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Using the PROMETHEE II Method for the Assessment of Recreational and Tourist Cycle Routes

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Abstract:

Purpose: *This article is devoted to route planning for the purposes of recreational and tourist cycling, presenting the results of research that employed the PROMETHEE II method for the assessment of such routes in Kraków and its suburban areas (Poland). It aims to contribute to the little-studied issue of the evaluation of recreational and tourist cycle routes that connect urban and suburban areas.*
Design/methodology/approach: *The research relies on one of the Multiple Criteria Decision Aid (MCDA) methods, PROMETHEE II. The variants of bike routes were compared in terms of different economic, social and technical criteria to arrive at a final ranking. The weights of the criteria were assigned based on the knowledge and experience of experts in bike infrastructure design as well as the opinion of bike users.*
Findings: *The findings show the factors that matter not only for the users of cycle routes, but also for entities in charge of creating such infrastructure. They also highlight the importance of various aspects that accompany route planning, such as cooperation between entities, integration with the railway system or the use of religious sites as the backbone of the route.*
Practical Implications: *The results of the study complement the current state of knowledge on the factors for planning and accessing the recreational and tourist bike routes. The conclusions can contribute to the broader transport and tourism policy of many regions, including suburban and rural areas. The method employed, because its universal character, may be used for assessment of cycle routes for various user types and different locations.*
Originality/Value: *Its uniqueness consists in that it includes the aspect of integration of cycle routes with railway infrastructure and employs one of the least common MCDA methods. Moreover the importance of the parameters of the recreational and tourist routes are analysed not only from the view point of the route users, but also entities in charge of creating such infrastructure.*

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1. Introduction

Cycling is one of the most sustainable means of travel (Handy *et al.,* 2014), which has now become a more important part of transport systems and of transport planning (Braun *et al.,* 2016; Koglin, 2015; Zhao *et al.*, 2018). Cycling is an active, eco-friendly form of mobility (Karanikola *et al.,* 2018; Kingham and Tranter, 2015) that covers distances long enough to enable many urban and suburban trips (Vernez Moudon *et al.,* 2005). Evidence is also mounting on the health-enhancing potential of cycling (Panter *et al*., 2016). In particular, cycling to work or to school can be a relatively high intensity activity that by itself might suffice for maximum health gain (Donaire-Gonzalez *et al*., 2015; Veisten *et al.,* 2011). However, a bike is not just a means of daily transportation; it is also a tool for tourism and recreation.

Xing *et al*. (2010) report that most cyclists only use bikes for recreational purposes. In addition, Park *et al*. (2011) found that recreational cycling is recognized as an entry point into longer term increases in utility and commuting cycling, and the shift from being a recreational cyclist to being a utilitarian cyclist is influenced by various factors, including bike infrastructure and trip characteristics. Deenihan *et al*. (2013) likewise suggest that the development of infrastructure for recreational cycle traffic leads to an overall increase in daily bike trips, especially to places of education.

According to Veillette *et al.* (2019), when cyclists are given a choice of several types of infrastructure on their daily work commute (a recreational path, a bi-directional protected lane and a painted lane), they are most likely to use the recreational path, followed by a painted lane. In the light of above information provided, developing appropriate recreational cycling infrastructure seems to be very important.

Suburban recreational areas, which form a natural "extension" of the city, are the best sites for the daily and weekend leisure of the residents of cities and the entire municipal region (Poniży, 2010). Their enormous potential, not only for recreation but also tourism, derives from the presence of important environmental and landscape attributes, open spaces and other (religious or historical) attractions. Building bike paths and cycle routes provides an excellent opportunity to boost tourism and recreation in individual communes (Meschik, 2012).

As emphasized by Sołtysik *et al.* (2016), for many visitors, these routes may even serve as a more important tourist product than the local natural assets. This type of infrastructure is also on the rise because planners and decision-makers increasingly recognize the potential of cycle tourism as a way to boost the attractiveness and competitive edge of areas located on the margins of mass tourism (Hoyer, 2000), as well as appreciate their contribution to stimulating tourist traffic and economic activity in the region, especially in rural communities (Briedenhann and Wickens, 2004; Gazzola *et al.,* 2018; Miloradov *et al.,* 2018).

This article is devoted to route planning for the purposes of recreational and tourist cycling, presenting the results of research that employed the PROMETHEE II method for the assessment of such routes in Krakow and its suburban areas (Poland). It aims to contribute to the little-studied issue of the evaluation of recreational and tourist cycle routes that connect urban and suburban areas, crucial for choosing the best route location. Its uniqueness consists in that it also includes the aspect of integration of cycle routes with railway infrastructure and employs one of the least common MCDA methods.

Moreover the importance of the parameters of the recreational and tourist routes are analysed not only from the view point of the route users, but also entities in charge of creating such infrastructure. It is divided into five sections. The first part outlines the background of the research in question, while the second presents the literature review. The third one is devoted to the research methodology employed in this study. The fourth describes the geographical area under analysis, along with possible route variants, and presents an experimental calculation and its results. The last part is devoted to a discussion of the results.

2. Literature Review

This section presents the results of the literature review in terms of concept of cycle tourism and its potential as well as research into bike traffic incentives and disincentives, and methods used in studies on where to build bike infrastructure.

2.1 Cycle Tourism Concept

Torkildsen (2005, p. 54) identifies recreation with various activities taken up for the purpose of restoring oneself, physically and mentally, from the rigours of work, and approaches it as a psychological process that may come about in various ways. In his own definition, Kraus (2001, p. 38) similarly presents recreation as human activities or experiences taking place in leisure time for the purpose of intrinsic satisfaction and reinvigoration, which are pleasurable, although may involve a degree of compulsion, extrinsic purpose and discomfort, or even pain or danger.

Cycle tourism, on the other hand, can be defined as a type of active outdoor tourism; an activity linked to the environmental assets in which it takes place, it is treated as an attraction in and of itself (Bończak, 2013). Even though it already forms an important part of sustainable tourism initiatives (Gazzola *et al.*, 2018), cycle tourism continues to elude a clear definition due to the scarcity of relevant literature and the disparity of perspectives on the subject. The common denominator of all the definitions thus far proposed (Kingham and Tranter, 2015; Ritchie, 1998; Ritchie *et al.,* 2010; Sustrans 1999) is its perception as a tourism activity that involves at least one night away from home, in which the bicycle forms an important element of the tourist experience. One of the most frequently quoted authors, Ritchie (1998, p. 568), points out that a "cycle tourist" is *"a person who is away from their home town or country for a period not less than 24 h or one night, for the purpose of vacation or holiday, and for whom using a bicycle as a mode of transport during this time away is an integral part of their holiday or vacation".*

He draws a distinction between a "cycle tourist" and a "recreational cyclist", where the latter is defined as a person involved in any recreational cycling activity or excursion, who is away from home for a period shorter than the time indicated in the definition above. "Recreational cyclists" treat cycling as a good way to spend their leisure time. Simonsen and Rorgensen (1998) further distinguish between different types of cycle tourists. For "cycling enthusiasts", the bicycle is the only means of transportation and the only way to spend their vacation, the very purpose of the trip is to cycle. In contrast, "occasional cyclists" only use their bike every now and then during their vacation, and see it as no more than a nice, alternative means of transport. Most cycle tourists fall somewhere in between these two extremes. Moscarelli *et al.* (2017), however, emphasize that cycle tourism is not and should not be considered as a sport only for the physically prepared, but as a nice cultural activity for all.

2.2 Potential of the Cycle Tourism

Developing recreational and tourist bike routes that direct traffic to and around suburban areas may not only help promote cycling as a form of active leisure, but also foster sustainable and environmentally friendly economic growth (Giovannini *et al.*, 2017; Lamont, 2015), as well as enhance the social status of a territory (Gazzola *et al.*, 2018; Lumsdon, 2000). The influx of cycle tourists expands the regional economy by inducing job opportunities and boosting small businesses run by local communities, which provide visitors with specially designed products and services, such as accommodation, technical support (Meschik, 2012), food (Lumsdon, 2000), including regional specialities, and activities related to local culture and tradition (Giovannini *et al.*, 2017).

Besides its economic benefits to local communities, cycle tourism also contributes to the reduction of traffic congestion and stands out as an environmentally sustainable practice, ensuring the efficiency of land use and reduction of pollution (Sustrans, 1999; Pociovalisteanu and Niculescu, 2010). Health benefits and a reduction in medical expenditure have also been observed (Bassett *et al.*, 2008).

In many cases, designing recreational and tourist cycle routes does not require a large financial investment, since it is possible to rely on existing resources and often under-used facilities such as forest trails, gravel roads and canal towpaths (Lumsdon, 2000), as well as existing roads with very low traffic intensity; on the one hand, this guarantees route continuity and, on the other, ensures that the main attractions are easily accessible along an attractive itinerary (Giovannini *et al.*, 2017). Moscarelli *et al.* (2017) also emphasize the advantages of integrating recreational and tourist cycle routes with the rail system. These involve more than just increased passenger flow on secondary lines and small and medium-sized stations, caused by the potential of cycle tourism to attract visitors.

Such integration also makes it possible to achieve synergy between the two means of transport, while the train easily covers large distances in a shorter time, the bicycle is more flexible and allows cyclists to visit and explore the surrounding areas. In addition, cycle tourism allows the revitalization of railway stations, especially small ones, by adding functions other than transport and filling up empty spaces with commercial activities related to cycling, art, culture or other creative disciplines (Kana, 2012).

Tapping this potential in an urban setting, however, requires an integrated approach (Stoffelen, 2018) and close cooperation between various stakeholders (Liu, 2003; Lumsdon, 2000), including the authorities of individual communes and the metropolis, since communes will not be able to effectively stimulate tourist traffic on their own (Mantey, 2017).

2.3 Incentives and Deterrents to Cycling

In the most general terms, the incentives and deterrents to cycling can be classified in three main categories: (1) individual factors (e.g., socio-demographic characteristics and perceptions); (2) social and cultural factors (e.g., socio-economic status of a neighbourhood); and (3) built and natural environment factors (e.g., bicycle infrastructure, distances to destinations, natural aesthetics) (Etminani-Ghasrodashti *et al.,* 2018; Heesch *et al*., 2015; Manaugh *et al*., 2017). Many studies have focused on the built environment and the physical infrastructure (Braun *et al*., 2016; Clark *et al*., 2019; Ghodrat Abadi and Hurwitz, 2018; Mertens *et al*., 2017).

In most research, recreational and transport cycling (cycling as a means of transport) have not been given separate treatment due to the small sample size (Heesch *et al*., 2015). Only a handful of studies have focused on the purpose of cycling; even those, however, fail to adequately address the features that distinguish transport cyclists from recreational cyclists and affect the frequency of their trips. Even less attention thus far has been devoted to bike path design for leisure cycling, despite its major role in promoting cycle recreation and tourism.

Although evidence from the research of Heesch *et al.* (2015) and McCarthy *et al.* (2016) suggests the development of different strategies to encourage the two types of cycling behaviour, there are also reasons to believe that many of the factors that influence transport cycling also have an impact on recreational cycling, these include, e.g., physical environment characteristics such as design, safety, prevalence of destinations and aesthetic features (Kamphuis *et al*., 2008). Giovannini *et al*. (2017) emphasize that whether intended for leisure or mobility needs, the level of cycling depends on the quality of available infrastructure, while Downward *et al.* (2009) indicate that, when planning infrastructure that targets both users, it is important to ensure that the infrastructure can cater for longer trips.

Deenihan and Caulfield (2015) found that tourists are willing to increase their cycling time by approximately 100% in order to cycle upon a cycling facility fully segregated from traffic rather than along a road without cycling infrastructure, and are willing to increase their time by 40-50% to be able to cycle along a road with a cycle lane rather than a road without cycling facilities. McCarthy *et al.* (2016) claim that safety is the highest-ranked concern when designing a cycle route for either commuters or leisure cyclists.

On the other hand, Giovannini *et al.* (2017) point out that safety is an essential feature cycle tourists require even more than transport cyclists and its lack seems to affect cycle tourists much more than cycle commuters. They go on to add that the continuity of cycle pathways and their attractiveness are factors that also affect cycling both for recreation and transport purposes, and emphasize that in the case of recreational cycling, the attractiveness of the routes is a necessary requirement.

This view is also supported by Downward and Lumsdon (2001), Etminani-Ghasrodashti *et al*. (2018), and Watthanaklang *et al*. (2016), whose studies provide evidence for the key role of attractiveness and landscape design for both recreational and tourist cyclists. The Sustrans report (1999) also underlines that cycle tourism requires not only safe, convenient and attractive cycle routes that have as little interaction with vehicular traffic as possible and cater for both long and short distance cycling, but also safer and easier access points into and out of cities and towns.

2.4 Methods Used in Studies on where to Build Cycling Infrastructure

In recent years, research devoted to cycling infrastructure location planning has largely relied on GIS techniques associated with population origin-destination data (Boettge *et al.*, 2017; Guerreiro and Rodrigues da Silva, 2013; Lowry *et al.*, 2016). In some studies, GIS is combined with multicriteria analysis or multicriteria analysis is employed as the only research tool. For instance, a multi-criteria approach to urban bicycle routing was applied by Song *et al.* (2014), who used a set of criteria and a multi-label correcting algorithm for computing the full set of Pareto routes.

To reduce the potentially very large number of Pareto solutions, they introduced a route selection algorithm, based on hierarchical clustering. A method for assessing a hierarchical structure of route selection criteria for bicycle route planning in urban environment was also presented in Hochmair (2004). Hochmair and Zhaohui (2013) applied ArcGIS Network Analyst extension for the route search, where algorithms for the fastest, safest, simplest, most scenic and shortest routes are embedded, while Su *et al*. (2010) proposed a GIS-based planner which incorporates variables that influence choices to travel by bicycle in selecting the preferred routing.

Martinelli Guerreiro *et al.* (2018) mixed data-mining for identifying potential bike users, GIS and multicriteria analysis in a comprehensive method for bicycle network planning and design. To compare the cycling path network built as a result of their research with networks created by the city of Sao Carlos, they used six cost criteria and six benefit criteria. Rybarczyk and Wu (2010) proposed a planning procedure for bicycle facilities at network level and neighbourhood level. They used GIS and a modified Simple Additive Weighting method to integrate all demand-related factors.

The GIS and Weighted Sum Method were applied by Ruda (2019) for new cycle path construction in the city of Přerov, while Hsu and Lin (2012) proposed a procedure based on GIS and a Fuzzy Analytic Hierarchy Process for planning bicycle networks in urban areas. Terh and Cao (2018), on the other hand, proposes a GIS multi-criteria decision analysis framework for the support of cycling path planning in Singapore. A Weighted Linear Combination model was used to derive the optimum locations for building cycle paths. It must be noted that all the studies outlined above focus on cycling infrastructure in urban areas, which is often dedicated for commute purposes. Some do not distinguish between different motivations for travel at all and fail to include factors with a special impact on recreational and tourist cyclists.

Rather fewer studies have been devoted to the planning of infrastructure for recreational and tourist cycling. McCarthy *et al*. (2016) developed a decision support tool for use in the route selection stage of inter-urban cycle routes for commuter and/or leisure purposes. The tool uses a matrix of criteria related to safety, directness, comfort, perceived security, coherence and attractiveness. Pedrosa *et al.* (2019) used the Network Analyst of the ArcGIS software and criteria related to length, slope, speed limit, track capacity, landscape and distance to industrial areas to define ideal touring cycle routes.

Milakis and Athanasopoulos (2014) proposed a methodology which involves multicriteria analysis with deliberation and the help of GIS software for planning the Athens metropolitan cycle network that can also be used for recreational trips. Some of the more important evaluation criteria used in this study were: difficulty in riding a bicycle, density of crossings, traffic intensity and speed, natural environment, built environment, accessibility to activities and accessibility to metro/railway stations.

According to the results of a survey conducted by Macharis and Bernardini (2015), the use of Multiple Criteria Decision Aids (MCDA) for the assessment of transportation projects has been on the rise, but only as few as 1% of all MCDA studies focus on bicycle traffic (as opposed to 22% devoted to mobility management and 10% to public transport). Transportation projects most commonly rely on the AHP method (33%), while one of the most recent MCDA methods, the PROMETHEE method (Preference Ranking Organization METHod for Enrichment Evaluations), is also one of the least frequently used (only 6% of transport-related research) (Macharis & Bernardini, 2015). This is confirmed by the literature survey presented earlier, none of the above analyses devoted to the location of recreational and tourist cycling infrastructure has relied on the PROMETHEE method. Its application to prioritizing EuroVelo8 routes was presented in the latest studies by Glavić *et al.* (2019), in which route variants were evaluated in terms of 4 criteria groups (roadway design, traffic operations and safety criteria, amenities criteria, economic criteria), and Glavić and Milenković (2018), where the following criteria groups were employed: technical, traffic, traffic safety and attractiveness. This rare used MCDA method is also applied in our research.

3. Research Methodology – Promethee II Method

MCDM is a discipline of knowledge derived from operational research, which allows decision-makers to make choices based on a finite set of criteria to achieve what is known as a compromise solution. Multi-criteria decision problems can be classified into three groups (Roy, 1990):

- selection problems, where the decision requires a choice of one from a finite set of variants,
- ranking problems, where the decision involves ranking a set of variants according to their quality (from best to worst, or the other way around),
- sorting problems, where the decision-maker assigns variants to pre-defined categories.

This article is based on a multi-criteria ranking problem and its solution is divided into the following stages:

- formulating the problem and identifying the members of the decision-making process,
- constructing variants,
- defining the criteria and specifying the preferences of the members of the decision-making process,
- creating a preference model for the members of the decision-making process (defining the weights of specific criteria and the sensitivity to their changes),
- the final ranking of variants (an experiment, e.g. with the use of specialist software).

The literature on the subject offers a variety of different methods for solving multi-criteria ranking problems. Some of the best known multi-criteria decision aid systems include: ELECTRE (Elimination Et Choice Translating Reality) (Roy, 1990), PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) (Brans and Mareschal, 2002), AHP (Analytic Hierarchy Process) (Saaty, 1980), and ANP (Analytic Network Process) (Saaty, 2001). PROMETHEE is a family of methods based on what is known as the outranking relation, proposed by B. Roy (the European school) (Roy, 1990). Available variants are ranked following a series of pairwise comparisons, the process relies on concepts similar to those employed in ELECTRE methods (i.e., indifference and preference thresholds).

The final ranking is derived from measures known as flows, which aggregate the individual results of elementary pairwise comparisons. The method was created in 1984 by J. Brans (Brans and Mareschal, 2002; Brans *et al.,* 1984; 1986; Figueira *et al.,* 2005) and consists of four stages: (1) constructing the outranking relation; (2) determining the preference index; (3) calculating the dominance flow for all variants; and (4) drawing up the final ranking.

The first two phases involve determining the value of the outranking relation, based on a generalized criterion, the preference index is first defined and a graph value ranking is drawn up to represent the preferences of the decision-maker in successive pairs of variants from set A. The subsequent two stages consider the dominance flows for each variant. The decision-maker is presented with a partial (PROMETHEE I) or complete ranking (PROMETHEE II) on a set of possible variants.

Stage 1: Constructing the outranking relation. The first phase begins with defining the set of analysed variants, a coherent family of criteria with their respective weights, and the values of criterion functions. The outranking relation is determined on the basis of the multi-criteria preference index π for variant a over variant b. The index is given by the following formula:

$$\pi \quad (a,b) = \frac{1}{\pi}\sum_{i=1}^{n}\pi_i \cdot H_i(a,b), where \ \pi = \sum_{i=1}^{n}\pi_i \qquad (1)$$

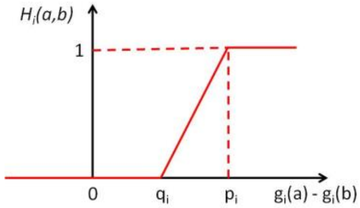
where:
π(a,b) – the decision-maker's multi-criteria preference index for variant *a* over variant *b* for all considered criteria,
$i = 1,2, \ldots n$ – the set of assessment criteria,
$H_i(a,b)$ – the preference function for criterion *i*

Stage 2: Determining preference indexes. The process requires introducing a preference function $H_i(a,b)$ in order to standardize relationships between variants and enable simultaneous pairwise preference comparisons for all criteria (standardizing all function values to values in the [0,1] interval). At this stage, the basic task of the decision-maker is to draw a preference function, based on the previous analysis of the dominance of variant a over variant b for every criterion i.

The preference function is expressed as a difference in the values of compared variants in terms of a given criterion, i.e., $g_i(a)$- $g_i(b)$. The value of the function increases along with the growing difference between $g_i(a)$ and $g_i(b)$; six basic preference modes can be distinguished (Brans *et al*., 1984; Figueira *et al*., 2005). Depending on the chosen shape of the function, the decision-maker must also specify additional information, such as, e.g. the indifference threshold and the strong preference threshold. In our case every criterion was presented with the use of the same, linear preference, function – V type (Figueira *et al*., 2005), for which indifference and preference thresholds must be defined (there is a linear increase in preference between them).

The linear type of the preference function represents a situation in which for a given criterion i, an indifference threshold qi and a preference threshold pi must be defined. The decision-maker also assumes that the preferences increase in a linear fashion from 0 to 1 in the interval between the indifference and the preference thresholds, respectively q_i and p_i. The visual representation of the preference function along with its mathematical notation is shown in Table 1.

Table 1. *Linear preference function – V type in the PROMETHEE II method, prepared on the basis of Figueira et al. 2005*

Type 5 – linear	
 Thresholds: preference p_i and indifference q_i	$H_i(a,b) = \begin{cases} 0 & gi(a) - gi(b) \le q_i \\ \frac{[gi(a)-gi(b)]-q_i}{p_i-q_i} & q_i \le gi(a) - gi(b) \le p_i \\ 1 & gi(a) - gi(b) > p_i \end{cases}$

Source: *Figueira et al. 2005.*

Building a preference model for a given decision-maker involves selecting an appropriate preference function shape $H_i(a,b)$ for every criterion i, as well as defining its characteristic parameters. Each function type is symmetric with respect to the difference between variants equal to zero. This means that for a positive difference between variants a and b, i.e., where $g_i(a) > g_i(b)$, the value of the preference function equals $H_i(a,b)$, and $H_i(b,a) = 0$. Hence, if $g_i(a) < g_i(b)$, the value of the preference function equals $H_i(b,a)$, and $H_i(a,b) = 0$.

Stage 3: The net flow for a given variant. At this stage, the values of net flows are determined for each variant. The net flow is the difference between the output dominance flow Φ^+ (a) and the input dominance flow Φ^- (a). The figure tells us how and to what extent a given variant outranks other n−1 variants. It is given by the following formula:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \tag{2}$$

where:

Φ^+ (a) – output dominance flow. The figure represents the degree of dominance of variant i over all other variants (it means that variant i belongs to the group of dominant variants).

Φ^- (a) – input dominance flow. The figure represents the degree of dominance of all other variants over variant *i* (it means that variant *i* is in the group of dominated variants).

Input and output flows are given by the following formulas:

$$\Phi^{+}(a) = \sum_{b \in A} \pi \ (a,b) \tag{3}$$

$$\Phi^{-}(a) = \sum_{b \in A} \pi \ (b,a) \tag{4}$$

Hence, variant *a* outranks variant *b* if Φ (a) > Φ (b); if Φ (a)=Φ (b), the variants are equivalent.

Stage 4: The final ranking is generated as an ordering of variants from best to worst, in descending order of net flows. As the main advantages of the method include:

- precise modelling of the decision-maker's preferences - preferences in relation to variants are expressed in relation to each criterion,
- the ability to define a preference function for each criterion,
- the decision maker can define weights for each criterion,
- the preference model includes weights of criteria and equivalence and preference thresholds, giving the possibility to capture and define a wide range of preferences,
- the weights of the criteria reflect the compromise between the criteria,
- during modelling and computational experiments, the actual values of the criteria evaluation are used, which eliminates the risk of making a mistake during transforming the data and increases the credibility of the obtained results.

The assessment of various areas in terms of tourist attractiveness is based on the analysis of many, often subjective, typically qualitative criteria, and therefore these criteria are difficult to estimate and quantify. This feature means that various multi-criteria tools supporting the decision-making process may be particularly applicable. It is worth noting that the AHP and PROMETHEE methods are among the most frequently used in tourism research among the multi-criteria assessment tools.

In connection with the above this study used the Promethee II method to select the best trajectory for a recreational and tourist cycle route. The decision problem was framed as a multi-criteria ranking problem, including several routing variants for recreational cycle paths in Krakow and its suburban areas. The decision-makers in the problem were defined as the authorities of the Krakow Metropolitan area, whose decisions largely depend on the preferences of bike users.

4. Applying the Promethee Method to the Assessment of Bike Path Routes in Krakow and its Suburban Areas

4.1 Characteristics of the Analysed Area

The area for which the variants of cycle routes were drawn up includes the southern neighbourhoods of Krakow and the northern areas of the commune of Mogilany (Lusina and Gaj), situated at the southern border of Krakow (Figure 1). Krakow is second largest Polish town in terms of population and area. Located in the south of the country, it serves as the main administrative hub of Malopolska and one of the most important academic, cultural, and tourist centres in Poland. Its southernmost neighbourhoods, Łagiewniki-Borek Fałęcki and Swoszowice, are both highly attractive destinations for tourism and recreation.

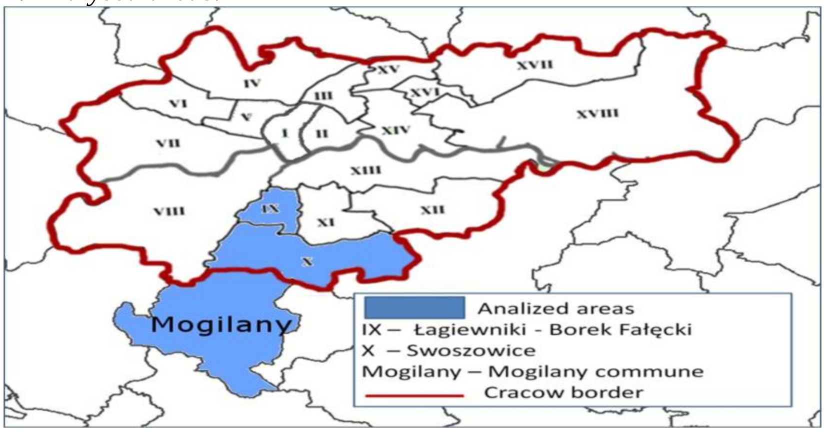
Łagiewniki-Borek Fałęcki is known as the site of the John Paul II Centre and the Sanctuary of Divine Mercy, one of the largest centres of pilgrimage in all of Europe, visited by more than 2 million people every year, including 500 thousand pilgrims from more than 100 different countries (Jackowski and Sołjan, 2010). The picturesque area of Swoszowice, on the other hand, boasts one of the oldest Polish health resorts, as well as the Barycz Fort and the Spa Park. Both neighbourhoods can be accessed by bus and train (and Łagiewniki-Borek Fałęcki also by tram); a total of three railway stations are located in the area. The bike path network is poor in these neighbourhoods, but plans for its development are underway, with several city bike rental stations already in place.

The commune of Mogilany consists of 10 villages, including Gaj and Lusina. It is an agriculture-based rural commune that abounds in tourist attractions (e.g., the "Cieszynianka" flower reserve, the Manor House Complex in Mogilany, the Bronaczowa Forest). The village of Lusina boasts the Słapa Manor Estate, a 17th-century manor house with an adjacent park, while Gaj has a very rich history, with the important Church of the Nativity of the Blessed Virgin Mary, which attracts many tourists and pilgrims.

In the future, a new tourist and pilgrim infrastructure will be built in the surrounding area. The project of the new centre is designed to encourage active leisure among users with different preferences, and thanks to its attractive location, the village is expected to attract not just pilgrims, but also cyclists. Even though the commune of Mogilany is already traversed by four tourist trails and two cycle routes, there is still a severe shortage of laid-out and marked bike paths. The development strategies of the gmina, however, recognize the need to develop the bike path network and ensure connections to major transport nodes, in order to promote daily bike trips and weekend cycle tourism in the region. For now, the commune only has access to bus services.

The main problem of the analysed area is its poor cycling infrastructure and its discontinuity (in terms of connections to the centre of Krakow), there is also little integration between bicycle and public transport. Laying out additional cycle routes and building new sections integrated with other means of transportation would considerably boost the recreational and tourist potential of the region.

Figure 1. *Analysed areas.*



Source: *Own study.*

4.2 Features of the Cycle Route Variants

Keeping in mind the problems and the potential of the analysed areas, three different cycle routes were designed to connect the southern neighbourhoods of Krakow to the northern areas of the Mogilany commune (Figure 2). Their objective was to promote the picturesque landscapes of Lusina and Gaj and stimulate bike recreation and tourism in the region. The routes are also likely to serve as an alternative for residents of neighbouring communes on their daily work and school commute to Krakow. Taking into account the advantages of integrating recreational and tourist cycle routes with the rail system, one of the variant was focused on providing such integration. All three variants are described below.

Variant I – the route starts at the tram and bus terminal in Łagiewniki and ends in the village of Gaj, by the Church of the Nativity of the Blessed Virgin Mary. The route is especially designed to promote tourism and pilgrimage, as it connects three important religious sites: the Sanctuary of Divine Mercy in Łagiewniki, the John Paul II Centre in Łagiewniki, and the above-mentioned church in Gaj. The route also traverses parts of the attractive area of Swoszowice.

It presents the cyclist with many picturesque landscapes, especially in sections that go through Lusina and Gaj, and includes many rest spots and a bike rental station. It has the lowest number of sections running beyond general vehicular traffic; for the route to be implemented, new sections of bike infrastructure must be built and traffic should be reorganized in selected streets. The route is 12.3 km long and takes nearly an hour to complete.

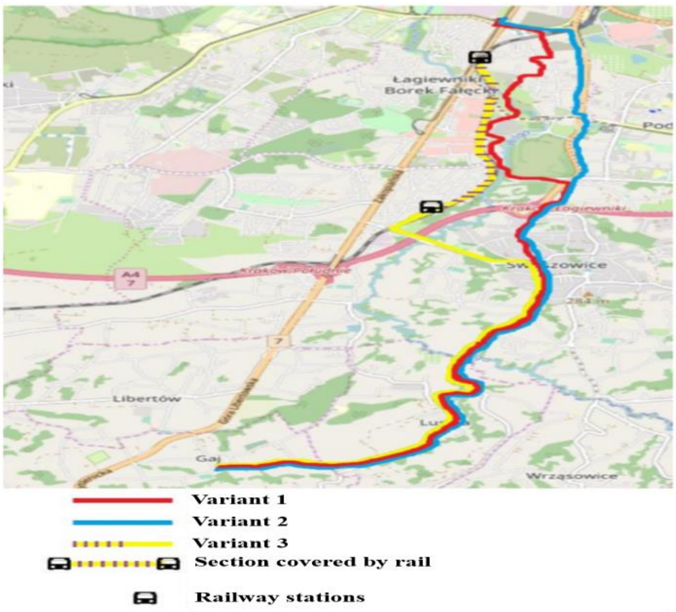
Variant 2 – just like route 1, variant 2 starts at the bus and tram terminal in Łagiewniki and ends by the church in Gaj. On the one hand recreational, the route also enables everyday commuting. The idea behind it is to continue the bike path from the city centre to the south of Krakow, which would allow the creation of a cohesive cycle connection to areas in the south of Krakow and beyond the municipal border. 2/3 of the route overlaps with route 1.

In comparison to route 1, route 2 runs along the main transport corridor, i.e. ul. Turowicza and ul. Herberta. It is less complex, easier, less hilly, but also offers fewer attractions. It has the highest number of sections running beyond general vehicular traffic and with good surface, but also requires the building of new bike infrastructure. The route is 11.1 km long and takes c. 45 minutes to complete.

Variant 3 – the route involves integrated bike and rail transport. It is shorter and less taxing, focusing on the picturesque landscapes of the commune of Mogilany. The route begins at the railway station of Krakow Łagiewniki. The train trip takes 6 minutes and ends at the station in Swoszowice, where it continues on bicycle and ends by the Church of the Nativity of the Blessed Virgin Mary in Gaj.

The route takes 35 minutes to complete (by rail and bike). The bike path is only 7.5 km long and the distance between the stops is 2.75 km. This is the only variant that does not require the building of any new bike infrastructure. The assumption is made that the trains will be adapted to transport bicycles and the frequency of train operation will be increased also on non-working days.

Figure 2. *Cycle route variants.*



Source: *Own study.*

4.3 Characteristics of Cycle Route Variants

Five criteria were adopted for the assessment of the three variants. The criteria included various social, technical and economic aspects of the problem and were selected based on a literature survey, keeping in mind the availability of data. Detailed definitions are shown in Table 2. The values for each criterion were then established for each analysed route variant (Table 3).

Table 2. *Assessment criteria*

Symbol	Criterion	Unit	Definition
C1	Route length	[km]	Total length of the route
C2	Comfort	[-]	It concerns the elevation of the route together with the condition of the path surface. The criterion is scored from 1 to 3, where 1 represents the lowest comfort, 2 – average comfort, and 3 – the highest comfort.
C3	Safety	[%]	Defines the proportion of sections that run beyond general vehicular traffic (pedestrian/bike corridors, in-road bike lanes, off-road bike lanes, contraflow lanes).
C4	Route attractivenes s	[-]	Includes the landscape attributes of the route, monuments, rest spots, religious sites, historical sites, as well as bike rental and maintenance stations. It also concerns route marking and availability of information about the area. The criterion is scored from 1 to 5, where 1 represents very low attractiveness and 5 represents high attractiveness.
C5	Building cost	[PLN]	Defines the cost of building additional route sections, split into types (pedestrian/bike corridors, in-road bike lanes, off-road bike lanes, contraflow lanes). In addition, the criterion includes newly-designed cycle lanes across junctions.

Source: *Own study.*

Table 3. *Characteristics of the three variants in terms of adopted assessment criteria.*

	Criterion	Direction of preference	Unit	Variant 1	Variant 2	Variant 3
C1	Route length	Max	[km]	12.3	11.1	10.25 (2.7 km by train, 7.5 km by bike)
C2	Comfort	Max	[-]	1	2	3
C3	Safety	Max	[%]	27.5	37.3	29.3

C4	Route attractiveness	Max	[-]	4.5	2. 5	3
C5	Building cost	Min	[PLN]	607 000	792 500	0

Source: *Own study.*

4.4 Constructing a Preference Model for the Decision-Maker

Modelling the decision-maker's preferences needs to consider two major aspects: the importance of the selected criteria and the sensitivity of the decision-maker to changes in their values. The former describes the significance of a given criterion to the subjects, who assign weights to individual criteria to express their subjective sense of the importance of each. In the PROMETHEE method, this importance is expressed on an absolute scale. The weights in this study were assigned to each criterion by experts (on a scale from 1 to 5, where 5 represents the most important and 1 a not very important criterion. The study were participated 18 experts in the field of transport (employees of Department of Transport Systems form the Cracow University of Technology and city managers/ planners from the Krakow Transport Authority). Experts assessed the problem both from the point of view of the transport manager and bike users. The obtained results are presented in Table 4.

Table 4. *Average weight of the criteria*

Average weight of the criteria			
Criterion		**Bike users**	**Transport managers**
Route length	C1	3.61	3.06
Comfort	C2	3.65	3.00
Safety	C3	4.39	4.18
Route attractiveness	C4	3.89	3.18
Building cost	C5	1.56	4.35

Source: *Own study.*

For the bike users safety and route attractiveness were identified as the most important criteria in the decision problem under study. These results are consistent with the literature survey. The slightly less important criteria are comfort and route length and the least important is the building cost. The results of the survey shows that in the case of transport managers, the construction cost is the most important criterion, then – safety and route attractiveness. Lower importance (but still relatively high) was accorded to route length and comfort.

Sensitivity to changes in criteria values tells us at which point the decision-maker begins to make a distinction between the two variants. In the PROMETHEE II method, it is defined by the indifference and preference thresholds established for each individual criterion. Using data in Tables 3 and 4, the values of the outranking relation were established based on the preference function. All the criteria were analysed as linear, i.e., type 5 of the preference function.

The preference models is shown in Figure 3 and Figure 4 where P represents the preference threshold and Q the indifference threshold. Experimental calculations were performed with the use of the Visual Promethee software.

Figure 3. *The decision-maker's preference model for bike users.*

Scenario1	C1	C2	C3	C4	C5
Unit	[km]	[-]	[%]	[-]	[PLN]
Cluster/Group	◆	◆	◆	◆	◆
Preferences					
Min/Max	max	max	max	max	min
Weight	3,61	3,65	4,39	3,89	1,56
Preference Fn.	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	0,50	0,47	1,00	0,62	253973
- P: Preference	1,87	1,80	9,96	1,96	782307
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	10,25	1,00	27,50	2,50	0
Maximum	12,30	3,00	37,30	4,50	792500
Average	11,22	2,00	31,37	3,33	466500
Standard Dev.	0,84	0,82	4,26	0,85	338447

Source: *Own elaboration with the use of Visual Promrthee version 1.2.0.0 software.*

Figure 4. *The decision-maker's preference model for transport managers.*

Scenario1	C1	C2	C3	C4	C5
Unit	[km]	[-]	[%]	[-]	[PLN]
Cluster/Group	◆	◆	◆	◆	◆
Preferences					
Min/Max	max	max	max	max	min
Weight	3,06	3,00	4,18	3,18	4,35
Preference Fn.	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	0,50	0,47	3,43	0,62	253973
- P: Preference	1,87	1,80	9,96	1,96	782307
- S: Gaussian	n/a	n/a	n/a	n/a	n/a
Statistics					
Minimum	10,25	1,00	27,50	2,50	0
Maximum	12,30	3,00	37,30	4,50	792500
Average	11,22	2,00	31,37	3,33	466500
Standard Dev.	0,84	0,82	4,26	0,85	338447

Source: *Own elaboration with the use of Visual Promrthee version 1.2.0.0 software.*

4.5 PROMETHEE II Experimental Calculations

The final ranking of variants was based on the preference model shown in Figure 3 for bike users, Figure 4 for transport managers and net dominance value Figure 5, i.e., the difference between output dominance and input dominance flow. The output dominance flow is a measure of the dominance of variant i over other variants, while the input dominance flow defines the degree of dominance of all other variants over variant.

Figure 5 show the net flow values for every criterion in the variant. For the bike users and transport managers the variant V1 shows a positive dominance flow for criterion C1 and C4, variant V2 for criteria C2 and C3, and variant V3 for criteria C2 and C5.

Figure 5. *Net flows for every criterion and variant.*

Bike users

Φ Preference Flows

	C1	C2	C3	C4
Variant 1	0,7555	-0,6982	-0,5357	0,8284
Variant 2	-0,1277	0,0000	0,8817	-0,5000
Variant 3	-0,6277	0,6982	-0,3460	-0,3284

Transport managers

Φ Preference Flows

	C1	C2	C3	C4
Variant 1	0,7547	-0,6982	-0,4877	0,8286
Variant 2	-0,1280	0,0000	0,8377	-0,5000
Variant 3	-0,6266	0,6982	-0,3499	-0,3286

Source: *Own elaboration with the use of Visual Promrthee version 1.2.0.0 software.*

Figure 6 shows tabular final ranking for all variants, ordered from best to worst based on their net flows. The higher the net flow, the better the option. The final results are also presented as a graph (Figure 7), better variants have net flows closer to 1 and are placed higher up along the vertical line. In accordance with the adopted method, the V2 variant is the best solution from the bike users' point of view, obtaining the Phi dominance flow value at the level of 0.04, while the lowest place in the ranking was given to the V3 variant with the Phi value at the level of -0.0709. Note a slight difference in the value of net dominance.

The V3 variant is the best solution from the transport manager 'point of view, obtaining the Phi dominance flow value at the level of 0.0730, while the lowest place in the ranking was given to the V1 and V2 variants with the very similar Phi value at the level of: -0.0361 and -0.0369. The Variants V1 and V2 can be considered for equivalent variants.

Figure 6. *Final ranking based on net flow (where Phi is net dominance flow, Phi+ input dominance flow and Ph- output dominance flow).*

Φ	Phi+	Phi-
Variant 1	0,3479	0,3170
Variant 2	0,2956	0,2556
Variant 3	0,2366	0,3075

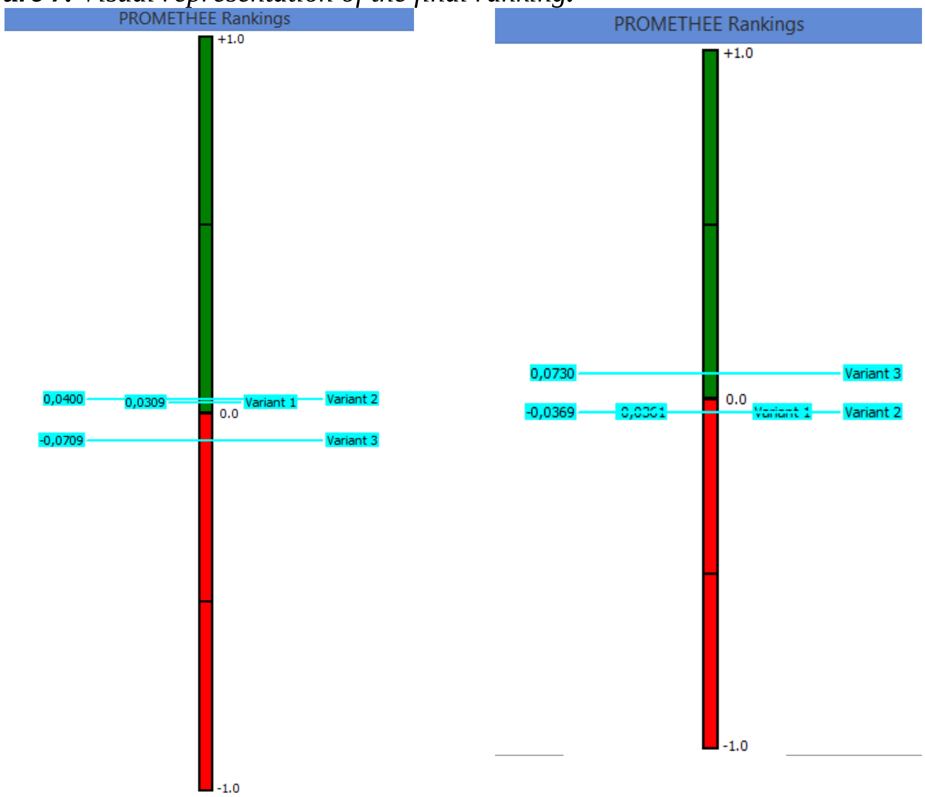
Bike users

Φ	Phi+	Phi-
Variant 1	0,2782	0,3144
Variant 2	0,2523	0,2892
Variant 3	0,3221	0,2490

Transport managers

Source: *Own elaboration with the use of Visual Promrthee version 1.2.0.0 software.*

Figure 7. *Visual representation of the final ranking.*



Bike users

Transport managers

Source: *Own elaboration with the use of Visual Promrthee version 1.2.0.0 software*

4.6 Summary of Obtained Results

As a result of the computational experiments, from the point of view of bike users and transport managers, two different rankings were obtained (Table 5). When comparing both rankings, one can see the differences in the positions taken by individual variants in these rankings. The variant most preferred by bike users is the V2 variant. The large impact on V2 variant first position has the C3 criterion (safety) both in terms of the value of the criterion and its importance. The variant preferred the most by the transport managers is the V3 variant mainly due to the low cost of construction of the route and the criterion related to the length of the route.

Table 5. *Final rankings*

Bike users		**Transport managers**	
Rank	**Phi**	**Rank**	**Phi**
V2	0,0400	**V3**	0,0730
V1	0,0309	**V1**	-0,0361
V3	-0,0709	**V2**	-0,0369

Source: *Own study.*

5. Discussion and Conclusions

The literature on the subject offers a broad range of studies on bike infrastructure design and planning, including those based on MCDA methods. The bulk of these, however, concern urban networks, and fail to distinguish between different bike users or focus exclusively on cycling as a means of transport. Even less attention is usually devoted to designing cycle routes for tourism and recreation, including those in suburban areas. This study aims to fill that gap. It relies on one of the least frequently employed MCDA methods, PROMETHEE, which allows us to assess variants of cycle routes in terms of different criteria and select the option that best meets the requirements and includes the sensitivity of the decision-maker to changes in criterion values.

The assessment criteria take into account the different parameters of route design for tourist and recreational traffic, rather than the attributes of the cycle network. They consider not only the most common technical and social factors (Giovannini *et al.*, 2017; Glavić and Milenković, 2018; McCarthy *et al.*, 2016), but also economic aspects, such as route building cost. The criteria were selected based on a literature survey, keeping in mind the availability of data. What is important and original, specific weights were assigned to individual criteria based on the knowledge, experience and opinions of both, bike users and transport managers/ experts in bike infrastructure design.

When the selected criteria are compared to those employed in similar studies (Giovannini *et al.,* 2017; Glavić, 2019; Glavić and Milenković, 2018; McCarthy *et al.*, 2016), it becomes evident that the highest-weighted criteria, i.e. attractiveness and safety, are also taken into account and emphasized in other analyses. It should be noted that the adopted set of criteria can be seen as universal set and, importantly, their values can be established without complex calculations or advanced software (such as GIS tools).

In accordance with the adopted assessment method, V3, which involves bike path integration with rail transport, ranks as the best variant for transport managers (mainly due to the low cost of construction), while the most preferred variant for bike users is V2 variant (mainly because of the safety reasons).

For the relative ranks of the three variants to change, different weights would have to be assigned to individual assessment criteria. Such sensitivity analysis could consider different kinds of decision-makers (e.g., different types of bike users) and their points of view. For instance V3 variant could be attractive for some cyclists. Avid cycling enthusiasts may consider it too easy; it also takes away the pleasure of cycling where the route is covered by train.

However, because of its integration with the railway system, V3 could be ideal for less consummate cyclists, as well as people with reduced mobility (children, seniors, etc.). Another way to influence the final ranking would be to adopt different indifference and preference thresholds that determine the decision-maker's sensitivity to changes in criterion values. Such fluctuations may be experienced differently; the same change in value will be very inconvenient for some, and much less important for others. For instance, changes in the building cost would be very inconvenient for a small commune, but would have less importance for larger communes or a metropolis that can fall back on a bigger budget.

The analysis presented in this article highlights the importance of various aspects that accompany the design and planning of cycle routes for recreation and tourism. These aspects can be taken into account by other regions in the process of bike infrastructure planning. The need to take the routes through urban and suburban areas emphasizes the role of cooperation between the authorities of different territorial units (communes, metropolises). The use of rail infrastructure to cover different legs of the route, on the other hand, shows the opportunities for integrating the bike with other means of transport to achieve an effect of synergy, in terms of increasing the use of public transport, enhancing user experience and boosting the tourist and recreational potential of the region.

Locating the routes in areas with a high density of religious sites shows that such attractions may also serve as the backbone for recreational and tourist trails, not unlike historic sites or attractive landscapes. Therefore, even though the analysis applies to local conditions and a specific case study, its conclusions can contribute to the broader transport and tourism policy of many regions, including suburban and rural areas.

The results of this study represent an important contribution to the current state of knowledge on the factors that matter not only for the users of recreational and tourist cycle routes, but also for entities in charge of creating such infrastructure. On account of its universal character, the method employed in the study may be used for the assessment of cycle routes for various user types, in urban, suburban and rural areas alike.

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