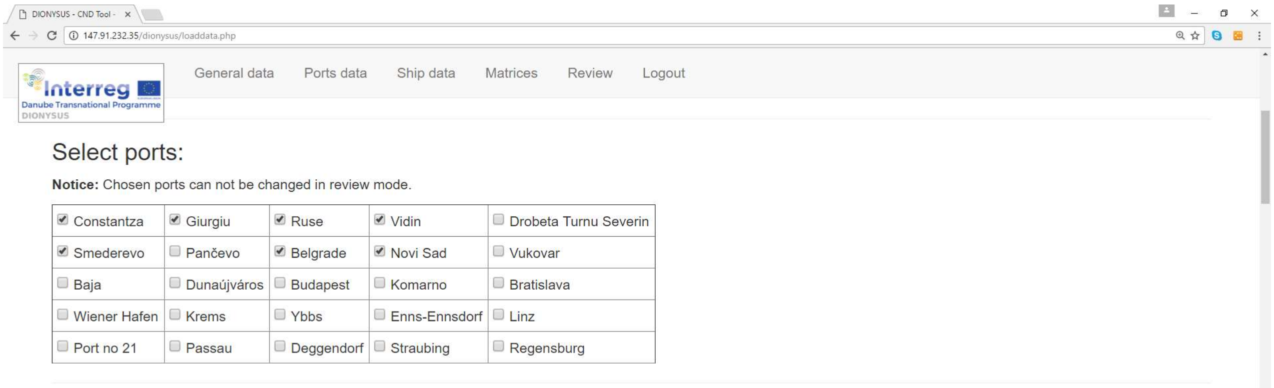


Figure 3. General data in the Example 1

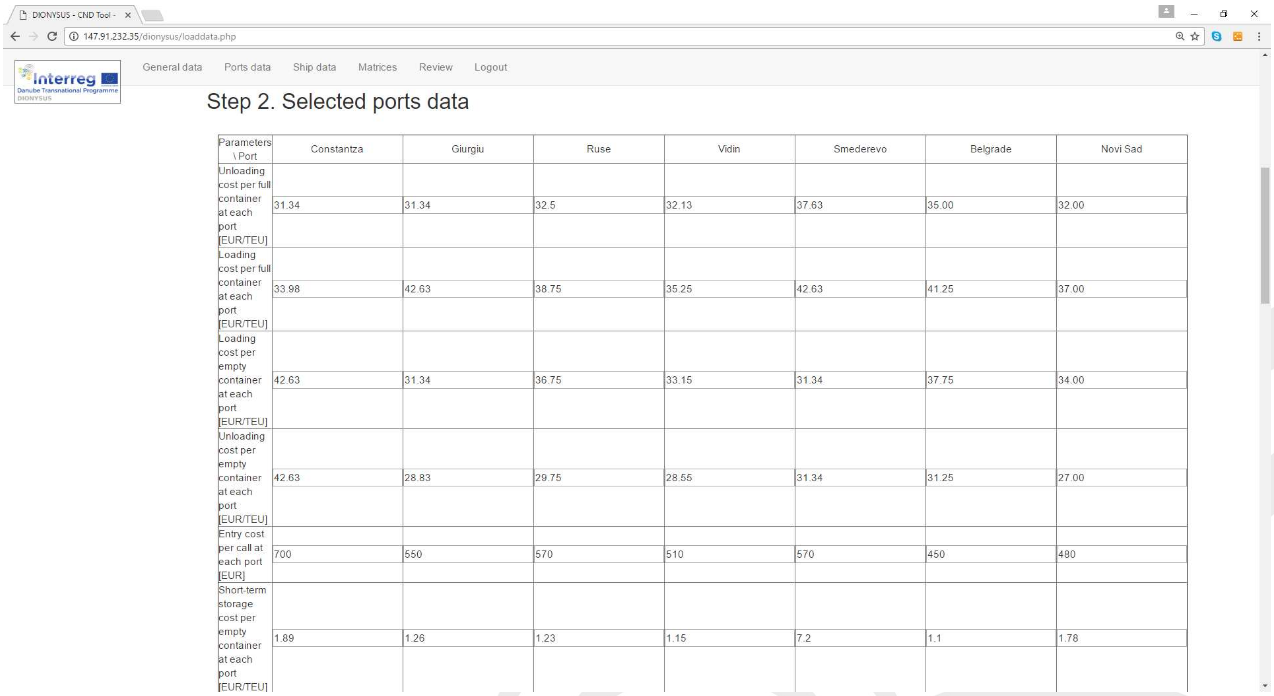
As can be seen from the Figure 3, the first step also requires selection of the possible ports of call in the container liner service. Figure 4 indicates that there are a total of 25 ports on the Danube in the database. Therefore, the user can select up to 25 ports in his example and the model, i.e. CND tool will recommend those, among selected, which should be called at in the liner service. User should be aware that the more ports are selected, the longer will be the calculation time. It could even happen that, due to complexity of the example, the CND tool might not be able to find optimal or any feasible solution. At the moment, our recommendation is that users select up to 10 ports in their examples. Selection of any port does not mean that the port will be included in the optimal container liner service. It only means that the CND tool will consider the possible inclusion of that port in the recommended container liner service. In our example, we selected the following ports: Constantza, Giurgiu, Ruse, Vidin, Smederevo, Belgrade and Novi Sad. As we have already explained, Port of Constantza will always be selected by default, as our assumption is that this port will be starting and ending port of any service on the Danube. Of course, based on the user needs, we can relax this constraint and allow the model to decide which will be the starting port on the service.



☑ Constantza	☑ Giurgiu	☑ Ruse	☑ Vidin	☐ Drobeta Turnu Severin
☑ Smederevo	☐ Pančevo	☑ Belgrade	☑ Novi Sad	☐ Vukovar
☐ Baja	☐ Dunaújváros	☐ Budapest	☐ Komarno	☐ Bratislava
☐ Wiener Hafen	☐ Krems	☐ Ybbs	☐ Enns-Ennsdorf	☐ Linz
☐ Port no 21	☐ Passau	☐ Deggendorf	☐ Straubing	☐ Regensburg

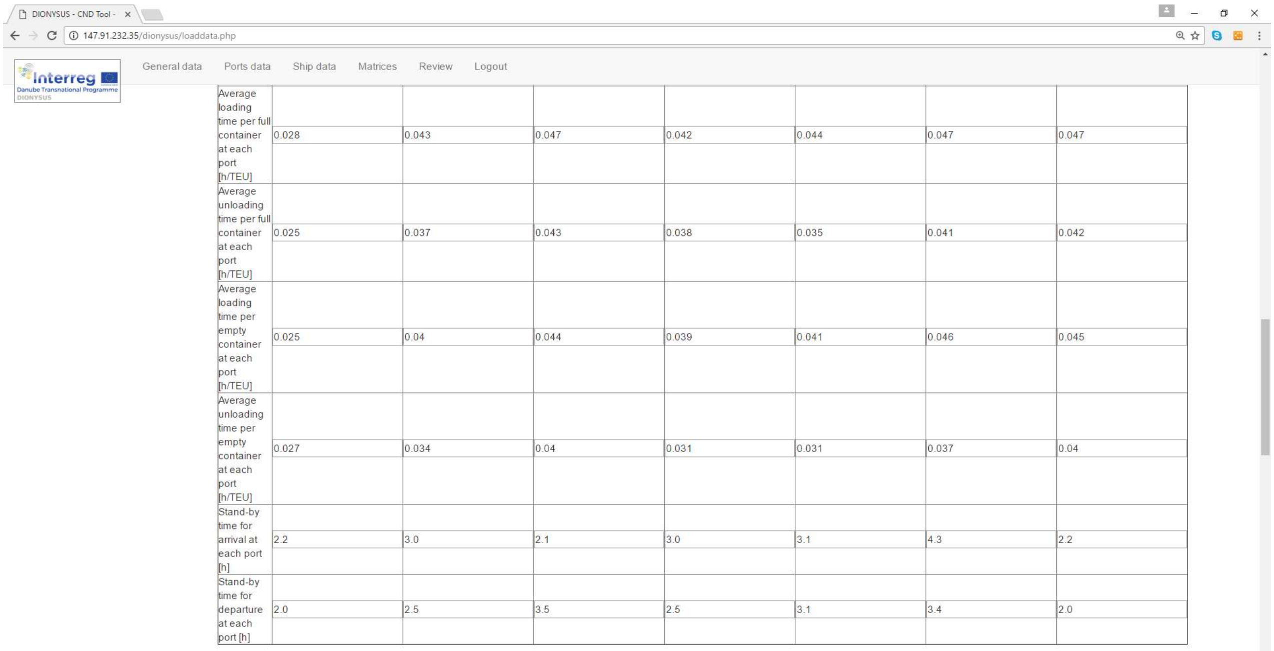
Figure 4. Selection of ports

After selection of ports, all time and cost-related data relating to these ports will be loaded in the Step 2. The user can go through all the data and make all necessary changes. This data is given on Figure 5 and Figure 6



Parameters \ Port	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Unloading cost per full container at each port [EUR/TEU]	31.34	31.34	32.5	32.13	37.63	35.00	32.00
Loading cost per full container at each port [EUR/TEU]	33.98	42.63	38.75	35.25	42.63	41.25	37.00
Loading cost per empty container at each port [EUR/TEU]	42.63	31.34	36.75	33.15	31.34	37.75	34.00
Unloading cost per empty container at each port [EUR/TEU]	42.63	28.83	29.75	28.55	31.34	31.25	27.00
Entry cost per call at each port [EUR]	700	550	570	510	570	450	480
Short-term storage cost per empty container at each port [EUR/TEU]	1.89	1.26	1.23	1.15	7.2	1.1	1.78

Figure 5. First group of port-related data



Average loading time per full container at each port [h/TEU]	0.028	0.043	0.047	0.042	0.044	0.047	0.047
Average unloading time per full container at each port [h/TEU]	0.025	0.037	0.043	0.038	0.035	0.041	0.042
Average loading time per empty container at each port [h/TEU]	0.025	0.04	0.044	0.039	0.041	0.046	0.045
Average unloading time per empty container at each port [h/TEU]	0.027	0.034	0.04	0.031	0.031	0.037	0.04
Stand-by time for arrival at each port [h]	2.2	3.0	2.1	3.0	3.1	4.3	2.2
Stand-by time for departure at each port [h]	2.0	2.5	3.5	2.5	3.1	3.4	2.0

Figure 6. Second group of port-related data

Step 3 requires provision of the ship-related data (Figure 7). The user can easily provide and change these inputs and therefore, evaluate possible deployment of various ships and tows on the container liner service.

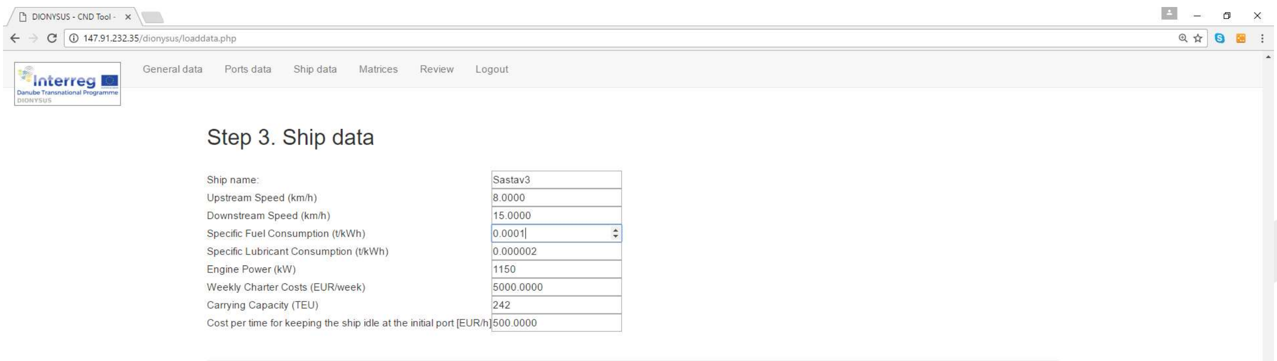
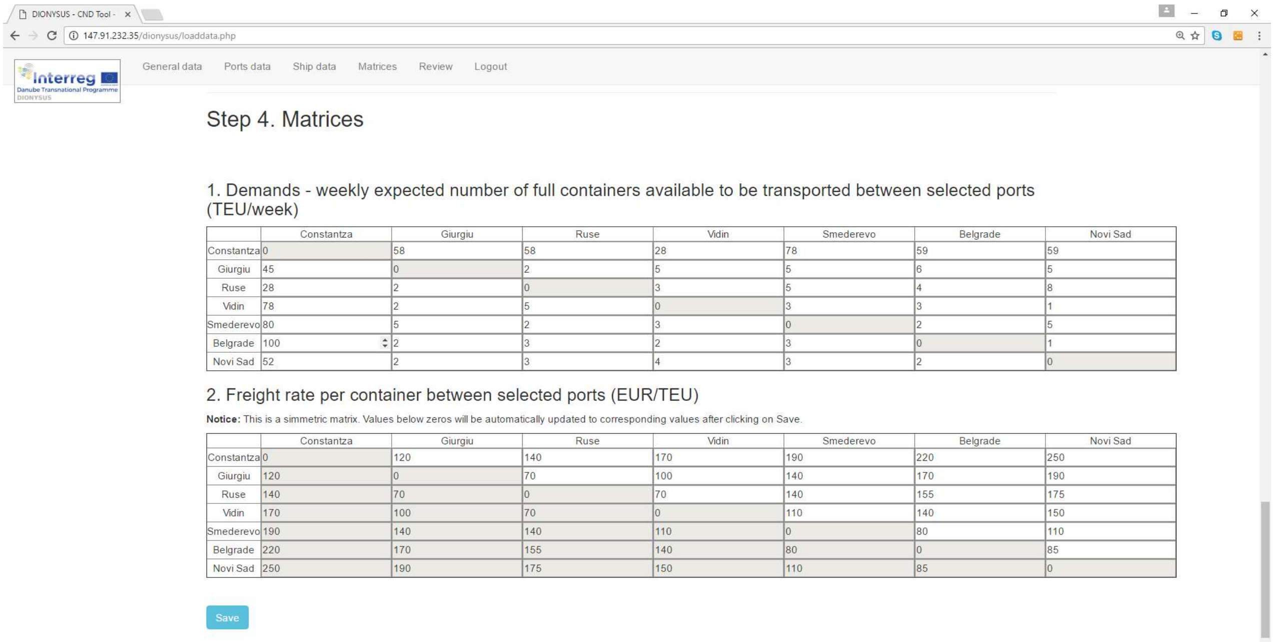


Figure 7. Ship-related data

In the last step 4, the user is required to enter the values of the following parameters:

- expected weekly number of full containers available to be transported between selected ports;
- freight rate per container between selected ports.

The user is expected to fill in these two matrixes with its own data. This data can be easily modified, so the user can evaluate the impact of different container demands between any two ports on the container liner service. Provided data, in our example, are given in the Figure 8.



Step 4. Matrices

1. Demands - weekly expected number of full containers available to be transported between selected ports (TEU/week)

	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Constantza	0	58	58	28	78	59	59
Giurgiu	45	0	2	5	5	6	5
Ruse	28	2	0	3	5	4	8
Vidin	78	2	5	0	3	3	1
Smederevo	80	5	2	3	0	2	5
Belgrade	100	2	3	2	3	0	1
Novi Sad	52	2	3	4	3	2	0

2. Freight rate per container between selected ports (EUR/TEU)

Notice: This is a simmetric matrix. Values below zeros will be automatically updated to corresponding values after clicking on Save.

	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Constantza	0	120	140	170	190	220	250
Giurgiu	120	0	70	100	140	170	190
Ruse	140	70	0	70	140	155	175
Vidin	170	100	70	0	110	140	150
Smederevo	190	140	140	110	0	80	110
Belgrade	220	170	155	140	80	0	85
Novi Sad	250	190	175	150	110	85	0

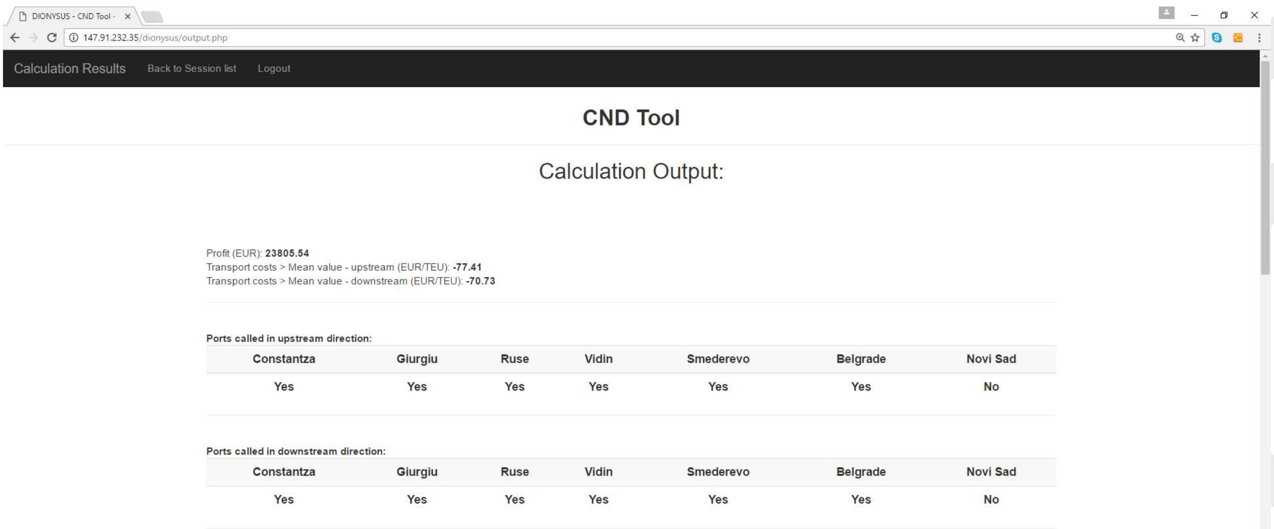
Save

Figure 8. Container demands and freight rates matrixes

8.2 Example 1 – Outputs

After provision of all necessary input data, the CND tool will perform all required calculations and the give the file with the recommendations about the design of the container liner service on the Danube. In our example, the service should include calling at the following ports (Figure 9):

- upstream: Constantza, Giurgiu, Ruse, Vidin, Smedervo, Belgrade
- downstream: Belgrade, Smederevo, Vidin, Ruse, Giurgiu, Constantza.



Calculation Results Back to Session list Logout

CND Tool

Calculation Output:

Profit (EUR): **23805.54**
Transport costs > Mean value - upstream (EUR/TEU): **-77.41**
Transport costs > Mean value - downstream (EUR/TEU): **-70.73**

Ports called in upstream direction:

Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Yes	Yes	Yes	Yes	Yes	Yes	No

Ports called in downstream direction:

Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Yes	Yes	Yes	Yes	Yes	Yes	No

Figure 9. Calling ports in the service – Example 1

Number of full container, suggested by the the CND tool, to be weekly shipped between any two ports included in the service, is given in the Figure 10.

Calculation Results Back to Session list Logout

Number of full containers to be shipped between called ports:

	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Constantza	0	19	58	28	78	59	0
Giurgiu	7	0	0	5	5	6	0
Ruse	4	0	0	3	5	4	0
Vidin	50	0	0	0	3	3	0
Smederevo	80	5	1	2	0	2	0
Belgrade	100	2	2	1	0	0	0
Novi Sad	0	0	0	0	0	0	0

Figure 10. Numbers of the full containers to be shipped between any two ports in the service – Example 1

In our example, balancing of container inflow and outflow at each port should be done through storing and leasing of containers. Obtained results related to the balancing needs are given in the Figure 11.

Calculation Results Back to Session list Logout

Number of empty containers to be shipped between called ports:

	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Constantza	0	0	0	0	0	0	0
Giurgiu	0	0	0	0	0	0	0
Ruse	0	0	0	0	0	0	0
Vidin	0	0	0	0	0	0	0
Smederevo	0	0	0	0	0	0	0
Belgrade	0	0	0	0	0	0	0
Novi Sad	0	0	0	0	0	0	0

Number of empty containers to be stored at each port:

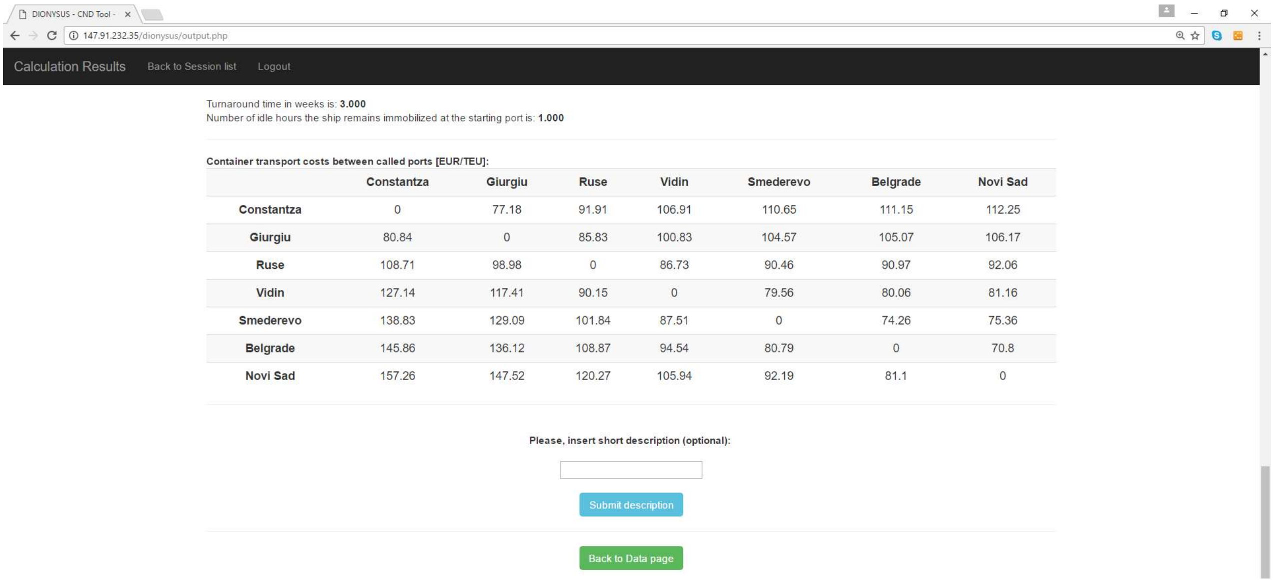
Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
0	3	45	0	1	0	0

Number of empty containers to be leased at each port:

Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
1	0	0	17	0	31	0

Figure 11. Balancing of containers inflow and outflow at each calling port

We indicated, in our example, that our preferred turn-around time is between 2 and 5 weeks. The CND tool took it into account and, based on the obtained results, gave the recommendation that the turn-around time of our service should be 3 weeks. Expected profit is around 24000 EUR per round trip. Transport costs between any two selected ports (either included in the service or not) are given in the Figure 12. These costs values incorporate total average transport costs per TEU for the ship, whose characteristics are given in the Step 3 and include loading and unloading costs of full and empty (if any) containers, average fuel and lubricant costs, average entry costs at any two ports, average storage and leasing costs, as well as average charter or fixed costs.



DIONYSUS - CND Tool -
147.91.232.35/dionysus/output.php

Calculation Results   Back to Session list   Logout

Turnaround time in weeks is: **3.000**
Number of idle hours the ship remains immobilized at the starting port is: **1.000**

Container transport costs between called ports [EUR/TEU]:

	Constantza	Giurgiu	Ruse	Vidin	Smederevo	Belgrade	Novi Sad
Constantza	0	77.18	91.91	106.91	110.65	111.15	112.25
Giurgiu	80.84	0	85.83	100.83	104.57	105.07	106.17
Ruse	108.71	98.98	0	86.73	90.46	90.97	92.06
Vidin	127.14	117.41	90.15	0	79.56	80.06	81.16
Smederevo	138.83	129.09	101.84	87.51	0	74.26	75.36
Belgrade	145.86	136.12	108.87	94.54	80.79	0	70.8
Novi Sad	157.26	147.52	120.27	105.94	92.19	81.1	0

Please, insert short description (optional):

Submit description

Back to Data page

Figure 12. Container transport costs between selected ports

9 Conclusions

This report assesses potential routes and services and introduces a tool for modelling of the container liner services on inland waterways. The outcome of this research enables us to identify opportunities and potential threats for container liner services, which are considered as a pre-condition to develop container transport on the Danube River.

We particularly emphasise favourable and unfavourable conditions, as well as recommendations for the modelling and launching container liner service on the Danube River. We describe the existing situation on the Danube based on the characteristics of the historical growth pattern phases of the European container barge network. After analysing these phases, it can be seen that existing situation on the Danube mostly corresponds to the first phase characteristics. Even more, it is easily noticed that the characteristics of the first phase have not yet been fully achieved on the Danube River. As one of the main finding, the next steps in the process of development of barge container transport on the Danube should be aimed at achieving the characteristics related to both the second and the third phase of this growth pattern. These characteristics should be taken as an action plan for the further development of container liner services on the Danube.

We have developed an online tool for optimal routing of a barge container ship on an inland waterway. It is based on the MILP model and aims to maximize the profit of the shipping company, while, at the same time, defines upstream and downstream calling sequence and number of loaded and empty containers transported between any two ports. Therefore, our model and the tool aims to facilitate decision-making processes at the strategic planning level, which relate to the establishment of a container barge network on the Danube River. Our approach is based on the development of a mathematical programming model that can be applied to give recommendations about establishing a container liner service on any inland waterway. We specifically analyze the possibilities of applying this model in an attempt to facilitate decision-making processes related to the establishment of this service on the Danube.

The aim of the proposed model is to enable each user to receive recommendations on the possibility of establishing a container liner service on the Danube River. Each user has the option of selecting the ports to consider, providing the appropriate time and cost-related data about selected ports, defining the basic characteristics of the ship that would be employed in container liner service, setting the expected demands and freight rates between ports, determining values of preferred turnaround times, as well as values of fuel and lubricant prices. Thus, by simply changing the values of these parameters, the user can get an indication of the cost-effectiveness of introducing or maintaining a container liner service on the Danube under various scenarios. In other words, the user can increase or decrease the values of each of these parameters and thus analyze the impact of such changes on the justification of the introduction or maintaining such services.

10 References

Alfandari, L., Davidović, T., Furini, F., Ljubić, I., Maraš, V., Martin, S. 2019. Tighter MIP Models for Barge Container Ship Routing, OMEGA: International journal of management science, Vol. 82, pp. 38-54.

COLD, Container Liner Service Danube, Technical report, via Donau, ÖIR, Port of Constantza, Final Report, Vienna, 2006.

EHOO, 2018. Container Market Report, DAPhNE project (Danube Ports Network), Interreg – Danube Transnational Programme, Project co-funded by European Union funds (ERDF, IPA).

Frémont, A., Franc, P., Slack, B., 2009. Inland barge services and container transport: the case of the ports of Le Havre and Marseille in the European context. Cybergeo: Eur. J. Geogr. 437, 2–17.

Karsten, C. V. 2015. Competitive Liner Shipping Network Design. DTU Management Engineering.

Konings, R., 2009, Intermodal barge transport: network design, nodes and competitiveness, Ph.D. Thesis, Technische Universiteit Delft.

Maraš, V., 2008, Determining Optimal Transport Routes of Inland Waterway Container Ships, in Transportation Research Record, No. 2062, Transportation Research Board of the National Academies, Washington, D.C., pp. 50-58.

Maraš, V., 2012, Routing of container ships on inland waterways, PhD., Faculty of Transport and Traffic Engineering, University of Belgrade, February 07, 2012.

Maraš, V. 2017. Liner shipping network design in sea and barge transportation, Monograph, ISBN 978-86-7395-374-8, University of Belgrade, Faculty of Transport and Traffic Engineering.

Maraš, V., Lazić, J., Davidović, T., Mladenović, N. 2013. Routing of barge container ships by mixed-integer programming heuristics, Applied Soft Computing, Vol. 13, Number 8, pp. 3515-3528.

Notteboom, T., 2006, Container barge networks in Europe: outgrowing the Rhine basin, in: Maritime Transport 3, pp. 277-295.

Notteboom, T., Konings, R., 2004, Network dynamics in container transport by barge, Belgeo-Revue belge de géographie 4, 461–478.

Notteboom, T., Yang, D., Xu, H., 2020, Container barge network development in inland rivers: A comparison between the Yangtze River and the Rhine River, Transportation Research Part A 132, 587–605.

Port of Constanta, 2019, Annual report, National company, Maritime Port Administration SA, Constanta.

Annex 1 CND tool – User manual

CND Tool could be opened by entering the following web address at the web browser[1]:

http://147.91.232.35/dionysus/.

Following *Login page* will open (Figure 13). Before login, it is needed to complete registration step, so please click on *Register link* (left image, rounded by red ellipse) and fill in requested data. You will be notified that registration is completed and then, please click on Login link (right image, rounded by red ellipse) and complete login step.

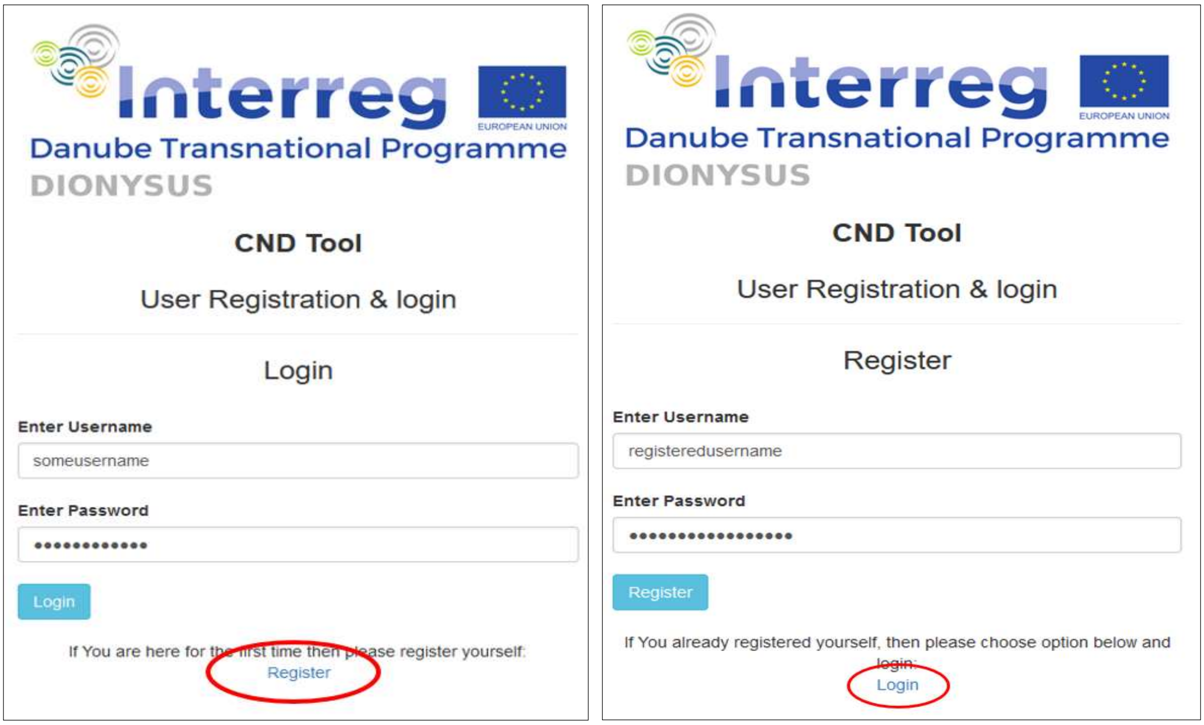


Figure 13. Login and Registration page

After succesful login, the *Activity review page* will open (Figure 14). To start new session, please click on radio button (1) and then click to *Start session* button (2).

[1] Tested on Microsoft Edge, Mozilla Firefox and Google Chrome, browser versions published after 2017.

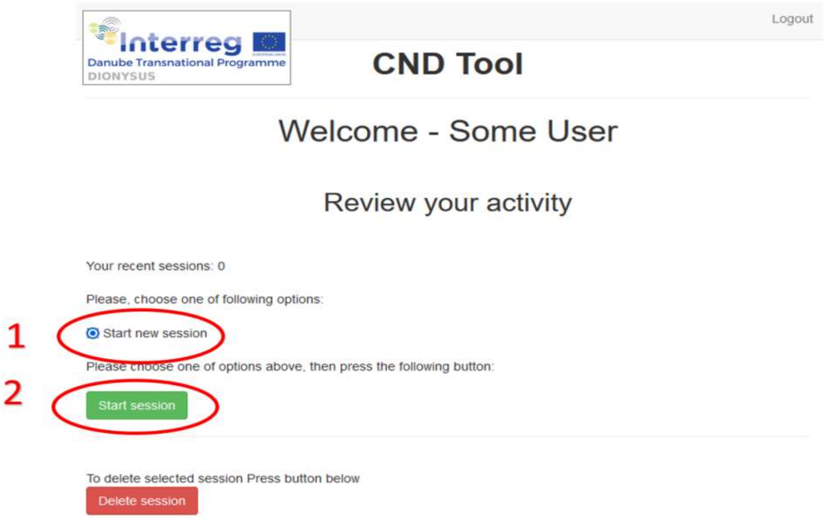


Figure 14. Activity review page

As new session starts, a data entry page will be open (Figure 15). First, you will need to enter general data (1), and make port selection (2). It is important to select all needed ports, since this option will become locked after click on *Save* button (3).

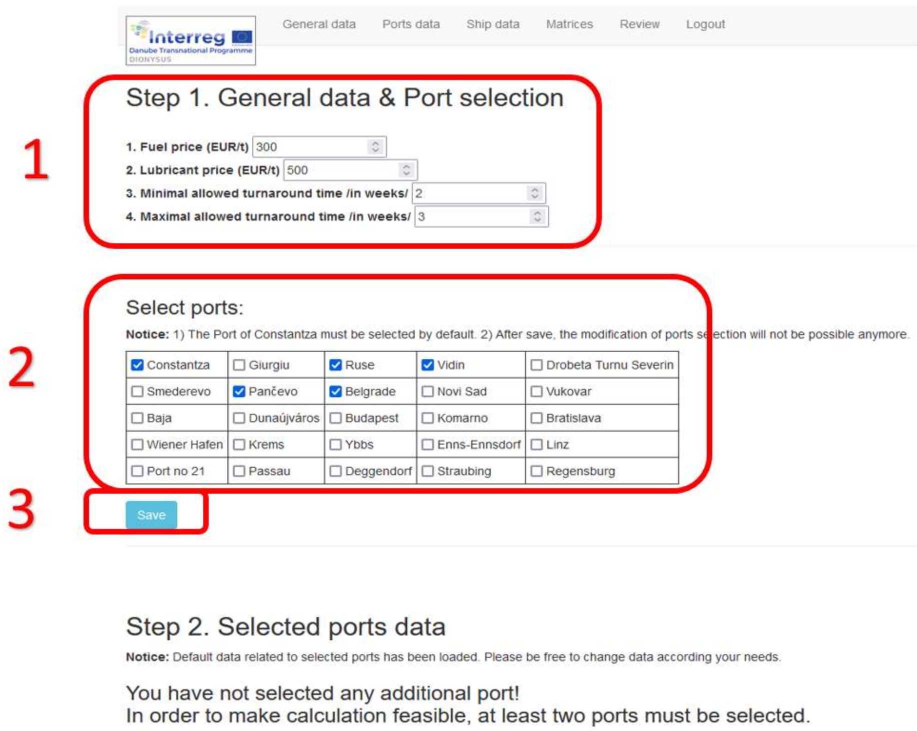


Figure 15. Data entry – Step 1

After clicking on the *Save* button, the table below Step 2 heading will be shown (Figure 16), with autoloaded corresponding data. Please be free to change them according your opinion and then click to save data, (*Save* button below table).

General data Ports data Ship data Matrices Review Logout

Step 2. Selected ports data

Notice: Default data related to selected ports has been loaded. Please be free to change data according your needs.

Parameters \ Port	Constantza	Ruse	Vidin	Pančevo	Belgrade
Unloading cost per full container at each port [EUR/TEU]	31.34	32.5	32.13	31.34	35.00
Loading cost per full container at each port [EUR/TEU]	33.98	38.75	35.25	56.42	41.25
Loading cost per empty container at each port [EUR/TEU]	42.63	36.75	33.15	37.61	37.75
Unloading cost per empty container at each port [EUR/TEU]	42.63	29.75	28.55	31.34	31.25
Entry cost per call at each port [EUR]	700	570	510	0	0
Short-term storage cost per empty container at each port [EUR/TEU]	1.89	1.23	1.15	0.63	1.1
Short-term leasing cost per empty container at each port [EUR/TEU]	1.26	1.21	1.24	1.89	1.78
Average loading time per full container at each port [h/TEU]	0.028	0.047	0.042	0.042	0.047
Average unloading time per full container at each port [h/TEU]	0.025	0.043	0.038	0.046	0.041
Average loading time per empty container at each port [h/TEU]	0.025	0.044	0.039	0.039	0.046
Average unloading time per empty container at each port [h/TEU]	0.027	0.04	0.031	0.041	0.037
Stand-by time for arrival at each port [h]	2.2	2.1	3.0	2.2	4.3
Stand-by time for departure at each port [h]	2.0	3.5	2.5	2.2	3.4

Save

Figure 16. Data entry – Step 2

After clicking on the *Save* button, the table below Step 2 heading will be shown (Figure 17), offering to submit ship parameters. Please submit requested data and click on button *Save*.

Step 3. Ship data

Ship name:	Shipname1
Upstream Speed (km/h)	22
Downstream Speed (km/h)	32
Specific Fuel Consumption (t/kWh)	0.0005
Specific Lubricant Consumption (t/kWh)	0.000004
Engine Power (kW)	1250
Weekly Charter Costs (EUR/week)	120
Carrying Capacity (TEU)	1150
Cost per time for keeping the ship idle at the initial port [EUR/h]	3

Save

Figure 17. Data entry – Step 3

Finally, at this point, the last two matrices could be submitted (Figure 18). Submission with click on the *Save* button below matrices will invoke *Calculate* button (green button below), which means that all needed data are submitted and calculation step could be attempted. Please click on buttons *Save* (1) and *Calculate* (2) to call for calculation *Procedure*.

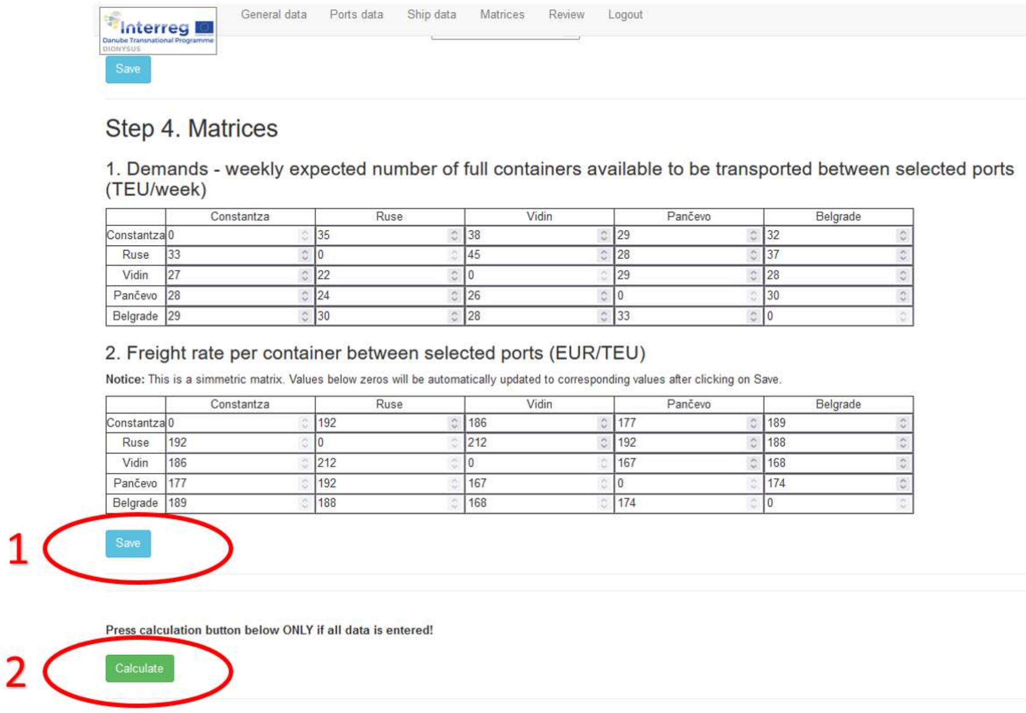


Figure 18. Data entry – Step 4

In case of successful calculation, the *Calculation Output* page will open with obtained results (Figure 19, left). On the bottom of the page, a *text field* for the description entry will be shown, followed by the *Back* button (Figure 19, right).

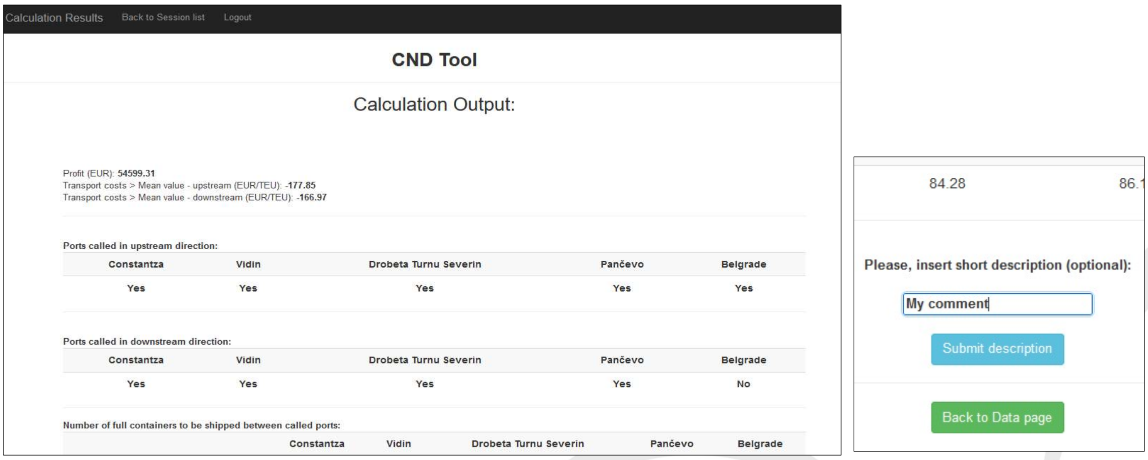


Figure 19. Successful Calculation Results Example (left) and comment textfield (right)

In case of unsuccessful calculation, an error message will be shown (Figure 20). This is a rare situation and usually means that some extremely meaningless data has been entered and you will need to change submitted data in order to obtain better results. In the beta period, this also could indicate a software bug, if you are absolutely sure that all submitted data is meaningful. In that case we recommend you to contact *Project technical Support*. *Data review* could be done by clicking *Back to Data* page button.

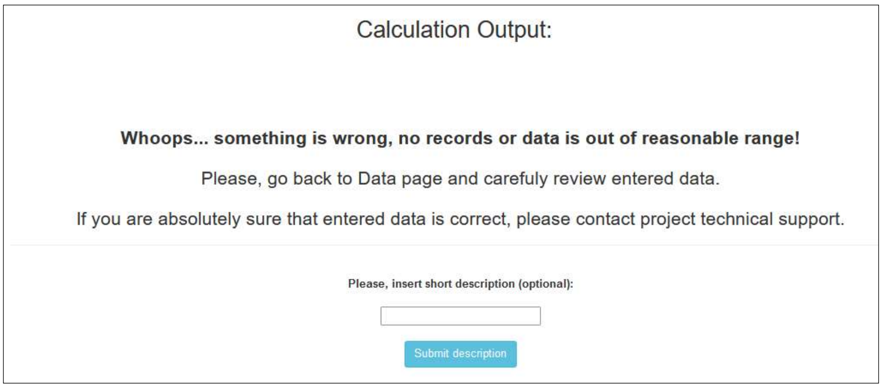


Figure 20. Calculation Error notification

If you need to delete some session, you can complete this operation in the Session list (Figure 21), before entering new or editing existing session, or by clicking *Back to Session* list / *Review* button, located at the Top menu. At the *Activity review* page, you will need to select session you need to remove (1) and then to click on *Delete Session* button (2).

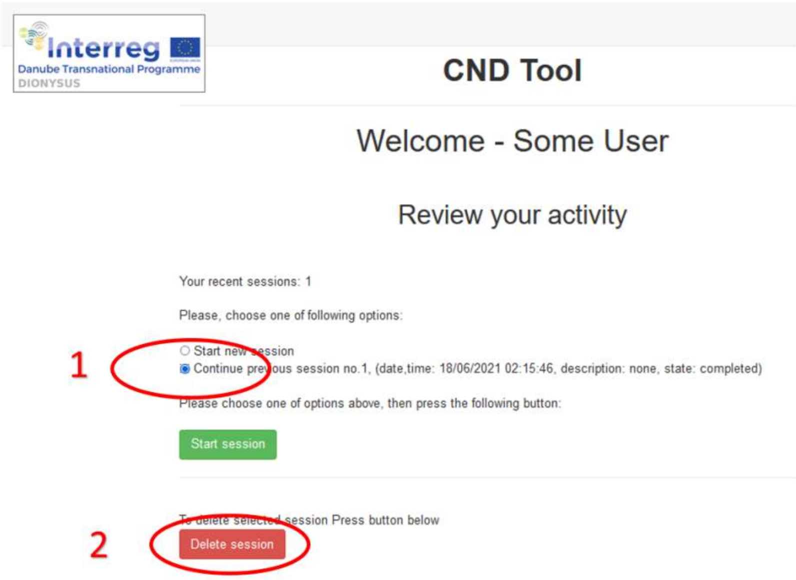


Figure 21. Delete Session steps – part 1

Then, the *Data review* page will open, offering possibility to check session data (Figure 22).

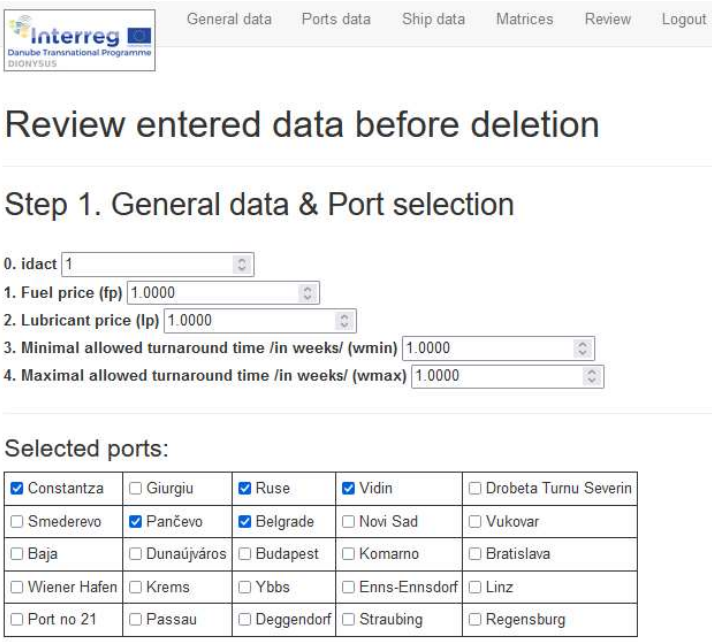


Figure 22. Delete Session steps – part 2

If you are sure that this session should be deleted, please press *Delete This Session* (red) button. Otherwise (Figure 23), please press *Go back* to session list (blue) button.

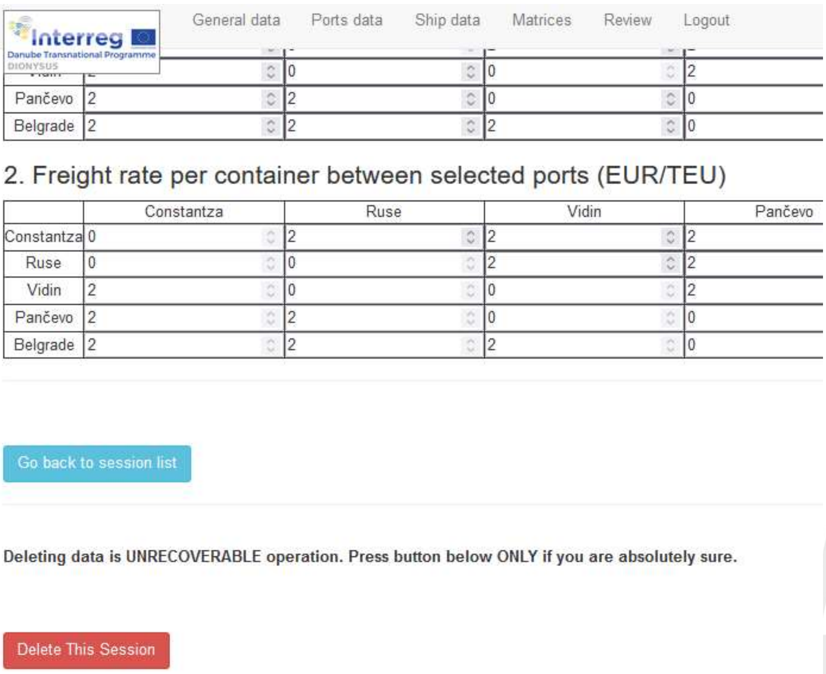


Figure 23. Delete Session steps – part 3