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Case Study on Relocation of Port Infrastructure using the Randomized Expert Panel Opinion Marginalizing Procedure

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Abstract. We present a case study related to the relocation of parts of port facilities in a Black sea port in Varna (Bulgaria). As the city and the port expanded over the years, the east sector of the port ended up being in the middle of the city center. This causes environmental and spatial planning problems to both the city and the port area. We present several alternatives to relocate part of the industrial activities of the port to another site further to the west sector of the port and utilize the emptied space for recreational, public and social activities. We then apply the Randomized Expert Panel Opinion Marginalizing Procedure (REPOMP) to rank the alternatives. The procedure utilizes a hierarchy of criteria to assess the alternatives from four major aspects – environmental, social, technological and economical. A total of 12 experts provided their estimates on how the alternatives meet all criteria as well as on the relative significance of each criterion. Bootstrap simulation is utilized to not only find the total marginal criterion of each alternative, but also its distribution and best estimate. We also tested whether there is significant difference between the ranking scores of the alternatives.

1. Introduction

Artificial intelligence (AI) has been a major scope of research and development for decades. Its focus is to elaborate techniques and methodologies that can teach an intelligent agent to analyse the environment and choose actions that maximize a certain task or objective [1]. AI has been developed with the specific focus to replicate the human intelligence in tasks that are of higher complexity. AI utilizes the tools of statistics, mathematics, linguistics, computational intelligence and symbolism. It has found application areas in healthcare, military science, finances, economics, etc. In complex tasks of decision making, intelligent agents learn and/or may be able to rely and use external knowledge, which is usually in the form of expert opinion and expert assessments. Hence, despite the development of the AI domain, the reliance on expert knowledge to build complex systems to process knowledge and make decisions is still present.

Making decisions about critical infrastructure (ports, industrial plants, transport networks, etc.) is a complex task, stemming from the fact that alternatives are usually defined and assessed on a large series of (usually contradicting) criteria and uncertainty is rather high [2]. Quantitative analysis through utility theory and subjective statistics is one possible way to handle such complex decisions

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(see [3, 4]) and it often has strong reliance on expert judgment. The task of bringing the multi-dimensional subjective estimates, given by the experts, to a total marginal indicator of the quality of each alternative then becomes crucial. The REPOMP method, initially proposed in [5] is a simplified way of tackling this complex task.

Previous works have developed and demonstrated the application of the expert-panel based approach to rank alternatives of various complexity – the REPOMP procedure (Randomized Expert Panel Opinion Marginalizing Procedure) [5]. REPOMP requires that the analysed alternatives are assessed based on a preliminarily defined hierarchy of criteria. Then a panel of experts assesses both the performance of each alternative against the criteria and the significance (weights) of each criterion at its hierarchical level. Due to its generalized nature, the REPOMP is adaptable to problems of varying nature and complexity. Some examples of applications so far include: selection of technology for waste treatment [5; 6], selection of alternatives for modernization and deployment of energy-efficiency measures for public buildings [6; 7], selection of structure and organization of national infrastructure in a European Union's Member State regarding the collection, usage, and dissemination of full-range spatial data (and spatial meta-data) following the INSPIRE directive [8; 6; 9]. Each of those example case studies depended on different number of experts, different hierarchy of criteria and different count of alternatives. The procedure also allows the analyst to use different sets of weight coefficients to the marginal criteria, thus acquire solutions based on different potential structure of experts (i.e. different prioritization of criteria). The mathematical procedures of REPOMP are realized in MATLAB functions, available free-of-charge upon request from the authors.

In this work, we present a case study related to infrastructural plans to modernize and restructure a sea port in the Black Sea city of Varna (Bulgaria). The analysis was conducted in 2012 within the work package 6 of the EU funded project ECOPORT 8: *Environmental management of trans-border corridor ports* (project code SEE/A/218/2.2/X). The information provided in the paper reflects the status of the port and its infrastructure at the time the study was conducted. Some parts of this study were initially presented in earlier works [10].

The way the city of Varna expanded over the years ended up in the port eventually being in the city centre with no ability to expand its industrial activities. This causes environmental, social and economic issues for the city. The restructure of the port has been the scope of political debate for over two decades. Advances in port technologies and logistics are making the problem even more crucial. Hence, the situation can be characterized as follows:

- The Port of Varna is situated within the urban area of the city. It causes traffic and noise pollution for the city area. The port has very limited abilities to expand and develop in future.
- Local and national governmental authorities have discussed the possibilities to relocate the port to a site far from the city. Different expert teams of architects and urban planning specialists worked on the elaboration of strategies to relocate the port and develop recreational and cultural centres in its place.
- At the time of start of this study, there was no official selected procedure to optimize the needs of the city and the port infrastructure;
- The discussion for the relocation of the port evokes serious political and economic confrontation, due to different interests that are affected by this decision;
- While the problem remains unsolved, further activities of local and national governmental institutions regarding the establishment of an environmental management system for the area of the port are impossible and unjustified.

In this study, we describe several alternatives to restructure (relocate) the industrial activities of the port and develop recreational and public centres in their place. A hierarchy of criteria is constructed, and the REPOMP procedure is implemented to select the best option according to a group of experts.

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In what follows, section 2 presents the structure and challenges of the Port of Varna and clarifies the objectives of this study. Section 3 presents the implementation and the results from the REPOMP procedure.

2. Characteristics of the Port of Varna

The port of Varna is the largest of the seaports of Bulgaria. It is located on the Varna bay, which is in the western end of the Black Sea, and close to lake Varna and lake Beloslav. The Port of Varna is part of (or services) the pan-European corridor 8, the Rhine-Main-Danube canal, and the TRACECA international transport corridor (Europe-Caucasus-Asia). The port area has significant developmental potentials with a stretch of about 45 km of inland waterfront on the lakes. The location of this zone is easily accessible by rail and road, and it also has proximity to the international airport in Varna. The port has two sectors – Varna East and Varna West, connected by inland canals. Since 2010, the Port of Varna implemented the Integrated Management System, which includes certified management systems to international standards ISO 9001:2008, BS OHSAS 18001:2007, ISO 14001:2004. The Port of Varna is one of the first Black Sea ports to be certified under the requirements of the International Ship and Port Facility Security Code (ISPS Code).

2.1. Port of Varna - East

The Port of Varna East is situated at the inner end of Varna Bay, only 1 km away from the city centre (see Figure 1). It is an important logistics operation link for the transit traffic to and from Central Europe routed via the Danubian Port of Rousse. The main section of this link is the transit railroad link Rousse-Varna. This is also the only passenger terminal along the sea road between Istanbul and Odessa. A special feature of the port is the multi-purpose use of the berths. All quays, except the passenger one, are utilized for handling of various types of cargo: general, containers, sugar, scrap, molasses, etc. The port has 14 berths with a total length of 2378 m and maximum depth of 11.3 m. The open storage area is 49 800 m^2 and the warehouses have the total area of 41 500 m^2. The equipment of the port consists of 28 cranes (up to 32 tonnes) and one gantry crane with lifting capacity of 30.5 tonnes, specialized in handling of containers. Part of the equipment is also the 2 reachstackers, forklift tracks, rail grain discharge station, quay ship loader for grain and unloading facility for molasses. An integral part of the port is the storage base, also known as The Dry Port. It is located 5 km away from the port on a total area of 13 000 m^2 and has 6 warehouses. It is specialized in storage of all types of cereals, soy and general cargoes.

Figure 1. The Port of Varna East

2.2. Port of Varna West

The Port of Varna West is the most modern and perspective facility at the northern Bulgarian coast (see Figure 2). It is located 30 km west of the city of Varna, on the western shore of the Beloslav Lake. It was constructed about 40 years ago and implements modern cargo handling operations. It is adjacent to the chemical factory of Devnya and enables direct handling directly on the ship. Most of the port berths are multifunctional and are used for handling of various general cargo: packed soda, fertilizers and cement, as well as metals, equipment, timber, etc. The port includes 18 mooring berths with total length of 3 223 m and maximum depth of 11 m. The storage area is 191 000 m^2 and the covered storage area is 27 000 m^2. The port is equipped with 27 portal cranes (up to 16 tonnes), 2 gantry cranes and one mobile crane with lifting capacity up to 100 tonnes. The equipment also includes 2 reach stackers, 3 rubber belt conveyors, loading facility for soda and fertilizers and 2 units of quay ship loaders for soda and fertilizers.

The Varna Ferry Complex (situated on the territory of the Port of Varna West) is the only place in the Black Sea region which has a rail ferry terminal with possibility to change the rail car bodies from European to Russian standard and vice-versa. This is a unique advantage to the ferry terminal offering one of the shortest and the cheapest roads for the cargo traffic between Europe and Asia. All berths of the port have a connection with the Bulgarian rail network. This fact provides excellent conditions to develop intermodal transport networks. With modern equipment, excellent transport links, rail ferry service and a crossroad location, the port is a convenient bridge for the cargo flows between Europe, Russia, Ukraine, Middle Asia, the Middle East and the Far East.

2.3. Challenges for the development of the Port of Varna at a national and European perspective

The preliminary analysis demonstrates that the port has no Port Monitoring System and no specific guidelines on main environmental issues regarding water quality, air quality, waste management, odour control, energy saving, rehabilitation of polluted areas, port development, etc. The development and deployment of an effective environmental monitoring system for the entire port infrastructure is a long-term, time-consuming and financially expensive initiative, which also caused political turmoil during discussions about the transport policy of the country. At the time our study initiated, a conclusion of whether to relocate some of the port industrial activities was not reached despite the analyses and consultations at various levels over the years.

Figure 2. The Port of Varna West

The strategy of “Motorways of the Sea” at the European Union (EU) level is another major reason why regional and national authorities in Bulgaria should pay attention to the development of Bulgarian maritime ports. The “Motorways of the Sea” concept, introduced in the “2001 Transport White Paper

– European transport policy for 2010: Time to Decide" [11] aimed to introduce new intermodal maritime-based logistics networks in Europe to improve the organization of transport in Europe. These networks should be sustainable and commercially more efficient than road-only transport. In this way, the EU transport strategy aimed to improve access to markets throughout Europe and provide alternatives to the road network for commercial and non-commercial traffic. The key focus of the strategy was better use of existing maritime transport resources and its adequate linkage to the railroad network and the inland waterways of the community, as part of an integrated transport network. The White Paper also postulated that the Motorways of the Sea should be part of the trans-European network (TEN-T) and funds should be made available for its development. Article 12a of the TEN-T guidelines [12] gives three main objectives for the sea motorways projects as follows:

(1) freight flow concentration on sea-based logistical routes;
(2) increasing cohesion;
(3) reducing road congestion through modal shift.

Four corridors were designated for the setting up of projects of European interest. The one related to Bulgaria is the corridor for south-west Europe (western Mediterranean, connecting Spain, France, Italy and including Malta and linking with the Motorway of the Sea of south-east Europe and including links to the Black Sea) (see Figure 3).

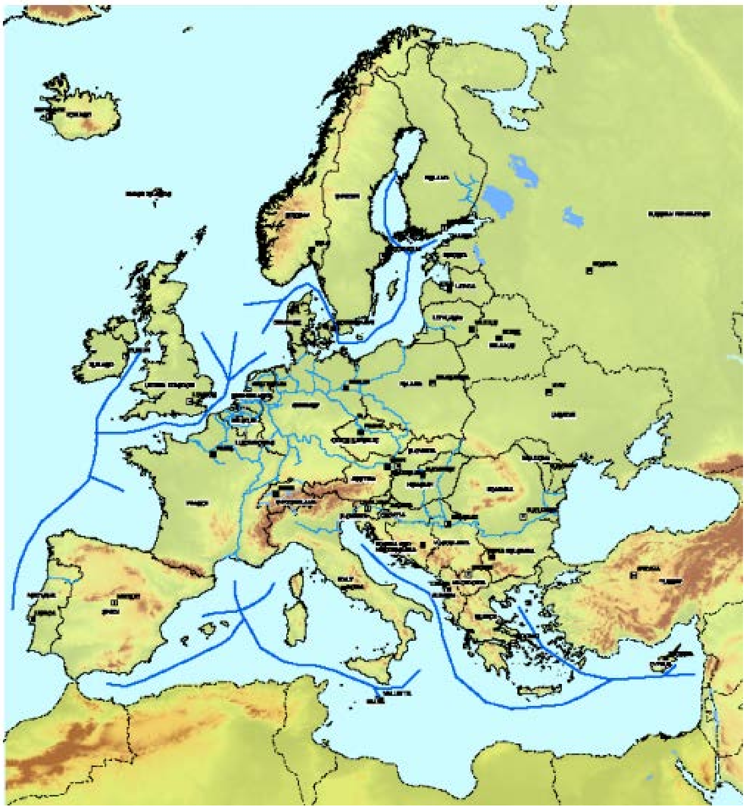

Figure 3. Map of the Motorways of the Sea

The next stage of the European transport strategy was presented in the 2011 Transport White Paper "Roadmap for a single European transport" [13]. It stressed the importance of Motorways of the Sea. This white paper adopted a roadmap of 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and boost growth and employment. At the same time, its aim is to dramatically reduce Europe's dependence on

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imported oil and cut carbon emissions in transport by 60% by 2050. The 2013 TEN-T Guidelines [14] redefined the Motorways of the Sea as the maritime dimension of the trans-European transport network and indicated that it should contribute towards the achievement of a European maritime space without barriers by the following:

(a) Maritime links between maritime ports of the comprehensive network or between a port of the comprehensive network and a third-country port where such links are of strategic importance to the Union;

(b) Port facilities, freight terminals, logistics platforms and freight villages located outside the port area but associated with the port operations, information and communication technologies (ICT) such as electronic logistics management systems, and safety and security and administrative and customs procedures in at least one Member State;

(c) Infrastructure for direct land and sea access.

All those European strategies increase the importance of adequate measures to maintain and develop transport infrastructure. However, it is up to industry, Member States and the Community to implement financially and operationally sound projects to use these maritime resources better for new intermodal maritime-based transport systems. All these concerns put Bulgaria under the necessity to comply with the sea motorways strategy and provide the possibilities for effective integration of the maritime ports into the international intermodal chain.

In Table 1, we specify some of the main strengths, weaknesses, opportunities and threads that the development of the port faced at the time our study was initiated. Hence, some of the key factors for the necessity to relocate some of the port industrial activities stem from the vicinity to the city centre, the transport problems, the environmental issues and the lack of free spaces for future port development, as well as the necessity to modernize and increase effectiveness of the port. This is also a topic embedded in the Strategic City plan of Varna, indicating two main issues:

1. Removal of activities and equipment for cargo-handling operations away from the city centre in accordance with the environmental and architectural considerations for urban development. The emptied space in the port should be utilized for recreational, commercial, public and cultural sites to improve the urban outlook of the area.

2. Relocation of the container terminal from the port of Varna East to the north coast of the Varna Lake. In this way larger container ships will have access to the port and the container turnover in the Black Sea would increase.

This problem has been under discussion at a local, regional and national level, and multiple projects have been developed to solve it. The main criteria in those projects were:

- Effective reconstruction of the “old” port into accessible zone with business, commercial and entertainment areas
- Connection with the old city centre – the Roman Baths, the Greek neighbourhood, the Sea Garden, etc.
- Preserving the existing valuable buildings and equipment
- Ensuring convenient communication and transport services
- Innovatory method in the functional and architectural appearance of the area

Our study analyses four alternative plans for the development of the Port of Varna East. Each of those alternatives imposes different scale of change to the current terrain of this section of the port, has impact on different berths of the port and assumes different activities to be established (or relocated) in the emptied areas. We have excluded from our study those alternative plans, which only analysed the first 5 berths of the port as these options were deemed rather ineffective since the future development of those berths is strongly dependent on the development of the whole port area. We utilize the REPOMP procedure to compare the four alternatives, based on a clearly defined hierarchy of criteria and with the involvement of 12 experts who provided their assessments.

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Table 1. Strengths, weaknesses, opportunities and threads to the development of the Port of Varna

STRENGTHS	WEAKNESSES
• Key location of the port in the pan-European transport networks • Increase in the container traffic, leading to decrease of the unhealthy impact on environment in the port area • Implemented Integrated Management System, including certified management system to the international standards ISO 9001:2008, BS OHSAS 18001:2007 and ISO 14001:2004 • Certification by the International Ship and Port Facility Security Code (ISPS Code)	• No system for environment pollution risk assessment • Insufficient activities in waste recycling • Existent pollutants in the territory and aquatory of the port • No self-monitoring system for pollutant components • No transparency in the environmental protection initiatives • Outdated infrastructure with limited abilities to be modernized
• Presence of EU strategies for the development of intermodal transport corridors • Development of national environmental legislation and programs harmonized with EU guidelines • Establishment administrative procedures to implement and enforce environmental legislation • Establishment of monitoring system for the port area • Attract EU funding for environmental monitoring and protection activities	• Significantly complicated national environmental legislation • High costs for environmental law enforcement • Poor compliance at regional and national level with EU regulations in the transport and environmental domains • Legislative and administrative obstacles in attracting EU infrastructural • Political and governmental dynamics not in favour of long-term infrastructural decisions and investment
OPPORTUNITIES	THREADS

3. Analysis of alternatives using the REPOMP procedure

In this section we shall present details about the four alternatives to be analysed, and we will also demonstrate the implementation of the stages of REPOMP.

3.1. Description of alternative plans for the development of the Port of Varna East

We analyse four alternatives on how the future Port of Varna East may look and operate.

Alternative 1: Establish the recreational centre at berths 1 to 10 emphasizing on business, shopping and studying areas

Alternative 1 is presented through design images in Figures 4 and 5. It is an alternative oriented to business and entertainment. The project presents a modern exterior with a spectacular view to the city centre and to the sea. One of the landmarks on this option is expected to be a five-star hotel with yacht club. The yacht club, adjacent to the hotel, is a suitable addition that outlines the maritime elements of the recreational centre. The alternative also assumes that the location will host a new City Hall and a Universal Hall. Those facilities shall serve citizens through series of civil, cultural and entertainment activities. A city library is to be established there. Important public events (e.g. conferences, voting campaigns, educational initiatives, etc.) are to be held at the conference facilities of those two buildings. Also envisaged by this alternative is the development of rental office spaces for local businesses, as well as shopping malls.
The transport connections to the other parts of the city will be provided through land (bus, car), rail (with the rail station close to the area) and waterway transport (through the passenger terminal at the port). In addition to using the green areas of the complex for walking and leisure, visitors will also be

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able to visit the Contemporary Art Museum, the Aquarium and Naval Historical Museum, as well as a swimming pool (which are currently in close vicinity to the area). Part of the current port is envisaged to remain for port activities and shall contain fleet service office and a storage yard.

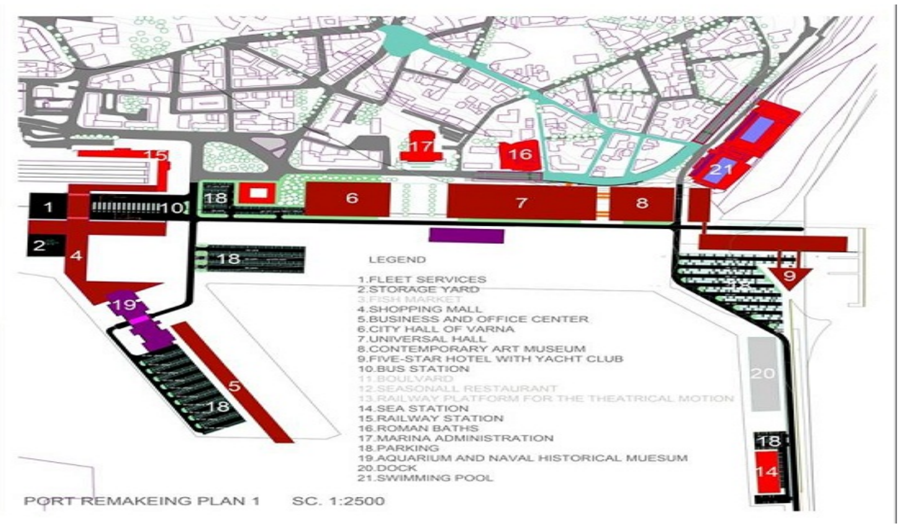

Figure 4. Scheme of Alternative 1

Figure 5. Outlook of the port under Alternative 1

Alternative 2: Establish the recreational center at berths 1 to 10 emphasizing on the new appearance of the City Hall and the city square

In this alternative, a key component is the establishment of a new City Hall for the municipal administration and local government, as well as to the establishment of a new city square. The building where the current local government is located is situated in the very centre of the city. While being iconic in its historical background, it is in an area with heavy traffic, high noise pollution, and limited access. The building has limited renovation capacity due to outdated construction, multiple floors and limited area of each floor. The City Hall in the project is only in four floors, with long corridors and multiple offices at each floor. This provides effectiveness and convenience of work, which in turn facilitates citizens. Additionally, the building shall be in a central position to the new city centre, with facilitated access. Cultural monuments, waterfront and green areas, sidewalks and alleys, streets with limited motor traffic, residential buildings, parking areas, and other new public buildings shall also be situated in the new city square. The overall idea of this alternative is to present Varna as a city, open to the sea and to the world. As it is obviously from the project pictures and schemes (see Figures 6 and 7), the new recreational centre will have modern appearance that improves the urban quality of the city and makes it more attractive to both citizens and visitors.

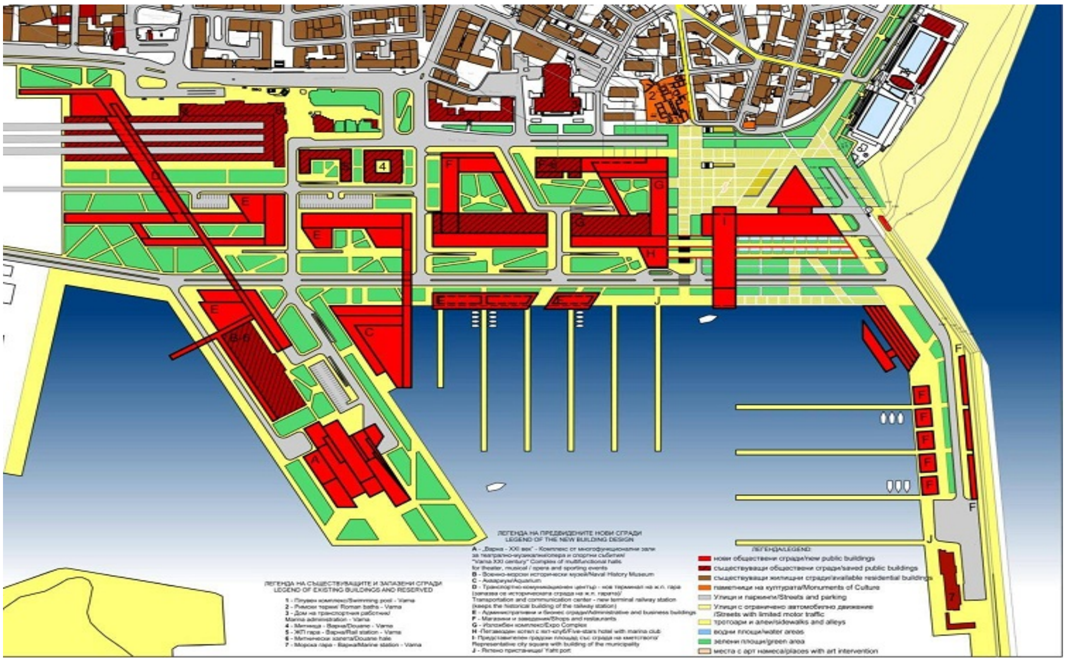

Figure 6. Scheme of Alternative 2

Alternative 3: Move the whole port and establish the recreational centre on the entire territory

In this alternative, the whole port is envisaged to be relocated along the Varna Lake, which is an option way more complicated than the idea for moving parts of the port. This requires larger free areas for the new port location, larger investments in both relocating the port and developing the recreational centre in its place. Hence, this is the alternative that is most complicated in terms of long-term planning and funding. Developing the center on the entire territory of the present port gives much more space for creative urban design, as well as possibilities to establish multiple facilities, cultural and public areas, etc. The ideas in Alternatives 1 and 2 can easily be combined (in terms of new buildings and facilities, new City Hall, new museums, business areas, transport facilities, halls and entertainment areas).

Alternative 4: Keep the port at its present location

This alternative represents the option to keep the Port of Varna East at its current location and do no activities towards the development of a recreational area. The ships will berth in the city area, near the residential buildings, the cargo-handling activities shall also be carried out in this area. The trucks traffic carrying different type of cargo shall continue passing through the city area. The pollution from cargo operations and supporting truck traffic shall continue to have its negative impact on the environmental profile and image of the city. Other solutions shall have to be found for the environmental and transport problems of the city, as well as the issues concerning its future development.

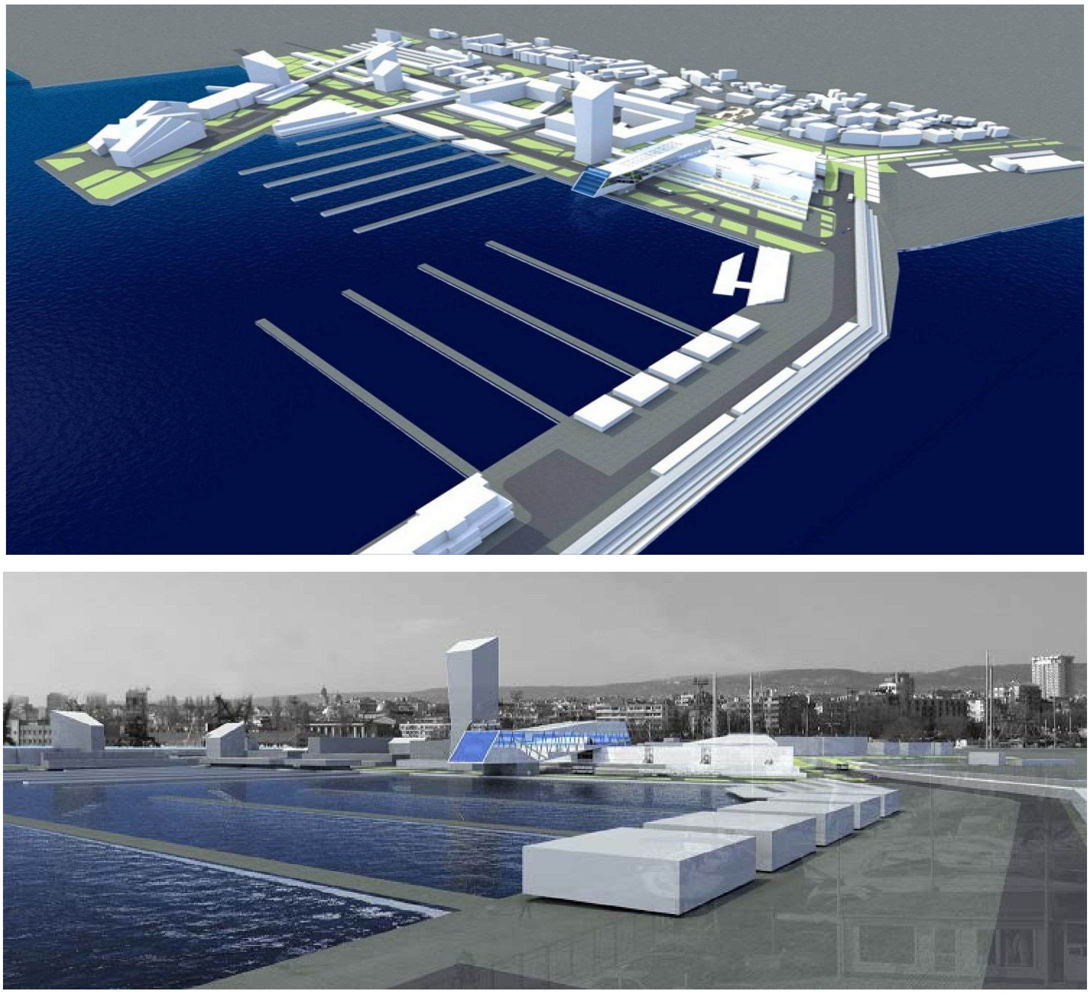

Figure 7. Outlook of the port under Alternative 2

3.2. Implementation of the REPOMP procedure

The REPOMP procedure (Randomized Expert Panel Opinion Marginalizing Procedure) was initially presented in [5] as a procedure to rank alternatives based on the subjective opinion of an expert panel in multi-criteria decision making (MCDM) situations (for further reading on MCDM, please refer to [15; 16; 17]). It allows to use arbitrary hierarchical structure of criteria to compare a certain number of alternatives based on marginal indicators, but also on their probability distribution, analysed using Bootstrap simulation [18]. REPOMP has five implementation stages as described in Figure 8.

The experts who volunteered and involved in this study were from the following organizations: City of Varna, Bulgarian Port Infrastructure Company, Navigation Maritime Bulgar Shipping Company, Varna Free University, and Technical University – Varna. To guarantee anonymity of the experts' opinions, we have elaborated the following procedure (see Figure 9).

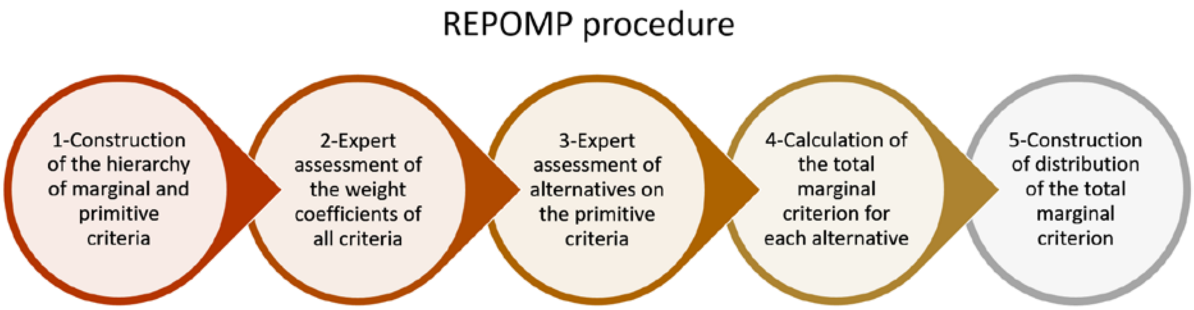

Figure. 8. Stages of the REPOMP procedure

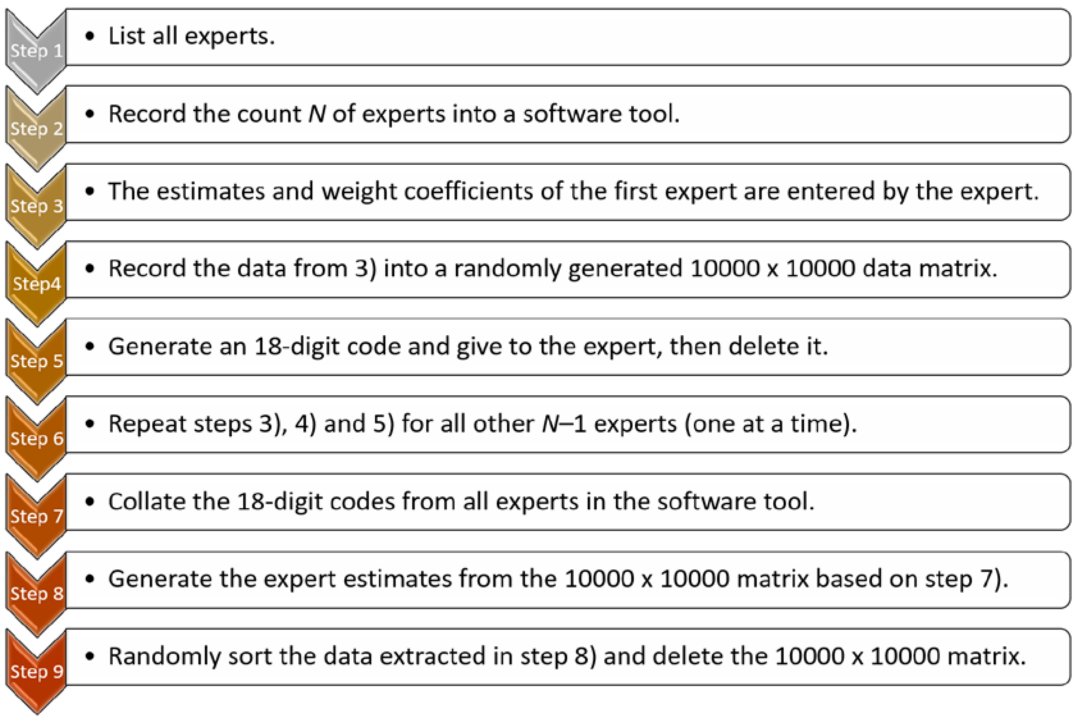

Figure 9. Structure of the algorithm to protect the anonymity of experts

In ***STAGE 1 OF REPOMP*** we need to construct the hierarchy of criteria. The total marginal criterion for assessment K is divided into b=4 base marginal criteria: K_1- Environmental; K_2 – Social; K_3-Technological, and K_4 **–** Economical. The hierarchy of criteria is presented on Figure 10 with their meaning given in Table 2.

Alternatively, the hierarchy of criteria can be modelled by denoting the index *ind* of any criterion with an index vector containing integer values. The set of sub-criteria for the *ind* criterion is denoted as S(*ind*). In our case the index vectors can be 0, 1, 2, 3 or 4 dimensional as shown in the first and third column of Table 3, whereas the correspondent sub-criteria sets are given in the second and third columns of the same table. The dimension of the index vector is also called level of the criteria. The only zero-level criterion is the total marginal criterion and its index is an empty vector, denoted as []. In the same way, for all primitive criteria S(*ind*) is an empty set, denoted as {}.

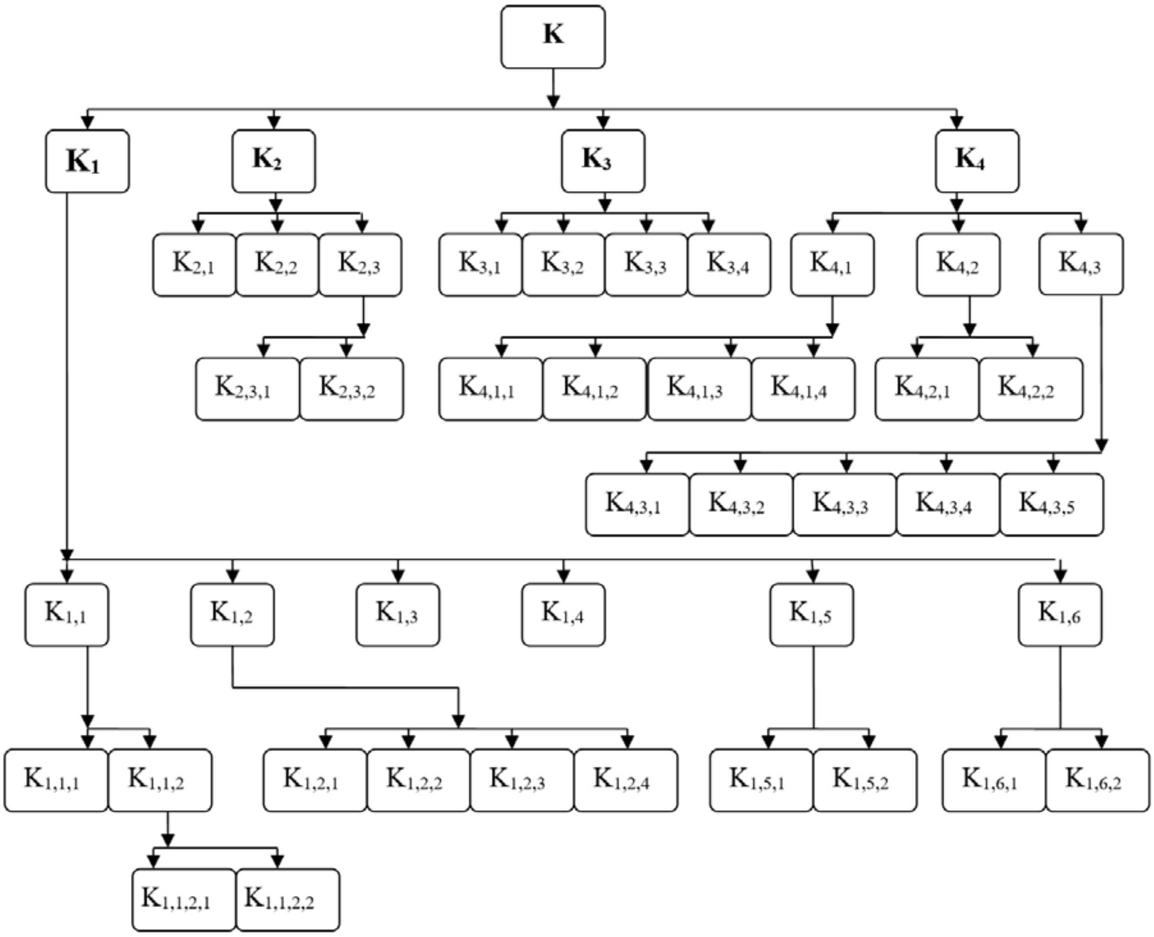

Figure 10. Hierarchy of criteria for the port development problem

In ***STAGE 2 OF REPOMP***, the following scale is utilized to assess the significance of the criteria: 0 – No significance; 1 – Low significance; 2 – High significance; 3 – Very high significance. A group of 12 experts made assessment of the weight coefficients of the primitive criteria (i.e. those which have no sub-criteria, see Table 2) and for the marginal criteria (those which have sub-criteria, see Table 2).

If the weight coefficient of the *ind* criterion is assessed by n_{ind}^{Y} experts, Y_r^{ind} being the mark given by the *r*-th expert, then the opinion of all experts for the weight coefficient of the criterion can be organized in a n_{ind}^{Y} -dimensional vector $\vec{Y}_{ind} = (Y_1^{ind}, Y_2^{ind}, \ldots, Y_{n_{ind}^{Y}}^{ind})$. The opinion of the experts regarding the weight coefficients is given in Table 4. The average of the weight coefficient of criterion *ind* is calculated for each criterion except for the 0-level one:

$$Y_{mean}^{ind} = \frac{1}{n_{ind}^{Y}} \sum_{r=1}^{n_{ind}^{Y}} Y_r^{ind} \text{ for } ind \neq [] \tag{1}$$

Table 2. Meaning of the criteria in the hierarchy from Figure 9. The marginal criteria are bolded.

K_1 – ENVIRONMENTAL	**$K_{1,1}$ – Air pollution in the port area**	$K_{1,1,1}$ – Gas emissions	
		$K_{1,1,2}$ – Dust emissions	$K_{1,1,2,1}$ – Non-organic emissions
			$K_{1,1,2,2}$ – Organic emissions
	$K_{1,2}$ – Water pollution and other impact in the port area	$K_{1,2,1}$ – Pollution from ships	
		$K_{1,2,2}$ – Pollution from cargo handling operations	
		$K_{1,2,3}$ – Impact on the tide levels	
		$K_{1,2,4}$ – Impact on currents near the port	
	$K_{1,3}$ – Urbanization of new areas		
	$K_{1,4}$ – Environmental risk and impact		
	$K_{1,5}$ – Noise pollution	$K_{1,5,1}$ – Levels of noise pollution during the day	
		$K_{1,5,2}$ – Levels of noise pollution during the night	
	$K_{1,6}$ – Increase in waste volumes	$K_{1,6,1}$ – Construction wastes	
		$K_{1,6,2}$ – Household and industrial wastes	
K_2 – SOCIAL	$K_{2,1}$ – Increase of employment		
	$K_{2,2}$ – Employee's health risk		
	$K_{2,3}$ – Ergonomic aspects	$K_{2,3,1}$ – Quality of external design of the new buildings	
		$K_{2,3,2}$ – Urban efficiency of the centre	
K_3 – TECHNOLOGICAL	$K_{3,1}$ – Design time		
	$K_{3,2}$ – Time to arrange administrative issues		
	$K_{3,3}$ – Time to construct the centre		
	$K_{3,4}$ – Meteorological influence and natural hazards		
K_4 – ECONOMICAL	**$K_{4,1}$ – Funding of the project**	$K_{4,1,1}$ – Currency risk	
		$K_{4,1,2}$ – Possibility for funding from international funds	
		$K_{4,1,3}$ – Amount of investment	
		$K_{4,1,4}$ – Time to return of investment	
	$K_{4,2}$ – Cost levels	$K_{4,2,1}$ – Consumption costs for utilities	
		$K_{4,2,2}$ – Depreciation costs	
	$K_{4,3}$ – Income levels	$K_{4,3,1}$ – Income from tourism	
		$K_{4,3,2}$ – Income from passenger maritime transport	
		$K_{4,3,3}$ – Income from concessions in the centre	
		$K_{4,3,4}$ – Increase of investments in the region	
		$K_{4,3,5}$ – Income from land price differences	

The only 0-level criterion is the total marginal criterion, which is the quantity utilized to rank the alternatives. In (1) we assume that each expert is equally important in the assessment process, but if the level of expertise is different, then a weighted average of the experts' estimates can be utilised instead of (1).

Note that Y_{mean}^{ind} should be treated as the relative significance of the *ind* criterion by the *r*-th expert within the marginal criterion that the *ind* criterion belongs to (e.g. the weight coefficient for $K_{4,1,2}$ represents its relative importance for the marginal criterion $K_{4,1}$). So, the first-level criterion is calculated based on the second-level criteria, whose relative coefficients of significance sum to one. Such a setup significantly helps the experts in their estimation of the weight coefficients. The normalized weight coefficient of criterion *ind* is calculated for each criterion except for the 0-level one:

$$\lambda_{ind} = Y_{mean}^{ind} \Big/ \sum_{inds \in S(ind)} Y_r^{inds} \qquad \text{for } ind \neq [] \tag{2}$$

The information in Table 4 is the same for all alternatives. It allows for automatic generation of the criteria hierarchy shown in Table 3.

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Table 3. Criteria indices and sub-criteria sets. The marginal criteria are bolded.

ind	*S*(*ind*)	*ind*	*S*(*ind*)
[]	{**[1]**,**[2]**,**[3]**,**[4]**}	[1,1,1]	{}
[1]	{**[1,1]**,**[1,2]**,[1,3],[1,4],**[1,5]**,**[1,6]**}	**[1,1,2]**	{[1,1,2,1],[1,1,2,2]}
[2]	{[2,1],[2,2],**[2,3]**}	[1,2,1]	{}
[3]	{[3,1],[3,2],[3,3],[3,4]}	[1,2,2]	{}
[4]	{**[4,1]**,**[4,2]**,**[4,3]**}	[1,2,3]	{}
[1,1]	{[1,1,1],**[1,1,2]**}	[1,2,4]	{}
[1,2]	{[1,2,1],[1,2,2],[1,2,3],[1,2,4]}	[1,5,1]	{}
[1,3]	{}	[1,5,2]	{}
[1,4]	{}	[1,6,1]	{}
[1,5]	{[1,5,1],[1,5,2]}	[1,6,2]	{}
[1,6]	{[1,6,1],[1,6,2]}	[2,3,1]	{}
[2,1]	{}	[2,3,2]	{}
[2,2]	{}	[4,1,1]	{}
[2,3]	{[2,3,1],[2,3,2]}	[4,1,2]	{}
[3,1]	{}	[4,1,3]	{}
[3,2]	{}	[4,1,4]	{}
[3,3]	{}	[4,1,5]	{}
[3,4]	{}	[4,1,2]	{}
[4,1]	{[4,1,1],[4,1,2],[4,1,3],[4,1,4]}	[1,1,2,1]	{}
[4,2]	{[4,2,1],[4,2,2]}	[1,1,2,2]	{}
[4,3]	{[4,3,1],[4,3,2],[4,3,3],[4,3,4],[4,3,5]}		

In ***STAGE 3 OF REPOMP*** we utilize a ranking scale, given in Table 5, to allow the experts to assess how each alternative complies with the primitive criteria. The alternatives are assessed against the primitive criteria by twelve experts. If an alternative is assessed against a primitive criterion *ind* by n_{ind}^{X} experts, X_r^{ind} being the mark given by the *r*-th expert, then the opinion of all experts for the alternative against the primitive criterion can be organized in a n_{ind}^{X}-dimensional vector $\vec{X}_{ind}$ =(X_1^{ind}, X_2^{ind} ,…, $X_{n_{ind}^{X}}^{ind}$). The opinion of the experts for the alternatives against the primitive criteria is given in Table 6.

In ***STAGE 4 OF REPOMP*** we calculate the total marginal criterion for the analysed alternatives. We can present each alternative as a multidimensional vector $\vec{T}$ (t_1, t_2, …, t_N) in the *N*-dimensional space of the experts estimates against the primitive criteria (i.e. t_i= X_r^{ind}). So the total marginal criterion X^m of the alternative is an *N*-dimensional real valued function *v*(.) of the coordinates of $\vec{T}$ of the alternative: X^m=$v(t_1, t_2, \ldots, t_N)$. The form of this function depends on the preferences over the criteria. If it is true that an alternative is always better than another if it has better scores, all else being equal, then there is preferential independence over the coordinates of $\vec{T}$. Then the value function has additive form [3]:

$$X^m = v(t_1,t_2,\ldots,t_N) = w_1(t_1) + w_1(t_1) + \ldots + w_N(t_N) \quad (3)$$

Table 4. Experts' opinion for the weight coefficients of the criteria

ind	n_{ind}^{Y}	$\vec{Y}_{ind}$	*ind*	n_{ind}^{Y}	$\vec{Y}_{ind}$
1	12	3 3 3 3 3 3 2 2 2 2 1 1	2,3,1	12	3 3 3 3 2 2 2 2 1 1 1 1
1,1	12	3 3 2 2 2 2 1 1 1 1 1 1	2,3,2	12	3 3 3 3 3 3 3 3 2 2 2 2
1,1,1	12	3 2 2 2 1 1 1 1 1 1 1 1	3	12	1 1 1 1 1 0 0 0 0 0 0 0
1,1,2	12	3 3 3 3 3 3 2 2 2 2 1 1	3,1	12	3 2 2 2 1 1 1 1 1 1 0 0
1,1,2,1	12	3 3 3 3 3 3 3 2 2 2 2 1	3,2	12	3 3 3 3 3 2 2 2 2 2 1 1
1,1,2,2	12	3 3 3 2 2 2 2 1 1 1 1 1	3,3	12	2 2 2 1 1 1 1 1 1 1 1 1
1,2	12	3 3 3 3 3 3 3 2 2 2 1 1	3,4	12	3 3 2 1 1 1 1 1 1 1 1 1
1,2,1	12	3 3 2 2 2 2 1 1 1 1 1 1	4	12	3 3 3 3 3 3 3 3 3 3 2 1
1,2,2	12	3 3 3 3 3 3 3 3 3 2 2 2	4,1	12	3 3 2 2 2 2 2 1 1 1 1 1
1,2,3	12	1 1 0 0 0 0 0 0 0 0 0 0	4,1,1	12	1 1 1 0 0 0 0 0 0 0 0 0
1,2,4	12	1 0 0 0 0 0 0 0 0 0 0 0	4,1,2	12	3 3 3 3 3 3 3 3 3 3 3 3
1,3	12	3 2 1 1 1 0 0 0 0 0 0 0	4,1,3	12	3 3 3 3 3 3 3 3 3 3 3 3
1,4	12	3 3 3 3 3 3 3 3 2 2 2 1	4,1,4	12	3 3 2 2 2 1 1 1 1 1 1 1
1,5	12	3 3 2 2 2 2 1 1 1 1 0 0	4,2	12	3 3 3 3 3 3 3 3 3 2 2 2
1,5,1	12	3 2 1 1 1 1 1 1 1 1 1 1	4,2,1	12	3 2 2 2 2 2 2 2 1 1 1 1
1,5,2	12	3 3 3 3 3 2 2 2 2 2 1 1	4,2,2	12	3 3 2 2 2 2 2 1 1 1 1 1
1,6	12	3 2 1 1 1 0 0 0 0 0 0 0	4,3	12	3 3 3 3 3 3 3 3 3 3 2 2
1,6,1	12	3 3 2 2 2 1 1 1 1 1 0 0	4,3,1	12	3 3 3 3 3 2 2 2 2 2 2 2
1,6,2	12	3 2 2 1 1 0 0 0 0 0 0 0	4,3,2	12	3 3 3 2 2 2 1 1 1 1 1 1
2	12	3 3 3 2 2 2 2 2 2 2 1 1	4,3,3	12	3 3 3 3 3 3 3 3 3 2 2 2
2,1	12	3 3 3 3 3 3 3 3 3 2 2 1	4,3,4	12	3 3 3 3 3 3 3 3 3 3 3 2
2,2	12	3 2 2 2 2 2 2 2 2 2 2 1	4,3,5	12	3 3 3 3 3 3 2 2 2 2 2 2
2,3	12	3 3 3 3 3 3 3 3 3 3 2 1			

To find the total marginal criterion, REPOMP utilizes the Churchman-Ackoff model to evaluate a set of alternatives based on multiple criteria [19]. The additive function is presented as

$$X^m = v(t_1,t_2,\ldots,t_n) = \mu_1 v_1(t_1) + \mu_2 v_2(t_2) + \ldots + \mu_N v_N(t_N) \tag{4}$$

Table 5. Ranking scale to assess how each alternative meets the primitive criteria

For criteria regarding emissions	0 – emissions below the lower assessment limit 1 – emissions between the lower and the upper assessment limit 2 – emissions on the upper assessment limit 3 – emissions over the upper assessment limit
For all other criteria	0 – excellent 1 – very good 2 – good 3 – satisfactory 4 – non-satisfactory 5 – non-acceptable

Table 6. Expert estimates for the four alternatives against the primitive criteria

ind	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	$\vec{X}_{ind}$	$\vec{X}_{ind}$	$\vec{X}_{ind}$	$\vec{X}_{ind}$
1,1,1	2 2 2 2 1 1 1 1 1 1 1 1	2 1 1 1 1 1 1 1 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0	4 4 4 3 3 3 3 3 3 3 3 2
1,1,2,1	2 2 2 1 1 1 1 1 1 1 1 0	2 1 1 1 1 1 1 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0	4 4 3 3 3 3 3 3 3 3 2 2
1,1,2,2	2 2 2 2 2 1 1 1 1 1 1 1	2 2 1 1 1 1 1 1 1 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0	4 4 4 4 4 3 3 3 3 3 3 2
1,2,1	3 3 3 2 2 2 2 2 2 2 1 1	3 3 2 2 2 2 2 2 2 1 1 1	3 2 2 2 2 2 1 1 1 1 1 1	5 4 4 4 4 4 4 3 3 3 2 2
1,2,2	2 2 2 1 1 1 1 1 1 1 1 1	2 2 1 1 1 1 1 1 1 1 0 0	1 1 1 1 1 1 0 0 0 0 0 0	4 4 4 3 3 3 3 3 3 3 2 2
1,2,3	1 1 0 0 0 0 0 0 0 0 0 0	1 1 0 0 0 0 0 0 0 0 0 0	1 0 0 0 0 0 0 0 0 0 0 0	2 2 0 0 0 0 0 0 0 0 0 0
1,2,4	1 0 0 0 0 0 0 0 0 0 0 0	1 0 0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0	2 0 0 0 0 0 0 0 0 0 0 0
1,3	3 2 2 2 2 2 2 2 1 1 1 1	3 2 2 2 2 2 2 2 1 1 1 1	5 5 5 5 5 5 4 4 4 4 4 3	0 0 0 0 0 0 0 0 0 0 0 0
1,4	4 3 3 3 2 2 2 2 2 2 2 2	4 3 3 3 2 2 2 2 2 2 2 2	3 2 2 2 2 2 2 1 1 1 1 1	5 5 5 5 5 5 4 4 4 4 3 3
1,5,1	3 3 2 2 2 2 2 1 1 1 1 0	2 2 1 1 1 1 0 0 0 0 0 0	2 2 2 2 1 1 1 1 1 1 1 0	4 4 4 3 3 3 3 3 3 3 3 2
1,5,2	3 3 2 2 2 2 2 1 1 1 1 0	3 3 2 2 2 2 2 1 1 1 1 0	3 3 3 3 3 2 2 2 2 2 1 0	4 4 4 3 3 3 3 3 3 3 3 2
1,6,1	2 2 2 2 2 2 1 1 1 1 1 1	2 2 2 2 2 2 1 1 1 1 1 1	4 4 3 3 3 3 3 3 3 3 2 2	0 0 0 0 0 0 0 0 0 0 0 0
1,6,2	3 3 3 3 2 2 2 2 2 2 2 1	3 3 2 2 2 2 2 2 2 2 1 1	4 4 4 3 3 3 3 3 3 3 2 2	4 4 4 4 3 3 3 3 3 3 3 2
2,1	3 3 3 3 3 3 2 2 2 2 2 2	3 3 3 2 2 2 2 2 2 2 2 1	5 5 5 5 5 5 5 4 4 4 4 3	0 0 0 0 0 0 0 0 0 0 0 0
2,2	3 3 3 3 2 2 2 2 2 2 2 1	3 2 2 2 2 2 2 2 2 2 1 1	3 2 2 2 2 2 2 1 1 1 1 0	4 4 4 3 3 3 3 3 3 2 2 2
2,3,1	4 4 3 3 3 3 3 2 2 2 2 1	4 3 2 1 1 0 0 0 0 0 0 0	4 4 4 4 3 3 3 3 2 2 1 1	5 5 5 5 5 5 5 5 4 4 4 3
2,3,2	4 4 4 3 3 3 3 3 3 3.2 1	2 1 0 0 0 0 0 0 0 0 0 0	4 4 4 4 3 3 3 3 3 2 1 1	5 5 5 5 5 5 5 5 5 5 5 5
3,1	3 3 3 3 2 2 2 2 2 1 1 1	3 3 2 2 1 1 1 1 1 1 1 0	4 4 4 4 4 4 4 4 3 3 2 1	0 0 0 0 0 0 0 0 0 0 0 0
3,2	3 2 2 2 2 2 2 2 2 2 1 0	2 2 2 2 2 1 1 1 1 0 0 0	5 5 5 5 5 5 5 5 5 5 4 3	0 0 0 0 0 0 0 0 0 0 0 0
3,3	3 3 3 3 3 3 3 3 2 2 2 1	3 3 3 3 3 3 3 3 2 2 2 1	5 5 5 5 5 5 5 5 4 4 3 3	0 0 0 0 0 0 0 0 0 0 0 0
3,4	3 3 3 3 3 3 2 2 2 2 2 2	3 3 3 3 3 3 2 2 2 2 2 2	2 2 2 2 2 2 2 1 1 1 1 1	5 5 5 5 5 5 5 5 5 5 4 3
4,1,1	1 1 1 1 1 1 1 0 0 0 0 0	1 1 1 1 1 1 1 0 0 0 0 0	2 2 2 2 2 2 2 1 1 1 0 0	0 0 0 0 0 0 0 0 0 0 0 0
4,1,2	2 2 2 2 2 2 2 1 1 1 1 0	2 1 1 1 1 0 0 0 0 0 0 0	1 0 0 0 0 0 0 0 0 0 0 0	5 5 5 5 5 5 5 5 5 5 5 5
4,1,3	4 3 3 3 3 3 3 3 3 3 2 2	4 3 3 3 3 2 2 2 2 2 1 1	5 5 5 5 5 5 5 5 5 4 4 4	0 0 0 0 0 0 0 0 0 0 0 0
4,1,4	3 3 2 2 2 2 2 2 2 2 2 1	3 2 2 2 2 2 2 1 1 1 0 0	5 5 5 5 5 5 5 5 4 4 3 3	0 0 0 0 0 0 0 0 0 0 0 0
4,2,1	4 4 3 3 3 3 3 3 3 3 1 1	4 4 3 3 3 3 3 3 3 3 1 1	3 2 2 2 2 2 2 2 1 1 1 1	5 5 5 4 4 4 4 4 3 3 3 3
4,2,2	4 3 3 3 3 2 2 2 2 2 1 1	4 3 3 3 3 2 2 2 2 2 1 1	3 3 2 2 2 2 2 1 1 1 1 0	4 3 3 3 3 3 3 3 2 2 2 1
4,3,1	2 2 1 1 1 1 1 1 0 0 0 0	2 2 2 2 2 1 1 1 1 1 1 0	1 1 1 1 1 0 0 0 0 0 0 0	5 5 5 5 5 5 5 5 5 5 5 5
4,3,2	1 1 0 0 0 0 0 0 0 0 0 0	1 1 0 0 0 0 0 0 0 0 0 0	1 1 0 0 0 0 0 0 0 0 0 0	5 5 5 5 5 5 5 5 5 5 5 5
4,3,3	1 1 1 1 1 1 1 0 0 0 0 0	2 2 1 1 1 1 1 1 1 0 0 0	1 0 0 0 0 0 0 0 0 0 0 0	5 5 5 5 5 5 5 5 5 5 5 5
4,3,4	4 3 3 3 2 2 2 2 2 2 1 0	4 3 3 3 2 2 2 2 2 2 1 0	4 3 2 2 2 2 2 2 1 1 1 0	5 5 5 5 5 5 5 5 5 5 5 5
4,3,5	5 5 4 4 4 4 3 3 3 3 3 3	2 1 0 0 0 0 0 0 0 0 0 0	4 4 3 3 3 3 3 3 2 2 1 1	5 5 5 5 5 5 5 5 5 5 5 5

The sum of μ_i in (4) should be equal to 1 for the total marginal criterion X^m to be properly scaled. The formulae (4) is impractical and extremely difficult to use. Instead, the criteria in Table 2 are calculated recursively for each alternative. The average rating of criterion *ind* is calculated for each primitive criterion:

$$X_{mean}^{ind} = \frac{1}{n_{ind}^{X}} \sum_{r=1}^{n_{ind}^{X}} X_r^{ind} \quad \text{for } S(ind) = \{\} \tag{5}$$

In (5) we assume that each expert is equally important in the assessment process, but if the level of expertise is different, then a weighted average of the experts' estimates can be utilised instead of (4) in the same way as it was proposed for the mean weighted coefficients. The average rating of criterion *ind* is calculated for each marginal criterion:

$$X_{mean}^{ind} = \sum_{inds \in S(ind)} \lambda_{inds} X_{mean}^{inds} \quad , \text{for } S(ind) \neq \{\} \tag{6}$$

The order of the calculations of the marginal criteria rating is important. Firstly, (5) must be applied for all ratings of the highest level, then for all ratings of the second-highest level, and so on till it is applied for the only criterion of 0-level, which is the total marginal criterion of the alternative:

$$X^m = X_{mean}^{[]} \tag{7}$$

The calculated rating of the criteria for alternative 2 are given in Table 7, where the total marginal criterion X^m is 2.1299. The same table also shows the order of calculation. The resulting values for the four analysed alternatives are given in the second column of Table 10.

Table 7. Criteria ratings for alternative 1. The marginal criteria are bolded.

ind	X_{mean}^{ind}	Calculation order	*ind*	X_{mean}^{ind}	Calculation order
[]	**1.6129**	**46**	**[2,3]**	**0.53571**	**38**
[1]	1.5641	42	[2,3,1]	0.91667	16
[1,1]	**0.76396**	**34**	[2,3,2]	0.25000	17
[1,1,1]	0.75000	1	**[3]**	**1.8108**	**44**
[1,1,2]	**0.77244**	**33**	[3,1]	1.4167	18
[1,1,2,1]	0.66667	2	[3,2]	1.1667	19
[1,1,2,2]	0.91667	3	[3,3]	2.5833	20
[1,2]	**1.2812**	**35**	[3,4]	2.5000	21
[1,2,1]	1.9167	4	**[4]**	**1.7140**	**45**
[1,2,2]	1.0000	5	**[4,1]**	**1.4069**	**39**
[1,2,3]	0.16667	6	[4,1,1]	0.58333	22
[1,2,4]	0.083333	7	[4,1,2]	0.50000	23
[1,3]	1.7500	8	[4,1,3]	2.3333	24
[1,4]	2.4167	9	[4,1,4]	1.5000	25
[1,5]	**1.3095**	**36**	[4,2]	2.5833	40
[1,5,1]	0.66667	10	[4,2,1]	2.8333	26
[1,5,2]	1.6667	11	[4,2,2]	2.3333	27
[1,6]	**1.6738**	**37**	[4,3]	1.0599	41
[1,6,1]	1.5000	12	[4,3,1]	1.3333	28
[1,6,2]	2.0000	13	[4,3,2]	0.16667	29
[2]	**1.4945**	**43**	[4,3,3]	0.91667	30
[2,1]	2.1667	14	[4,3,4]	2.1667	31
[2,2]	1.9167	15	[4,3,5]	0.25000	32

In ***STAGE 5 OF REPOMP*** we apply simulation techniques to construct the distribution of the total marginal criterion. If we were able to include all possible experts in our analysis, we would calculate the true total marginal criterion for each alternative X^{true}. However, we only have a sample of the whole population of experts, hence the calculated X^m is only an estimate (the actual one) of X^{true} for each alternative. If we were able to acquire information from another set of experts, then we would have another estimate of X^{true}. If we hypothetically had a great number (M) of expert panels, then we would obtain a great number of point-estimates $(X^m)_i$, for i=1, 2, …, M. Then we could also construct the distribution and find numerical characteristics for the total marginal indicator (e.g. mean, standard deviation, confidence intervals, etc.). To generate those M number of expert panels' estimates, we can adopt the computer-intensive Bootstrap simulation method [18]. It requires no information about the parameters of the process and needs to use data that consists of "independent and identically distributed data points" [20]. For further details regarding the essence and justification of the Bootstrap method, please refer to [21]. Using Bootstrap, we generate a large number M of pseudo-realities, for each alternative. In each pseudo-reality, synthetic learning samples of the same size as the original sample are generated by drawing with replacement from the original data. For example, the 9th synthetic sample of the weight coefficients and the estimates against the primitive criteria for alternative 2 are given respectively in Table 8 and 9.

Then each learning sample is processes as in stage 2 and stage 4 of REPOMP to obtain its synthetic total marginal criteria. As a result, synthetic ranking balls $\left(X^m\right)_i^{synt}$, i=1, 2, …, M are obtained. For example, $\left(X^m\right)_9^{synt}=1.6249$ is calculated as a synthetic ranking ball of Alternative 2 in the 9th pseudo reality using (1), (2), (5), (6), and (7) over the data in Table 8 and Table 9. The main assumption of the Bootstrap method is that the way the actual estimate deviates from the true parameter is the same as the deviation of the synthetic estimates from the actual one. Hence the distribution of the total marginal criterion constructed using the synthetic samples will give us information on what the true parameter X^{true} is based on the actual value X^m.

Table 8. Synthetic experts' opinion for the weight coefficients of the criteria in the 9th pseudo-reality for Alternative 2

ind	n^Y_{ind}	$\vec{Y}_{ind}$	*ind*	n^Y_{ind}	$\vec{Y}_{ind}$
1	12	1 3 1 3 3 2 3 3 2 2 3 3	2,3,1	12	3 1 3 3 1 3 1 1 1 2 2 2
1,1	12	2 2 2 1 2 1 3 3 1 2 1 1	2,3,2	12	3 2 3 2 3 2 3 3 3 3 3 3
1,1,1	12	2 3 3 2 2 2 3 1 1 1 2 1	3	12	0 0 1 0 1 1 0 1 1 1 0 0
1,1,2	12	3 3 3 3 3 3 3 2 2 3 3 3	3,1	12	0 0 2 0 1 3 3 2 1 2 2 1
1,1,2,1	12	2 2 2 2 2 2 2 2 3 3 3 1	3,2	12	3 2 2 3 3 2 1 2 2 2 2 2
1,1,2,2	12	3 1 3 3 2 2 1 1 1 2 3 3	3,3	12	1 1 1 2 1 1 1 1 1 2 1 1
1,2	12	3 3 2 3 1 3 3 3 3 2 2 3	3,4	12	1 1 1 2 1 1 1 1 1 3 1 1
1,2,1	12	3 1 1 1 2 2 1 2 2 1 1 3	4	12	3 3 3 3 3 1 3 3 3 3 3 3
1,2,2	12	3 2 3 3 3 3 2 3 3 3 3 3	4,1	12	2 1 1 1 2 2 3 3 2 1 2 2
1,2,3	12	0 0 0 0 0 0 0 1 1 0 0 1	4,1,1	12	1 0 0 0 1 1 0 1 0 1 0 0
1,2,4	12	0 0 0 0 1 0 1 0 0 0 0 0	4,1,2	12	3 3 3 3 3 3 3 3 3 3 3 3
1,3	12	2 0 1 0 1 2 0 0 0 2 1 1	4,1,3	12	3 3 3 3 3 3 3 3 3 3 3 3
1,4	12	3 3 2 2 2 2 3 3 3 3 2 3	4,1,4	12	1 3 2 2 1 2 1 1 2 1 1 3
1,5	12	1 1 3 2 1 1 1 1 1 1 2 1	4,2	12	3 2 3 3 3 3 3 3 2 2 3 3
1,5,1	12	1 2 1 3 1 1 1 1 1 1 1 1	4,2,1	12	3 3 2 1 1 2 1 1 2 2 1 2
1,5,2	12	2 1 2 2 3 1 2 2 2 3 2 2	4,2,2	12	2 1 1 2 3 3 3 2 2 3 3 2
1,6	12	1 1 0 0 0 1 0 1 0 0 0 0	4,3	12	3 3 3 3 3 3 3 3 3 3 3 3
1,6,1	12	2 3 1 2 1 0 1 3 0 1 1 3	4,3,1	12	3 2 3 3 2 3 2 2 2 3 3 2
1,6,2	12	0 0 3 1 0 0 1 2 3 1 2 0	4,3,2	12	1 1 3 1 1 1 1 2 1 1 2 1
2	12	3 2 2 3 2 3 3 2 3 2 2 2	4,3,3	12	3 2 3 2 2 3 2 3 3 3 3 3
2,1	12	3 1 3 1 1 3 2 2 3 3 3 3	4,3,4	12	3 2 3 3 3 3 3 3 2 3 3 3
2,2	12	2 2 2 2 2 2 2 2 2 2 2 3	4,3,5	12	2 2 2 2 2 3 2 2 2 3 3 2
2,3	12	3 3 2 1 3 3 3 3 3 3 3 3			

Table 9. Synthetic experts' estimates for the alternative 2 against the primitive criteria in the 9th pseudo-reality.

ind	**Alternative 2**	*ind*	**Alternative 2**
	$\vec{X}_{ind}$		$\vec{X}_{ind}$
1,1,1	1 1 1 1 0 0 1 1 0 1 1 1	2,3,2	0 2 0 0 2 2 0 0 0 0 0 0
1,1,2,1	1 0 0 0 1 0 1 0 1 0 0 2	3,1	1 1 1 0 1 3 1 0 2 1 1 0
1,1,2,2	1 1 0 1 2 1 0 2 0 0 0 2	3,2	0 2 2 0 1 0 0 2 0 2 1 1
1,2,1	2 2 2 3 2 2 1 2 3 1 2 3	3,3	3 3 1 2 3 3 3 3 2 3 3 3
1,2,2	0 1 1 1 1 1 1 0 1 1 2 0	3,4	2 3 2 2 3 3 3 2 3 3 3 2
1,2,3	0 0 0 0 0 0 0 0 0 0 0 0	4,1,1	1 0 1 0 0 1 0 0 0 1 0 1
1,2,4	1 0 0 0 0 0 0 0 0 0 0 0	4,1,2	1 1 0 1 0 0 1 1 0 1 0 1
1,3	2 2 3 2 2 1 1 1 2 1 2 2	4,1,3	2 2 4 2 3 3 1 3 2 3 3 1
1,4	2 2 3 3 3 2 3 3 3 4 2 2	4,1,4	2 2 2 3 3 3 2 2 2 2 0 2
1,5,1	2 0 0 2 2 0 2 0 0 0 0 1	4,2,1	4 3 3 3 3 3 3 3 1 3 4 3
1,5,2	3 2 1 2 3 2 2 1 2 1 1 1	4,2,2	3 3 2 1 3 4 3 2 1 1 2 3
1,6,1	2 2 1 1 2 2 2 2 1 1 1 1	4,3,1	1 1 1 2 2 1 2 2 0 0 1 1
1,6,2	2 2 1 1 2 1 2 1 2 2 2 2	4,3,2	1 0 0 0 0 0 0 0 0 0 0 0
2,1	3 3 2 2 2 3 1 2 3 1 2 2	4,3,3	1 1 1 2 0 1 0 0 1 0 1 1
2,2	1 2 2 2 2 3 1 2 2 2 1 2	4,3,4	3 4 3 1 2 2 3 1 3 2 3 2
2,3,1	0 2 0 3 1 1 0 2 1 0 0 1	4,3,5	0 1 0 0 0 0 0 0 0 1 0 2

To alleviate biases in the calculation process, we obtain the best randomized point estimate X_{best}^{m} as the mean of the synthetic ranking balls $\left(X^{m}\right)_{i}^{synt}$, flipped around the actual estimate X^m:

$$X_{best}^{m} = 2X^{m} - \sum_{i=1}^{M}\left(X_{i}^{synt}\right)/M \tag{8}$$

We can easily calculate the standard deviation σ_X of the best randomized point-estimate X_{best}^{m} by:

$$\sigma_X = \sqrt{\sum_{i=1}^{M}\left(X_{i}^{synt} - \sum_{i=1}^{M}\left(X_{i}^{synt}\right)/M\right)^{2} \Big/ (M-1)} \tag{9}$$

We generated 1000 pseudo-realities and calculated the synthetic total marginal criterion for each alternative. The results are given in the third and fourth column of Table 10. The results show that Alternative 2 is the best (*Establish the recreational centre at berths 1 to 10, emphasizing on the new appearance of the City Hall and the city square*), followed by Alternatives 1, 3 and 4. The densities of the total marginal criteria X^m for each alternative are also constructed, based on the synthetic rating marks (see Figure 11).

Table 10. Sample estimate, best point estimate and standard deviation of the total marginal criterion for each alternative

Alternative	Total marginal criterion X^m	Best estimate X_{best}^{m}	Standard deviation σ_X
1	2.1299	2.1265	0.0431
2	1.6129	1.6139	0.0445
3	2.1427	2.1397	0.0451
4	3.0392	3.0391	0.0349

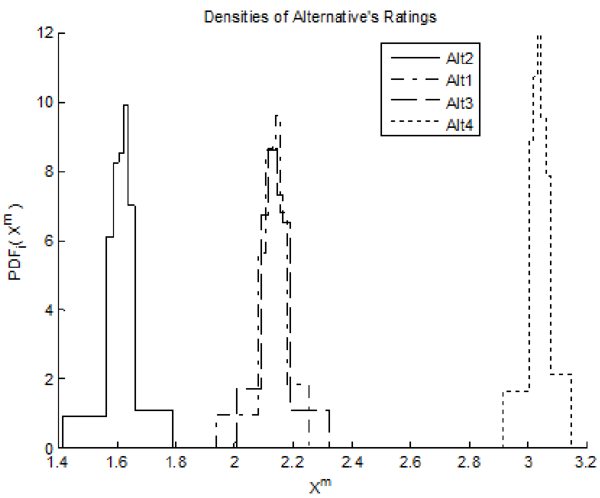

Figure 11. Densities of X^m for each alternative

Previous works [7; 22] extended the REPOMP results to test if the alternatives are significantly different (or else the difference in their ranking scores is negligible). The alternatives are grouped into pseudo-indifference classes, where the alternatives are indifferent to at least one of the other alternatives in the class (unlike classical indifference classes, where all elements in the set are indifferent to each other) [22]. The same work demonstrated that in such cases, the resulting relation of strict preference over pseudo indifference classes may end up being non-transitive. So, it is demonstrated in theoretical discussion and practical cases studies that this relation is strongly dependent on the significance level of comparisons to allocate alternatives into groups. In our study, at a significance level of 0.05, three pseudo-indifference classes are formed, as shown in Figure 12. The p_{value} is given above the connecting lines. Hypothesis testing is applied to each consecutive alternative.

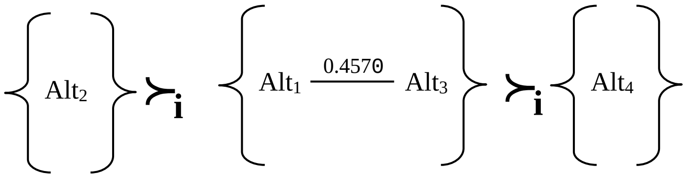

Figure 12. Grouping of alternatives in pseudo-indifference classes at significance level of 0.05

4. Conclusion

The REPOMP procedure replaces the usually-complex multi-criteria utility analysis that a classical decision-making procedure would require with an easy-to-use procedure based on expert estimates. The calculations of the total marginal criteria and their distribution under stages 4 and 5 of REPOMP, as well as the analysis of indifference classes are performed using original MATLAB functions. The functions are available free of change upon request from the authors. At the time of publication of this paper, the Port of Varna East has already undergone part of the renovations and restructures envisaged in the Alternative 2, recommended by our study.

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5. References

[1] Luger G. and Stubblefield W. 2004 *Artificial Intelligence: Structures and Strategies for Complex Problem Solving* (5th ed., Benjamin/Cummings)

[2] Hertz D. and Thomas H. 1984 *Practical risk analysis: an approach through case history* (Bath, Avon, John Wiley, Pitman Press Ltd)

[3] French, S. and Insua D.R. 2010 *Statistical Decision Theory: Kendall's Library Of Statistics 9*. (Chichester, UK: John Wiley & Sons Ltd.)

[4] Wright G. and Ayton P. 1994 *Subjective Probability* (Chichester, UK: John Wiley&Sons)

[5] Tenekedjiev K., Kamenova S. and Nikolova N.D. 2004 *J Cleaner Prod.* **12(4)** 353-360

[6] Nikolova N., Ivanova S., Georgieva G. and Tenekedjiev K. 2015 *Bootstrap evaluation of expert panel opinion in case studies solved by REPOMP*, In: Zlateva I., Raykov V., and Nikolov N. (Eds.) *Progressive Engineering Practices in Marine Resources Management* (IGI Global, pp. 48-76)

[7] Parushev P., Nikolova N.D., Kobashikawa C. and Tenekedjiev, K. 2006 REPOMP-Screening of Energy Saving Alternatives in an Education Building *Proc. International IFAC Workshop on Energy Saving Control in Plants and Buildings* (2-5 October 2006, Bansko, Bulgaria) pp. 37-42

[8] European Commission 2007 *Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the*

European Community (INSPIRE) (OJ L 108, 25.4.2007, p. 1–14) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0002&from=EN

[9] Ivanova S., Nikolova N.D., Kalinov K., Georgieva G., Mednikarov B. and Tenekedjiev, K. 2013 Selection of Adequate Models for Development of Spatial Data Infrastructure Using REPOMP *Proc. First International Conference of the Black Sea Association of Maritime Institutions; Actual Problems of Marine Shipping* (Admiral Ushakov Maritime State University, Novorossiysk, Russia, 25-27 June 2013) pp. 264-274

[10] Nikolova N.D, Armenski I., Tchikova K. and Tenekedjiev, K. 2012 Expert Assessment of Alternatives to Change the Location of the Port of Varna *Proc. 13th IFAC Symposium on Control in Transportation Systems CTS'2012* (September 12-14, Sofia, Bulgaria) pp. 347-352

[11] European Commission 2001 *White Paper: Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System* (28.3.2011 COM(2011)) https://ec.europa.eu/transport/sites/transport/files/themes/strategies/doc/2011_white_paper/white-paper-illustrated-brochure_en.pdf

[12] Official Journal of the European Union 2004 *Decision No 884/2004/EC of the European Parliament and of the Council of 29 April 2004 amending Decision No 1692/96/EC on Community Guidelines for the Development of the Trans-European Transport Network* (L 167 /1 – L 167 /38)
http://ec.europa.eu/ten/transport/legislation/doc/2004_0884_en.pdf

[13] European Commission 2011 *White Paper – Roadmap for a single European transport 2011* (28.3.2011 COM)
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0923:FIN:EN:PDF

[14] Official Journal of the European Union, *Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU*, https://publications.europa.eu/en/publication-detail/-/publication/58c00e4e-b59c-4b64-ad83-3d1a02b33fe8/language-en

[15] Belton V. and Steward T.J. 2002 *Multiple Criteria Decision Analysis – an Integrated Approach* (Kluwer Academic Publishers, USA)

[16] Baucells M. and Sarin R. 2003 *Man Sci* 49(8) pp. 1105-1118

[17] Hogarth R. and Karelaia N. 2005 *Man Sci.* 51(12) 1860–1872

[18] Efron B. and Tibshirani, R.J. 1993 *An Introduction to the Bootstrap* (Chapman &Hall).

[19] Britton G.A. and McCallion H. 1994 *Sys Pract* **7(5)** 487-521

[20] Press W., Teukolski S., Vetterling W.T. and Flannery B. 2007 *Numerical Recipes: the Art of Scientific Computing* (Third Edition, Cambridge University Press)

[21] Shao J. and Tu D. 1995 *The Jackknife and Bootstrap* (Verlag, New York, NY: Springer)

[22] Nikolova, N.D., Ivanova, S., Georgieva, G., Tenekedjiev, K., Non-Transitive Binary Relation of Preference in the Case of Random Value Functions, Derived from REPOMP *Proc. Fourth International Workshop Proceedings – Studies on Knowledge Discovery, Knowledge Management and Decision Making EUREKA-2013* (26-28 November, Mazatlan, Mexico), pp. 255-261