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Research Article

Decision Support Framework for Cycling Investment Prioritization

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Considering the significant potential for environmental, economic, social and health benefits from cycling, transport planners around the world are considering a wide variety of strategies for its promotion. However, cycling investments still have to find their place in a coherent package among other policies. Different constraints often imply a need for prioritization in cycling project implementation. The need for prioritization list of proposed investments can be caused by different factors such as available budget, available time, and regulatory constraints. Evaluation of investments in cycling infrastructure is a field of study that still requires further development, as previous research has mostly focused on questions of what to build and where. Previously used cost-benefit methods have substantive and procedural limitations in dealing with non-commensurable effects, and dealing with multiple conflicting objectives stemming from different stakeholders. On the contrary, development of prioritization list is formulated here as a semi-structured decision problem, thus belonging to the group of multi-criteria analysis (MCA) methods. The MCA methodology implemented in this decision-support framework is based on Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). The expert-based decision-support framework includes procedures for defining list of evaluation criteria and their weights, scoring of alternatives, and sensitivity analysis. Presented decision-support framework is applied on six bicycle sections of the EuroVelo route 8 through Montenegro. Results provide a list of prioritized infrastructural investments, as well as list of criteria with weights, and sensitivity analysis. Decision-support framework is discussed in the context of further professionalizing of cycling planning, as well as short-term and long-term structuration of organization learning in the transition country context. Finally, this development opens up directions for further contextualization of decision criteria, and greater consideration of user attitudes in cycling promotion.

1. Introduction

Considering the significant potential for environmental, economic, social and health benefits from cycling, transport planners around the world are considering a wide variety of strategies for its promotion [1–4]. It has been proven that successful strategies have to employ coordination of both land use and transport planning interventions, including policy packaging [5–9]. In addition to soft measures, such as campaigns, improvements of cycling infrastructure remain an essential measure for systemic change of transport system based on changing users' behaviour [9–14]. However, more significant infrastructural changes are still limited by a chronic lack of funding and leadership [15–17]. In the context of constrained funding sources, planners often revert to evaluation of cycling investments using the conventional tool of cost-benefit analysis (CBA) [18]. Despite its widespread use, CBA often suffers from several challenges when applied to cycling planning, such as uncertainty about the magnitude of cycling benefits and costs [1, 19, 20]. For example, previous research argues that health benefits are overestimated in CBA because cyclists already include them in their decisions [21]. This uncertainty is underlined with the fact that there is a wide range of factors that contribute to people's willingness to cycle, with the importance of these factors being highly subjective and often immeasurable [22–24]. In addition, CBA often cannot address the questions of equity and has procedural disadvantages when considered from a process perspective, as it often does not support communication and trust-building among planning stakeholders [25, 26]. Such procedural perspective is an important aspect to consider as a challenge of CBA-based methodologies.

Besides CBA, there has been a range of decision support systems developed for aiding the process of cycling network planning. One of the first works uses geographic information system (GIS) network database to analyse cyclist route data [27]. The trend of using GIS-based decision support systems for cycling network planning continues in the following decades [28–33]. These previous works use supply or demand-based models, or their combination, to suggest optimal choices for locating new infrastructure, with only some focusing on what infrastructure to build. Thus, there is an absence of research into how to prioritize systematically facilities that are to be built, as opposed to location decisions of new facilities. In the recent research efforts, there is an increasing interest in applying multi-criteria analysis (MCA) techniques in combination with GIS [29, 34, 35]. This trend points towards an underlying problem in cycling planning in general, which is that most plans include several conflicting and often non-commensurable objectives [35, 36]. In particular, MCA allows explicit consideration of multiple criteria, such as qualitative or quantitative, monetary or non-monetary effects, and application of criteria weights. Furthermore, the use of MCA techniques allows for greater transparency in the planning process, as different stakeholders can contribute to decision criteria and weights used for project evaluation [35].

Despite the advent of MCA techniques in cycling decision support systems, none of the previous studies focused on existing cycling infrastructure and decision of timing prioritization of investments. Only one study dealt with the assessment task of selecting bike projects from a public pool with limited funds [36]. Developing a prioritization list of bike-path section investments belongs to the scope of multi-criteria and multi-alternative challenges, with users and system objectives often being in contradiction. For example, users want to have maximally best riding surface, while the infrastructure management agency aims to reduce asset management costs. In addition, infrastructure management agency has responsibility for long-term asset strategy, often bound to significant infrastructural costs over many years, while users are focused on immediate riding experience. Having in mind this need to balance contradicting objectives in the context of multitude of choices and their significant consequences, transport planners face a semi-structured decision challenge, where decision-making is not intuitive. Thus, the objective of this paper is the development of a decision-support framework (DSF) for selecting the optimal prioritization list for bike-path section investment. The next section will present an expert-based decision-support framework centred on Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) multi-criteria decision analysis technique. Moreover, this methodological framework integrates Modified Digital Logic (MDL) method for criteria weights determination. Decision-support framework is tested on the EuroVelo case study, with six bike path sections located on the coast of Montenegro. Following the results from the implemented DSF, the discussion of implications is provided, including recommendations for future research.

2. Decision-Support Framework Formulation

The general basis for formulating any DSF includes knowledge and model management components. Knowledge management component structures processes focused on acquisition and structuring of stakeholders' knowledge in a communicative planning setting, such as in-person workshop meeting. Model management component focuses on the capacity for coherent ordering of competing alternatives in a discrete decision space. Secondary to knowledge and model management are dialog management (e.g., development of graphical user interface) and database management (e.g., development of interrelated data structure) components, which are out of the scope of this paper. Overall, this DSF is intended to support, not replace, stakeholders' role in the planning process. Considering the multitude of conflicting criteria stemming from both planners and bike users' perspective, as well as a range of advantages and disadvantages of each section, DSF is based on MCA methodology. MCA refers to the process of evaluating the final alternative optimality among a number of alternatives by defining the decision criteria and their weights. The MCA application results in the ranking of alternatives, from the most to the least favourable, thus allowing comparison of alternatives. The following two sections will describe details of knowledge and model management.

2.1. Knowledge Management. In order to define knowledge management components and process, it is important to structure the decision problem, from initially vague and ill-defined to one that can be formulated and analysed analytically [37]. Overall, this structuring of the decision problem requires identification of the problem, selection of an adequate analytical approach, and development of a detailed analytical procedure. In particular, there are several requirements for decision-support that this DSF takes into account. The first requirement is the analytical comparison of alternatives that is required in planning processes. The second requirement is transparency of the decision-support process that can be justified at the policy-making level, in particular highlighted with cross-referencing to the relevant information sources. The third requirement is the usability of DSF, related to commonly available data sources and in-use time. The fourth requirement relates to delivering evaluation outputs in a multifaceted form that can be used as a communication medium in multi-actor planning processes. Finally, the fifth requirement relates to the adaptability of DSF to be used among different planning agencies, with a reasonable amount of transferability effort. Following these requirements, formulation of the knowledge management process requires defining actor roles, activities, and their scheduled timing.

Considering the fact that different actors in the planning process can contribute with their goals, concerns, and uncertainties, there is a need for explicit stakeholder involvement

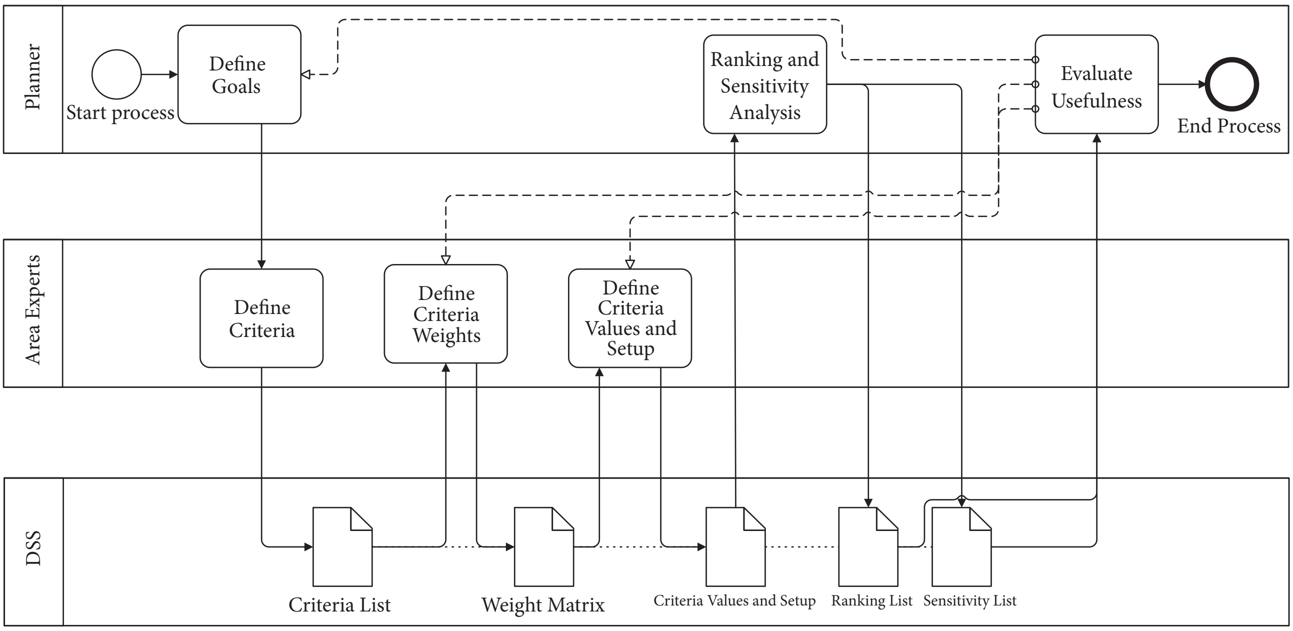


Figure 1: Knowledge management roles, activities, and process outputs.

[38, 39]. Stakeholder analysis can be used as an established procedure in itself [40], which can help in determining the range of expertise about particular transport system, including also the involvement of cycling advocates or land use planners. This DSF emphasizes that problem structuring based on the principles of decision theory should account for input and evaluation by an expert group having a deep understanding of the case study transport system. In general, groups of experts should be between four and six people, to allow sufficient diversity of opinions while still having possibility for simultaneous discussion. In addition, by bringing in experts with different roles and backgrounds, discussion allows for complementary knowledge exchange. However, knowledge management process is defined so that there is one planner as the main moderator (Figure 1). In addition to the moderator planner and area experts, process management has to take into account tasks related to the digital decision-support system (DSS). Namely, process management has to be based on the understanding that digital planning tools also play an important role in decision-making process. Each one of the actors, namely, planner, area experts, and DSS, is represented in horizontal layers of the process diagram.

Clear and transparent representation of the decision problem is important for analytical formulation based on the decision theory principles, and knowledge management process. Here, understanding the underlying rationales of localized planning principles is crucial for the effective bicycle infrastructure planning, as opposed to countries with well-established cycling infrastructure and culture, such as the Netherlands or Denmark [41]. These planning rationales are especially important for defining the decision space, as a set of alternatives, goals, and decision criteria. Once the alternatives are identified, as a set of bike-path sections, it is important to define measurable and verifiable goals [13]. Furthermore, criteria are defined accounting for knowledge about user attitudes [2, 22, 24], as well as local infrastructural conditions, such as section geometry, amenities, safety, and economic aspects [23]. Defining of criteria also has to take into account their scoring, especially in relation to available data. Thus, following the definition of decision criteria and their importance, scoring of alternatives is based on the data about case study bike-path sections. As the last sub-process, sensitivity analysis is essential for determining the impact to alternative ranking due to changes in the value of a particular variable (i.e., value of criteria weight). Figure 1 shows sequence of activities as well as outputs from each of these sub-processes. In addition to the solid arrows, depicting the standard workflow for this DSF, dashed lines represent the opportunities for short-term and long-term feedback loops. These loops would allow iterative approach to decision-making, with short-term loops allowing the redefinition of criteria weights and values, and long-term feedback loop aiming for redefining the decision-making goals. Thus, this iterative decision-making process is similar to the structure existing in a Delphi method and relies on in-person participation in a workshop setting.

2.2. Model Management. Some common MCA methods used in transport planning applications include the Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS), Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), and Elimination and Choice Expressing Reality ELECTRA [39, 42–49]. This DSF centres on Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), as the outranking method capable of accommodating a larger number of criteria and alternatives [50]. In practice, PROMETHEE method is a group of methods, where PROMETHEE I is used for partial ranking of alternatives, and PROMETHEE II is used for complete ranking of alternatives [51, 52]. The integration of PROMETHEE I and II, as well as MDL method, into a DSF is presented below.

2.2.1. Calculation of Criteria Weights. Modified Digital Logic (MDL) method of subjective evaluation of criteria weights was used to determine the criteria weights. Each expert individually evaluated weights of the criteria and assigned points to the alternatives in a chart. Then, mean values of the obtained individual weights were used. MDL method is used to address this issue by suggesting pair-wise comparisons of criteria [53]. The decision makers use digital scoring scheme of {1, 2 and 3} to represent the less (1), equal (2), or more important (3) criteria. After all pair-wise comparisons are made, the MDL weights can be calculated as

$$w_j = \frac{\sum_{k=1}^{n} C_{jk}}{\sum_{j=1}^{n}\sum_{k=1}^{n} C_{jk}}, \quad j \text{ and } k = \{1, \ldots, n\} \text{ and } j \neq k \tag{1}$$

If two criteria j and k are equally important, then $C_{jk}=C_{kj}=2$, otherwise $C_{jk}=3$ and $C_{kj}=1$ if the criteria k is more important than the criteria j. If the criteria k is less important than the criteria j, then $C_{jk}=1$and $C_{kj}=3$.

2.2.2. Evaluation of Alternatives. The detailed procedure for implementing the evaluation of alternatives using PROMETHEE II method consists of the following five steps.

Step 1 (determination of deviations based on pair-wise comparisons).

$$d_j(a,b) = g_j(a) - g_j(b) \tag{2}$$

where $d_j(a,b)$ is the difference between the evaluations (g) of alternatives a and b per criterion.

Step 2 (application of the preference function for each criteria).

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \quad j = 1, \ldots, m \tag{3}$$

where $P_j(a,b)$ is the preference of alternative a in comparison to alternative b per criterion, as a function (F) of $d_j(a,b)$. The purpose of preference function is to translate differences observed between two actions on a given criterion, to a normalized scale of 0-1 degree of preference.

Step 3 (calculation of an overall or global preference index).

$$\forall a, b \in A, \quad \pi(a,b) = \sum_{j=1}^{m} P_j(a,b)\, w_j \tag{4}$$

where $\pi(a,b)$ of a over b (from 0 to 1) is defined as the weighted sum $p(a,b)$ of each criterion, and w_j is the weight associated with the jth criterion.

Step 4 (calculation of positive and negative outranking flows/PROMETHEE I partial ranking).

$$\varphi^{+}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(a,x) \tag{5}$$

$$\varphi^{-}(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x,a) \tag{6}$$

where $\varphi^{+}(a)$ and $\varphi^{-}(a)$ are the positive outranking flow and negative outranking flow for alternative, respectively.

Step 5 (calculation of net positive and negative outranking flow/The PROMETHEE II complete ranking).

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \tag{7}$$

where $\varphi(a)$ denotes the net outranking flow for each alternative.

The preference flows are computed to consolidate the results of the pairwise comparisons of the actions, and to rank all the actions from the best to the worst one. The PROMETHEE I partial ranking is based on the rule that $aP^{I}b$ if and only if $\Phi^{+}(\mathrm{a}) \geq \Phi^{+}(\mathrm{b})$ and $\Phi^{-}(\mathrm{a}) \leq \Phi^{-}(\mathrm{b})$. The PROMETHEE II Complete Ranking is based on the net preference flow, which combines the two other preference flows in a single summary score. So alternative a is preferred to alternative b in the PROMETHEE II ranking $aP^{II}b$ if and only if $\Phi(\mathrm{a}) > \Phi(\mathrm{b})$. In addition to the numerical comparison, evaluation of alternatives is based on PROMETHEE Rainbow, which shows the detail of the *Phi net* flow computation, emphasizing the strong and weak features of each action. In this visualization, a bar is drawn for each action, and different slices of each bar are coloured according to the criteria. Thus, each slice is proportional to the contribution of one criterion (flow value times the weight of the criterion) to the *Phi net* flow score of the action. Positive (upward) slices correspond to strengths, while negative (downward) slices correspond to weaknesses. This way, the balance between positive and negative slices is equal to the Phi score. Actions are ordered visually from left to right according to the PROMETHEE II Complete Ranking.

2.2.3. Sensitivity Analysis. The sensitivity analysis is carried out to see the stability of the results, and to give all the answers to the possible variation of individual weight criteria ranging from 0% to 100%, relative to the weights determined in this study. As part of PROMETHEE method, weight sensitivity analysis can be done using Walking Weights or Stability Intervals analysis, with the latter one used in this DSF. In particular, Stability Intervals show how the *Phi* score and the PROMETHEE II ranking vary as a function of the weight of a criterion and identify the interval of stability of the first place and complete ranking [54].

3. Case Study Context Description

EuroVelo 8 is one of 14 bicycle routes across Europe, in total length of 5,888 km, connecting popular tourist destinations

Figure 2: EuroVelo 8 bicycle route (source: http://www.eurovelo8.com/).

through 11 countries, such as Barcelona, Monaco, Venice, Dubrovnik, Montenegro Coast, and Cyprus (Figure 2). The case used for implementation of this DSF is the part of EuroVelo 8 route which passes through Montenegro in a total length of approximately 195 km. Potential users of this route include holiday cyclists, cyclists on day trips for leisure, commuters and daily cyclists, and fitness cyclists. The country of Montenegro has a low level of bicycling transportation, related to the undeveloped cycling culture, mountainous terrain, and weather conditions in northern part of country. This can be changed with realisation of EuroVelo bike route through Montenegro. This bike route is intended to serve dual purpose, for touristic biking along Montenegro coast and for daily-commute movements in cities on route. As previously identified in the context of South-East Europe, planning and policy for sustainable transportation face knowledge gaps in relation to investment decisions and significant budgetary constraints [55–61]. Thus, route investment needs to realise in stages, so division to sections and prioritization of sections need to be done. In addition, improvements for different sections differ, e.g., based on the context of the section, such as urban or rural. Consequently, improvements can include such aspects as signage, lighting, lane widening, intersection treatments, etc. This need for regulatory-based prioritization is an excellent case for application of the above DSF.

In general, criteria development and scoring have been drawn also from EuroVelo guidelines for route development [62]. These guidelines highlight safety, attractiveness, coherence, directness, and comfort as principles for route selection and development. In addition, elements of EuroVelo routes include route infrastructure, services, and supporting promotional and organizational elements. In the route development process, guidelines focus special attention on the action plan, including investment priorities. Choosing an optimal list of prioritized routes includes aspects of section geometry, section attractiveness, traffic operations, traffic safety and economic aspects. Thus, the task is to evaluate all the most important sections characteristics, such as geometry, level of service, attractiveness, safety, traffic, social and economy, which define the basic characteristics of sections and alignment. The above DSF is applied on the six EuroVelo 8 sections, during a workshop with participation by different stakeholders including experts from the fields of transport planning, traffic operations, transport policy, transport economics and environment, bike association representatives and local authorities. This combination has allowed for a sufficient diversity of opinion to emerge, while still being able to have a common understanding on some of the core issues.

The EuroVelo 8 part through Montenegro starts at the border crossing with Croatia and passing the Bay of Kotor, through Trojica and Njeguš, leading to Cetinje. Then, it crosses Rijeka Crnojević, reaches Virpazar, from where it leads through Ostros to the border crossing with Albania, Sukobin. Route EuroVelo 8 through Montenegro has attractive and diverse sections, along with a relatively comfortable ride. The route starts its path along the coastal part, which is without significant climbs in the extremely attractive ambience of the Bay of Boka Kotorska with few historical cities that have historical sightseeing opportunities such as fortress, old ports, churches, and old city centres. The mountain part that follows is more demanding for cycling; the path goes up to 1,100 m.a.s.l. This part of the route also has an extraordinary attraction, as it offers an excellent view from the old Austro-Hungarian road upon the entire Bay of Kotor, the mountain range, and the national park Lovćen. The next section offers a new type of attraction - cycling around Skadar Lake. Table 1 includes geometric characteristics of existing roads and description of each of the six sections. These sections have been defined as individual functional sections of the entire bike path length. That means that this section has uniform environmental and technical characteristics, and that they can functioning individually.

4. Results from the Application of Decision-Support Framework

4.1. Criteria List and Criteria Weights. Trough detailed analysis, the experts identified and defined criteria groups, as well as individual criteria (Table 2). In total, four groups of criteria were defined, namely, Technical and geometry criteria, Traffic operations and safety criteria, Amenities criteria, and Economic criteria, with a total of 15 criteria.

4.2. Determination of Criteria Weights. Table 3 presents the values of the pair comparison of criteria according to the marks of the experts for each field of expertize agreeing on values during workshops. The final weight values were obtained using the equation (1), while seeking a consensus among the experts.

4.3. Determination of Criteria Values for Each Alternative, Preference Function, and Preference Thresholds. Table 4 presents scoring of the criteria, preference functions, and preference thresholds. The scoring was done with deterministic values where they are obtainable, where nonscoring is done by using a scale evaluation. The criterion function is max or min depending on criteria. For example, max means higher score is better for safety criteria. Experts chose preference functions and determine indifference and preference thresholds per each criterion as well as performing scoring of alternatives per each criterion. The shape of the preference functions in this case is either linear or V-shape, depending on the scale of underlying criterion. V-shape has variable preference degree and one preference threshold, while linear preference function has degree of preference that is increasing linearly between two thresholds. Only maximum altitude

Table 1: Detail characteristics of EuroVelo 8 sections through Montenegro.

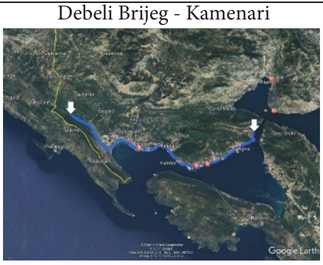
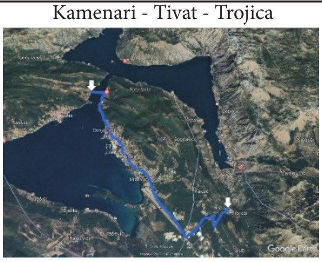
Section Name	Geometrical characteristic	Description
Debeli Brijeg - Kamenari 	(i) Length: 24.4 km (ii) Cross section profile: 7.00 m on rural sections and 4-6.00 m on urban sections (iii) Longitudinal profile: mostly level terrain, average grades >2%, with max altitude difference of app. 70 m (iv) Curvature: low (v) Pavement condition: good	(i) Route starts at the border with Croatia, going through touristic city Herceg Novi and many smaller touristic places. First third of road length is rural while the rest is costal road along Boka Kotorska bay, mostly passing through urban areas. (ii) This section is with intensive vehicular traffic volumes, especially through cities.
Kamenari - Tivat - Trojica 	(i) Length: 15 km (ii) Cross section profile: 7.00 m on rural sections and 4-6.00 m on urban sections (iii) Longitudinal profile: mostly level terrain, average grades >2%, with max altitude difference of app. 60 m (iv) Curvature: low (v) Pavement condition: good	(i) Mostly urban section starts in Kamenari, going with ferry to Lepatani and passing through touristic city Tivat. After city of Tivat, route is passing mostly through rural areas, and ends at settlement Trojica. (ii) This section is with high vehicular traffic volumes, especially through cities.
Trojica - Njeguši - Čekanje - Cetinje 	(i) Length 40.2 km (ii) Cross section profile of existing roads 3-4m (iii) Longitudinal profile: mostly mountain terrain, average grades 5%, with max altitude difference of 1050m (iv) High curvature (v) Pavement condition: bad	(i) Route starts in Trojica, going through rural mountain terrain to the city of Cetinje. This section is almost completely rural. (ii) This section is with very low vehicular traffic volume.
Cetinje -R.Crnojevića -Virpazar 	(i) Length: 38.5 km (ii) Cross section profile: 4-6.00 m (iii) Longitudinal profile: mostly mountain terrain, average grades 4%, with max altitude difference of 700m (iv) Curvature: high (v) Pavement condition: bad	(i) Route starts in Cetinje, going through rural mountain terrain to Virpazar. This section is almost completely rural. (ii) This section is with very low vehicular traffic volume.
Virpazar - Godinje - Ostros 	(i) Length: 34.5 km (ii) Cross section profile: 3-5.00 m (iii) Longitudinal profile: mostly mountain terrain, average grades 3%, with max altitude difference of app. 400m (iv) Curvature: medium (v) Pavement condition: bad	(i) Route starts in Virpazar, going through rural hilly terrain to Ostros. This section is almost completely rural. (ii) This section is with very low vehicular traffic volume.
Ostros-Sukobin (Albania border) 	(i) Length: 23.1 km (ii) Cross section profile: 3-4.00 m on regional road and 7.00 m on main road (iii) Longitudinal profile: mostly mountain terrain, average grades 3%, with max altitude difference of app. 480m (iv) Curvature: medium (v) Pavement condition: average	(i) Route starts in Ostros, regional road going through rural hilly terrain to Vladimir. The rural road is from Vladimir to border with Albania. This section is almost completely rural. (ii) This section is with very low vehicular traffic volume.

Table 2: Definition of criteria.

Criteria groups	Criterion name	Description
Roadway design criteria	Cross section profile	Width of road cross section profile (m)
	Pavement condition index	Condition of roadway surface, i.e. quality of roadway surface (scale 1-5)
	Maximum altitude difference	Altitude difference between lowest and highest road section (m)
	Road alignment	Horizontal and vertical curvature alignment (°/km)
	Signage quality	Qualitative and quantitative rating of signage on section (scale 1-5)
Traffic operations and safety criteria	Traffic flow speed	Average speed of vehicles on section (km/h)
	Vehicular traffic volume	Average annual daily traffic (veh/day)
	Cycling on bike lane or mixed traffic lane	Evaluation per section (% of separated lane from total section length)
	The overall level of cycling safety on the section	Road safety index evaluation per section (scale 1-5)
Amenities criteria	Capacities for food, drinks and accommodation	Evaluation per section (scale 1-5)
	Bike parking, repair services and bicycle rental locations	Evaluation per section (scale 1-5)
	Vicinity of cultural and historical attractions, natural sights, resting areas etc.	Evaluation per section (scale 1-5)
Economic criteria	Bike path construction costs	Bill of quantity (EUR)
	Land use value, population around bike section	Evaluation per section (scale 1-5)
	Touristic and economic development	Evaluation per section (scale 1-5)

difference criterion has linear shape, under the assumption that altitude has a linear relationship to propensity to cycle.

4.4. Evaluation of Alternatives

4.4.1. The PROMETHEE Flows. There are two PROMETHEE ranks that are based on a calculation of preferential flows, including PROMETHEE I partial ranking, and PROMETHEE II complete ranking. Although both ranking are performed, PROMETHEE II complete ranking is used for final ranking. The PROMETHEE Table (Table 5) shows the Phi, Phi+ and Phi- scores. Analyzing the flows given in Table 5 according to PROMETHEE II complete ranking can be concluded that best ranked section is S2 Kamenari -Trojica followed by section S1. This is also confirmed with the PROMETHEE I partial ranking where according to Phi+ flows best ranked is section S2 and according to Phi- flows best ranked section is also S2, while the other alternatives have a significantly worst value of positive, negative and net flow. The lowest ranked alternative is S4.. By analyzing the ratios of Phi+ and Phi- values for the first ranked and all the other alternatives, we can see that first placed section S2 (Kamenari - Trojica) is having a slight advantage compared to the section S1 Debeli Brijeg-Kamenari. However, sections S6, S5, S3 and S4 are significantly distant from the first two ranked sections.

4.4.2. The PROMETHEE Rainbow. The PROMETHEE Rainbow presented on Figure 3 is a disaggregated view of the PROMETHEE II complete ranking. It shows the details of the Phi net flow computation, emphasizing the good and weak features of each action, with different slices of each bar coloured according to the criteria. Sections are ranked from left to right according to the PROMETHEE II Complete Ranking, ordered as route sections two, one, six, five, three, and four. For each of the cycling sections, one can see criteria that are positive features above the zero value, and negative features below the zero value. Thus, one can conclude for each of the ranked alternatives, the number of positively and negatively affecting criteria, and their relative importance, within each alternative, but also in relation to other alternatives.

4.5. Sensitivity Analysis.

Table 6 shows us the extent to which the values of criteria weight can reach so that the first place in the ranking list section will remain the same. Table 6 shows the absolute stability of the first place by most of criteria. Only

Table 3: Comparison of criteria according to expert evaluations.

	Cross section profile	Condition of roadway surface	Maximum altitude difference	Road alignment	Signage quality	Traffic flow speed	Vehicles traffic volume	Cycling on bike lane or mixed traffic lane	The overall level of cycling safety on the section	Capacities for food, drinks and accommo-dation capacities	Bike parking – racks, covered, locked, surveil-lance, repair services and bicycle rental locations	Vicinity of cultural and historical attrac-tions, natural sights, resting areas etc.	Bike path con-struction costs	*Land use value, popula-tion around bike section*	WEIGHTS OF CRITERIA
Cross section profile	2	2	1	2	1	2	2	1	1	2	2	1	1	2	*5%*
Condition of roadway surface	2	2	1	2	2	2	2	1	1	3	3	2	2	3	*7%*
Maximum altitude difference	3	3	2	3	2	2	2	2	2	3	3	2	2	3	*8%*
Road alignment	2	2	1	2	2	2	2	1	2	2	3	2	2	3	*7%*
Signage quality	3	2	2	2	2	2	2	1	2	2	2	1	1	2	*6%*
Traffic flow speed	2	2	2	2	2	2	2	1	1	1	2	1	1	2	*6%*
Vehicles traffic volume	2	2	2	2	2	2	2	1	1	2	3	2	1	3	*7%*
Cycling on bike lane or mixed traffic lane	3	3	2	3	3	3	3	2	2	2	3	2	2	3	*9%*
The overall level of cycling safety on the section	3	3	2	2	2	3	3	2	2	1	1	1	1	2	*6%*
Capacities for food, drinks and accommodation capacities	2	1	1	2	2	3	2	2	3	2	3	1	1	3	*7%*
Bike parking, repair services and bicycle rental locations	1	1	1	2	1	1	3	2	3	2	2	1	2	2	*6%*
Vicinity of cultural and historical attractions, natural sights, resting areas	3	2	2	2	3	3	2	2	3	3	3	2	2	3	*8%*
Bike path construction costs	3	2	2	2	3	3	3	2	3	3	2	2	2	2	*8%*
Land use value, population around bike section	2	1	1	1	2	2	1	1	2	1	2	1	2	2	*5%*
Touristic economic development	2	1	1	1	2	2	1	1	3	1	3	1	2	2	*6%*

Note: If two criteria j and k are equally important, then $Cjk=Ckj=2$, otherwise $Cjk=3$ and $Ckj=1$ if the criteria k are more important than the criteria j. If the criteria k are less important than the criteria j, then $Cjk=1$ and $Ckj=3$.

Table 4: Evaluation table with scoring, preference functions, min/max, thresholds values and criteria weights.

	Cross section profile	PCI	Maximum altitude difference	Road alignment	Signage quality	Traffic flow speed	AADT	Bike lane or mixed traffic lane	Cycling safety	Capacities for food, drinks and accom-modation capacities	Bike parking, repair services and bicycle rental locations	Vicinity of cultural and historical attrac-tions, natural sights	Bike path construc-tion costs	Land use value, popula-tion around bike section	Touristic and economic development
Preference parameters															
Min/Max	max	max	min	max	max	min	min	max	max	max	max	max	min	max	max
Weight	5.00	7.00	8.00	7.00	6.00	6.00	7.00	9.00	6.00	7.00	6.00	8.00	8.00	5.00	6.00
Preference Fn.	V-shape	V-shape	Linear	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape
Preference	3.00	3.00	800.00	3.00	4.00	40.00	4500	15.00	0.50	4.00	0.50	3.00	100000	3.00	3.00
Evaluations															
Section 1: D. Brijeg - Kamen.	6.50	4.00	70	5.00	4.00	70.00	3500	10.00	3.00	4.00	3.00	5.00	250000	5.00	5.00
Section 2: Kamenari -Trojica	6.50	4.00	60	5.00	5.00	60.00	5000	15.00	3.00	5.00	3.00	5.00	250000	5.00	5.00
Section 3: Trojica - Cetinje	4.00	2.00	1050	2.00	1.00	40.00	500	0.00	2.00	3.00	2.00	5.00	150000	4.00	4.00
Section 4: Cetinje - Virpazar	5.00	2.00	700	2.00	3.00	60.00	500	0.00	2.00	2.00	2.00	3.00	150000	3.00	3.00
Section 5: Virpazar - Ostros	4.00	2.00	400	2.00	1.00	40.00	500	0.00	2.00	3.00	2.00	4.00	150000	3.00	4.00
Section 6: Ostros - Sukobin	3.50	3.00	480	2.00	4.00	50.00	500	0.00	2.00	3.00	2.00	4.00	150000	3.00	4.00
Statistics															
Minimum	3.5	2.0	60	2.0	1.0	40.0	500	0.0	2.0	2.0	2.0	3.0	150000	3.0	3.0
Maximum	6.5	4.0	1050	5.0	5.0	70.0	5000	15.0	3.0	5.0	3.0	5.0	250000	5.0	5.0
Average	4.9	2.8	460	3.0	3.0	53.3	1750	4.2	2.3	3.3	2.3	4.3	183333	3.8	4.2
Standard Dev.	1.2	0.9	347	1.4	1.5	11.1	1820	6.1	0.5	0.9	0.5	0.7	47140	0.9	0.7

Table 5: Ranking of the sections using PROMETHEE method.

Rank	Section	Phi	Phi+	Ratio+	Phi-	Ratio-
1	Section 2: Kamenari -Trojica	0.3327	0.4710		0.1383	
2	Section 1: Debeli Brijeg - Kamenari	0.2677	0.4101	0.87	0.1424	0.03
3	Section 6: Ostros - Sukobin	-0.0893	0.1286	0.27	0.2179	0.58
4	Section 5: Virpazar - Ostros	-0.1347	0.1115	0.24	0.2462	0.78
5	Section 3: Trojica - Cetinje	-0.1514	0.1186	0.25	0.2701	0.95
6	Section 4: Cetinje - Virpazar	-0.2249	0.0875	0.19	0.3125	1.26

Table 6: Analysis stability of the first place for all sections of EuroVelo 8 route through Montenegro.

Criteria groups	Criteria	Stability of the first ranked section
Technical and geometry criteria	Cross section profile	0% - 100.0%
	Pavement condition index	0% - 100.0%
	Maximum altitude difference	0% - 100.0%
	Road alignment	0% - 100.0%
	Signage quality	0% - 100.0%
Traffic operations and safety criteria	Traffic flow speed	0% - 47.13%
	AADT	0% - 19.94%
	Cycling on bike lane or mixed traffic lane	0% - 100.0%
	The overall level of cycling safety on the section	0% - 100.0%
Amenities criteria	Capacities for food, drinks and accommodation capacities	0% - 100.0%
	Bike parking – racks, covered, locked, surveillance, repair services and bicycle rental locations	0% - 100.0%
	Vicinity of cultural and historical attractions, natural sights, resting areas etc.	0% - 100.0%
Economic criteria	Bike path construction costs	0% - 31.87%
	Land use value, population around bike section	0% - 100.0%
	Touristic and economic development	0% - 100.0%

the criteria Traffic flow speed, AADT, Bike path construction costs do not retain the absolute stability of the first place.

5. Discussion

The final ranking list of alternative sections suggests the following order: S2 Kamenari –Trojica; S1 Debeli Brijeg – Kamenari; S6 Ostros – Sukobin; S5 Virpazar - Ostros; S3 Trojica – Cetinje; S4 Cetinje – Virpazar. The resulting decision-making process developed for knowledge management component of this decision-support framework focuses on explicating stakeholders' knowledge about specific aspects of cycling planning, along with overall planning goals. Definition and grouping of decision criteria is one of the central elements in explicating and incorporating expert knowledge. Thus, a list of criteria is a result in itself (Table 2), as other planning agencies can recognize many of these criteria in relation to their own goals. In addition, criteria weights are particularly important result, as they have crucial role in the analytical procedure for prioritizing alternatives. Here, looking at criteria weights from Table 4, and relating those to PROMETHEE Rainbow from Figure 3, one can find important relations overall and per alternative. For example, bike path constructions costs were among negative criteria for two top alternatives, while among positive criteria for other four alternatives, having high criteria weight overall. On the other hand, road alignment criteria as well as bike parking, services and rental locations criteria are highly positive for two top prioritized alternative sections. In addition, one could conclude that some criteria have been particularly positive for some sections, such as maximum altitude difference for section 5, or vicinity of cultural and historical sights and natural attractions for section 3. Besides the ranking list presented above, PROMETHEE II ranking has shown that the differences between the first and second positions are narrow. However, the first two ranked sections have significant advantage over other sections, sometimes having

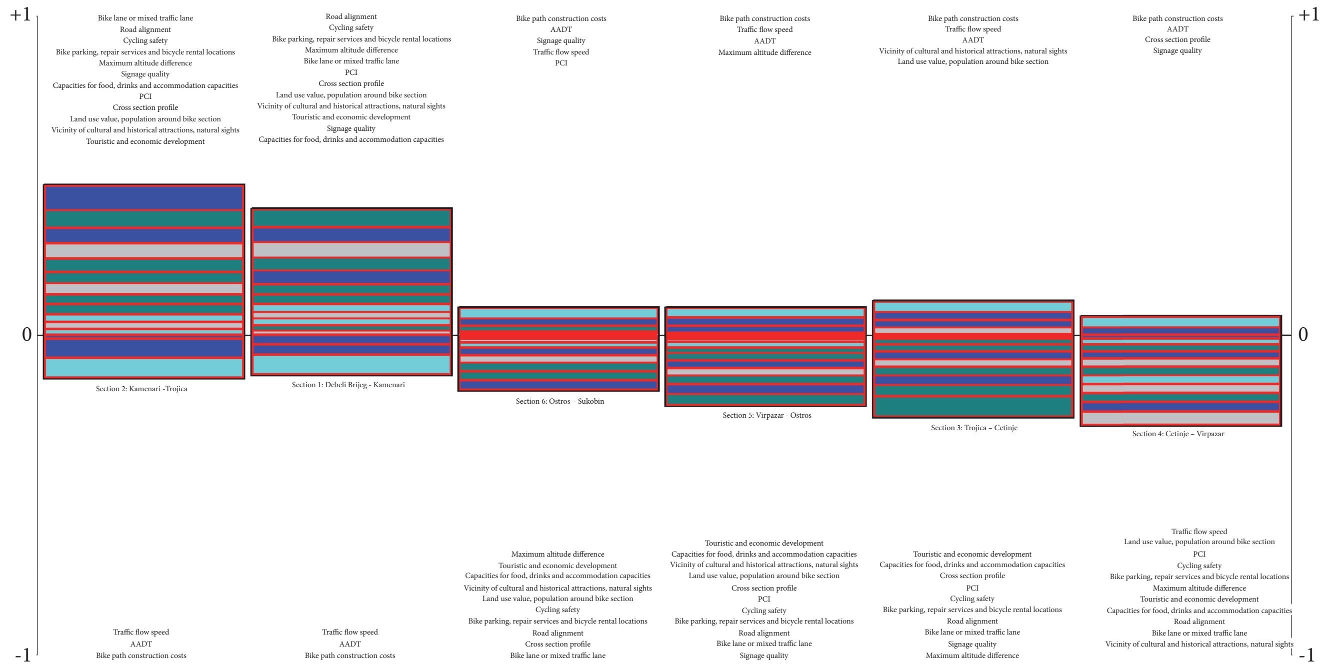


Figure 3: Promethee rainbow for all sections of EuroVelo 8 route through Montenegro.

even four or five-fold difference in scores (Table 5). Finally, sensitivity analysis showed the significant stability for most of the criteria (Table 6). However, some criteria had the low stability of the first place, where changing the weight of these criteria by more than 19.94% to 47.13%, would result in the first ranked section changing position to lower rankings. In addition, bike path construction costs have a sensitivity range limit of 31.78%, making it also a criterion with low stability. It is interesting to note that these criteria with lower stability are relying on objectively measured parameters.

In addition to the immediate results for this case study, actual implementation brings about evaluation of usefulness of such a decision-support framework for professionalization of cycling planning. The important aspect of this work is the learning process that planning experts had to go through during the application, resulting to discussions about applicability of results, and long-term organizational memory. Such learning aspects are especially important by including previously emphasized alignment and integration with other infrastructural investments and policies [6, 7, 9, 11, 13]. Moreover, important learning aspect is also related to the role that investment into cycling infrastructure has in developing cycling culture in this particular context. Planning processes can be strengthened by the capacity for analytical comparison of alternatives, as well as with cross-referencing to the relevant information sources, and acceptable time required for analysis. This analytical capacity is complemented with the capacity to account for non-monetary aspects and fuzzy objectives, often being unavoidable in transport planning. Furthermore, this decision-support framework is highly adaptable for use among different planning agencies, while expecting a reasonable amount of transferability effort. Such transferability would mainly rely on defining goals and criteria for the local context. However, one of the most important aspects of usefulness includes the capacity to deliver evaluation outputs in a multifaceted form, including tables and graphics. Such deliverables provide essential material for use as a communication medium in a multi-stakeholder planning process, but also are an essential process memory deliverable that is to be used in the future planning processes.

Here, it is important to highlight the importance of inclusive discussion, in relation to the moderated structure depicted in Figure 1. As one of the central aspects of knowledge management component is that interaction among area experts is guided by the moderator, it is important to highlight lessons learned during case study workshop. Moderator's role is extremely important in establishing a working environment where all participants feel safe to speak freely, and where different types of knowledge can join the discussion. Often, this role also includes guiding the discussion by highlighting shared interests (e.g., environmental sustainability, health promotion), and greater challenges behind immediate domain of cycling planning and promotion. Balancing the amount of moderation with respect to supporting active and engaged stakeholder participation is especially important for a sense of security and encouragement to share diverse knowledge. In order to expand the knowledge scope, the process can benefit from including experts with various backgrounds, such as planning, economics, operations, or maintenance. However, in addition to sharing knowledge, moderation is especially important for the general sense of openness in communication, where participants are open to hearing constructive criticism through careful listening and avoidance of defensive responses. Here, it is important to emphasize the importance of decision-support database management outputs, such as criteria lists or weight matrix, as they are helping in reducing the cognitive load among participants, thus allowing focus on higher cognitive processes, such as questioning of their assumptions. In particular, these tangible tabular or graphical outputs are important milestones for developing communication process memory, enhancing repeatability and assessment of planning processes.

The mediated process of communication should not be confused with simply people talking to each other during a given session. Rather, the communication process should be understood as process of deliberation, leading to increased internal (i.e., interpersonal among participants) and external (i.e., with non-participants and for overall validity) trust building in a decision-making process. An essential aspect is relationship building and process of understanding the knowledgebase and terminology of the other stakeholders, increasing the understanding of potential reaction in future interactions. Thus, if communication is to build interpersonal trust, it is important to understand the necessity for transparent and uniform presentation of alternative decisions. Highlighting the fact that this is a decision-support, not a decision-making framework, it is important to relate the above processes to the principles of organizational learning in transport planning and policy. Capacity for knowledge acquisition (incl., tacit and explicit knowledge), high level of communication, and trust between participants are important preconditions for supporting learning that this decision-support framework establishes. In addition, formulation of knowledge management component encourages understanding of planning process as iterative learning experience, with feedback loops. In particular, iterations are essential aspect of relating deliberation to consensus on the group level, and group learning, in addition to individual learning. Such iterations would also include development of supporting guidelines for appraisal, updated for variance of different planning cases.

In the context of organizational learning, we should distinguish capacity of this decision-support framework to aid short-term and long-term structuration of learning. When compared to cost-benefit analysis, multi-criteria methods are much more adaptable for exploratory, what-if, analysis. This feature is particularly enabled by changes in decision criteria weights, allowing development of alternative plans. Certainly, a good example of such exploratory analysis is assigning weight of zero to some group of criteria, such as amenities or economic group of criteria, depending on trips served by cycling network, or if one aims to assess the relative importance of infrastructural aspects. If one considers long-term structuration of inter- and intraorganizational learning, it is very important to pay special attention to experimentation with different experts joining workshops. Such long-term experimentation relates to the institutional and organizational aspects of cycling policy development. In particular, decision-support framework implementation would also ask for description of roles for the primary actors, and their degree of mutual collaboration and coordination. Such assessment of institutional structures and relations would also lead to identifying timely opportunities for involvement of citizens and advocacy groups, and overall assessment of organizational structure coordination. Besides revisions of roles and responsibilities in planning processes in relation to coordination, long-term structuration would also involve revisions of set of goals and available implementation actions, contributing partially to what to implement question. Moving beyond simple policy copying from places considered successful in promoting cycling, stakeholders can identify major contextual barriers and assess public acceptance of suggested actions. For example, this approach would ask for development of coherent policy packages instead of simply a list of policy measures [63], combining a selection of pull and push, or infrastructural and promotional measures, to account for local cycling culture.

6. Conclusion

Using bicycles as a transport mode has proven to be beneficial for environmental, social, and economic sustainability. Similarly, investing in cycling is gathering increasing importance worldwide. However, cycling investments still have to find their place among other policies, in coordination, financing, and monitoring processes with a range of time, budgetary, and regulative restrictions. In addition to previous literature that has emphasized the question of where to build and what to build, the question of cycling investment prioritization remains an open research domain [33–35]. Taking into account the fact that investment prioritization is part of the larger organizational coordination challenge, there is a need for finding an optimal solution through a formulation of a decision-support framework. Such a decision-support framework has to be based on understanding that true optimal solutions only exist if we consider a single criterion [43, 50]. In real planning situations, basing decision-making on only one criterion would be insufficient to account for complex infrastructural and behaviour interdependencies, thus failing to account for multiple conflicting and frequently non-commensurable objectives, stemming from a multitude of stakeholders [38, 46, 47].

In order to properly design facilities and policies that will stimulate bicycle use, especially in cases of constraints, this research formulates a decision-support framework capable of accounting for multiple criteria in the process of prioritization of the bicycle path sections investments. This decision-support framework responds to both substantive limitations (e.g., uncertain cost calculations) and procedural limitations (e.g., not supporting stakeholder communication and development of mutual trust) of classical cost-benefit analysis used in transport planning [19, 25, 26]. The central model management component of this decision-support framework is Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). Based on the principles of multi-criteria decision theory, formulation aims for informing stakeholders in terms of both interpretation of the results and interaction. In addition, the framework had to take into account the specific context of transition country, with lacking cycling infrastructure as well as cultural challenges with cycling.

Based on PROMETHEE, the net preference flow is the balance between the positive and negative preference flows and thus considers and aggregates both the strengths and the weaknesses of the action into a single measure. The positive preference flow measures how much an action a is preferred to the other n-1 ones. Thus, this is a global measurement of the strengths of action a, meaning the larger Phi+ value, the better the action. The negative preference flow measures how much the other n-1 actions are preferred to action a. It is a global measurement of the weaknesses of action a, thus smaller Phi- value means better action. The proposed decision-support framework is applied on a part of EuroVelo 8 route passing through Montenegro, including total of six functionally and geometrically separate alternative sections. The ultimate ranking list of alternative sections suggests the following order: S2 Kamenari –Trojica; S1 Debeli Brijeg – Kamenari; S6 Ostros – Sukobin; S5 Virpazar - Ostros; S3 Trojica – Cetinje; S4 Cetinje – Virpazar. Besides the ranking list presented above, PROMETHEE II ranking has shown that the differences between the first and second positions are narrow.

Finally, it is important to highlight limitations of the research presented here, and directions for future research. One should be aware that, for many of the alternatives, it is impossible to determine their scores per criterion in a fully analytical manner. Thus, the lack of analytically determined data in the scoring procedure for each of the alternatives per criterion is a limitation of this paper. This is a necessary trade-off with data availability, having in mind the planning context of transition country, where data collection procedures still have to be fully developed. In addition, there is a relation of this decision-support framework to other analysis tools used in cycling planning processes. Such tools would most likely be based on GIS or travel demand modelling principles. In addition, when deciding about investment prioritization, it is also important to consider the attitudes of the bike path users. This could help in identifying additional criteria, in addition to improving scoring of alternatives. Thus, future efforts should aim at surveying users about their current behaviour and expectations, contributing to the ranking methodology development. Moreover, transferability of this decision-support framework to cases of urban investment prioritization should also be taken into account.

Data Availability

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

Conflicts of Interest

All the authors declare that there are no conflicts of interest regarding the publication of this paper.

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