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The formulation and evaluation of transport route planning alternatives: a spatial decision support system for the Via Baltica project, Poland

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ABSTRACT

Transport planning plays an undeniably key role in the economic growth of any region. However, when done heedlessly this planning can be detrimental to the biophysical and social environment of the region. In transport route planning generally one or a few alternative routes are proposed, usually representing the interest of the proponent. If required, an environmental impact assessment is carried out on these alternatives. Although, EIA and SEA are meant to be effective in taking informed decisions about the proposed route, these alternatives – the heart of impact assessment – are themselves devised in a subjective and non-spatial manner.

Such an approach may easily overlook routes, which could otherwise have been more suitable. A planning system that directly takes into account environmental and socio-economic considerations in selecting alternative routes facilitates sustainable development. This paper presents a holistic and coherent spatial multi-criteria network analysis method for the generation of optimal routing alternatives under different policy visions, in a network of existing roads.

The presented methodology was case-tested for the highly contested 340 km portion of the Via Baltica corridor in Poland, a part of the trans-European transport network (TEN-T) program. The methodology shows its ability to serve as a versatile effect-based decision support system for transport route planning at a strategically higher level of planning, particularly for (geographically) large-scale investment schemes.

1. Introduction

Regional economic development can be attributed to a large extent to the provision of infrastructure in general and transport infrastructure in particular. As such, transport infrastructure can be instrumental to strengthening competitive positions of countries and regions. This fact has led to an increasing pressure to construct, widen and further extend highway systems. However, ecological and social problems, associated with infrastructure and transport, have also generated a more critical attitude towards large transport infrastructure projects by non-governmental organizations as well as the general public. These problems are gaining a more significant role in political decision making and voters' interest.

Probably one of the most prominent examples of such problems in recent years is the Via Baltica highway project in Poland. The highway project, which is commonly seen as being very important to the improvement of accessibility between EU's Central European countries, was suspended in 2007 due to fear of irreversible ecological damage to important natural sites protected under European Union (EU) law. Even though several economically and environmentally more sound alternative routes existed, they had never been considered as acceptable alternatives by the decision makers according to the Committee on Petitions of the European Parliament (2007) and several frontline environmental non-governmental organizations (NGOs) such as BirdLife International (2007), CEE Bankwatch Network (2005) and OTOP (2007). A detailed chronology, with supporting documents, of the events that led to the halt of this project by the EU is described in Keshkamat (2007).

In transport route planning generally one or a few alternative routes are proposed, often representing the interest of the proponent(s). If required, an Environmental Impact Assessment (EIA) or Strategic Environmental Assessment (SEA) is carried out on these alternatives. Although, EIA and SEA are meant to be effective in taking informed decisions about the proposed intervention, these alternatives are themselves devised in a subjective and/or non-spatial manner (Steinemann, 2001). Such an approach may easily overlook route alternatives, which could be much more suitable from environmental, social and economic points of view. Thus

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subjective bias tends to dominate the planning at the critical early stage. Political and industrial lobbying is also known to play a key role in the identification of the route alternatives. This consequently leads to stakeholder dissatisfaction and disillusionment with the entire planning process (Valve, 1999; Fitzsimons, 2004). An efficient planning system that, through EIA or SEA, directly takes into account these environmental, social and economical considerations in formulating, assessing and selecting alternative routes facilitates sustainable infrastructure development.

The Via Baltica project is no exception to this norm. Long before the EU commenced legal infringement procedures against the Polish government for breach of EU environmental laws, key officials from the European Bank for Reconstruction and Development, had already expressed the need for a transparent method that can formulate and assess effect-based transport route alternatives (Kennedy and Haumer, 1999).

To address the above need, in this paper the design and implementation of a systemic, spatial method for generating effect-based transport route alternatives is discussed. This method accounts for environmental regulations and concerns, while integrating equally important considerations such as transport system efficiency, safety, socio-economic demands, technical and financial viability, while also supporting stakeholder involvement. A GIS interface generates graphical as well as quantitative results, thus providing planners with a comprehensive and holistic Spatial Decision Support System (SDSS), which can enable an objective comparison of various route alternatives.

2. Transport network planning and alternative generation

EIA and SEA are internationally accepted and often legally required procedures to minimize adverse impacts and enhance the benefits of infrastructure developments. The generation of alternatives, which is at the heart of EIA and SEA, is perhaps the most underdeveloped part of the assessment processes (Glasson et al., 1994; Sadler and Verheem, 1996; Niekerk and Voogd, 1999; Treweek, 1999; Steinemann, 2001; IAIA, 2008). Therefore, a rational, transparent stakeholder-based process for the generation of alternatives is required to be able to improve EIA and SEA and thence decision-making.

In many of such environmental assessments a wide range of environmental effects and indicators have to be considered, requiring the management and analysis of a large amount of information and data, both spatial and non-spatial, for which GIS provides a platform for spatial modelling, analysis and assessment. Moreover, as most environmental assessments involve several alternative options and numerous stakeholders with different views and perceptions, GIS-based spatial decision support tools and particularly spatial multi-criteria assessment (SMCA) tools provide effective techniques to assess cumulative impacts and to carry out a vulnerability or suitability analysis in order to evaluate alternatives. Such methods, gained universal acceptability from the work of Jankowski (1995) and Malczewski (1996, 1999), when traditional multi-criteria evaluation methods were combined with GIS and support for multiple alternatives in a group decision-making environment.

Much research has been carried out in the use of GIS methods in EIA of roads (Li et al., 1999; Blaser et al., 2004; Affum and Brown, 2002, etc.). SMCA as a technique has been used also to solve routing problems in utility infrastructure, such as for pipeline routing (Rescia et al., 2006; Yusof and Baban, 2004), transmission line routing (Bailey et al., 2005) and in telecommunication network design (Paulus et al., 2006).

However, the use of GIS in the very preliminary stage of transport route planning itself has hardly been done. One of the few such examples is provided by Grossardt et al. (2001), who introduce a coherent methodology to route formulation based on environmental criteria. In this method, stakeholder priorities such as economic development, connectivity, ecological factors (wetlands and endangered species), recreational areas, etc. have been combined to generate a continuous geographic surface, which functions as a composite cost or cumulative impact map. This map is a raster map in which every pixel corresponds to a weighted sum of the scores of individual impedance elements. This preliminary step of their process is similar to a SMCA approach. Grossardt et al. (2001), then proceed to use a cost-weighted distance algorithm to identify the least cost path across this SMCA surface.

The cost-distance function used by Grossardt et al. (2001) is a (raster-based) analysis in which the impedance map (based on composite-costs) is used to determine the least cost path between a designated origin and any other point(s). The end result is a route, one cell wide, which delineates the least cost path between the points. This method tries to find the path of least impedance regardless of the length and the existing road segments. Hence, the total route length is never within the control of the method. Such a route would be uneconomical to construct and maintain, but also inefficient in terms of vehicle-kilometres and vehicle-hours. Since this method is a raster-based approach it is better suited for network and route generation rather than prioritizing and upgrading existing networks. Further, the selection of pixel size in this method seems to be done more for data-processing convenience than from a spatial effects perspective.

Based on the above mentioned discussion, a Spatial Decision Support System (SDSS) for generating and assessing effect-based transport route alternatives from existing transport networks has been developed here. This system will be described in subsequent paragraphs.

3. Geographical characteristics of the study area and the project

The Via Baltica corridor development plan, regarded as one of the European Union's highest-profile project in the Baltics, links Germany, Poland, Lithuania, Latvia, Estonia, Finland, Sweden and Norway. It aims to create a rapid and effective transport corridor from Scandinavia to Eastern and Central Europe and is expected to play a key role in the socio-economic development of the new European Union member countries (Poland, Latvia, Lithuania and Estonia) and remote underdeveloped regions in the older European Union countries of Finland and Sweden.

This portion from Warsaw (central Poland) to Budzisko (on the Lithuanian border), has run into major conflicts of interest because of the 300 km long, 150 km wide corridor swath overlapping with some of the most ecologically sensitive and protected areas of Europe. With four internationally protected nature areas (Natura 2000), four National Parks, 12 Landscape Parks, 10 National Reserve areas and numerous other unprotected and/or transitional woodlands of significant ecological importance lying within the corridor swathe, the area is known for its rich natural bio-diversity.

Good planning would necessarily have to account for the habitats of several endangered species of flora and fauna located in this region to prevent critically fragmenting them. On the other hand, immense economic benefits of having an international highway plying through would strengthen the competitive economic position of the region. The region is very much dependant on agriculture, nature-tourism and the trade flowing through it.

The Via Baltica highway is planned as a series of upgrades of contiguous existing roads (in the corridor swathe) to expressway standards. Furthermore, the project embraces Europe's ideals of intermodal transport through the parallel development of the Rail Baltica high-speed railway. Fig. 1 shows an overview of the study area and the existing road network.

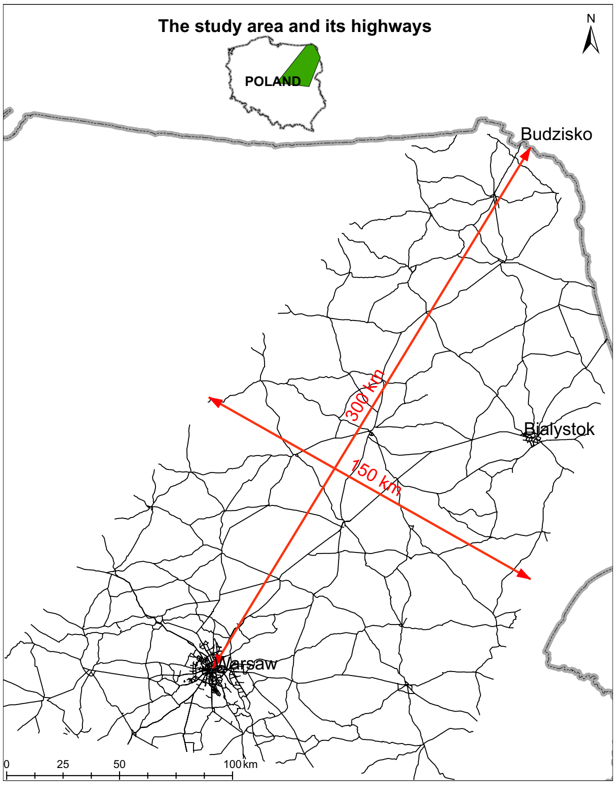

Fig. 1. Overview of the study area and existing road network.

The study area is predominantly a gentle rolling terrain. There are no steep slopes or sudden breaks in the terrain. The highest elevation is 300 m and the lowest elevation is 59 m approximately 50 km away. Hence from the perspective of highway planning, slope regimes do not form a serious consideration in any part of this region. The soils range vastly from glacial soils and peat to fluvial soils. Peat fires are not uncommon in this area and peat also forms a serious geotechnical concern during the construction of the highway.

4. The method

In this section a Spatial Decision Support System (SDSS) for the formulation and evaluation of route planning alternatives for existing transport networks will be discussed. In order that the method gains acceptability amongst infrastructure planners, stakeholders, investors and current practitioners of EIA and SEA, the following requirements are seen as important to the method:

1. The optimal route needs to use only contiguous existing roads (in the corridor swathe).
2. The method must be holistic and cross-disciplinary in its approach and should be capable of addressing the whole range of criteria and priorities relevant to the above mentioned targeted groups. It should also be amenable to addition of other criteria and priorities not included in this case study.
3. The method should be developed in such a way that it can easy be used in other areas and/or other transport developments.
4. The method should be uncomplicated, transparent, back-traceable and capable of stakeholder involvement.
5. The method should be user-friendly, time and cost-effective.

In pursuance of these principles a method has been formulated as conceptualised below in Fig. 2.

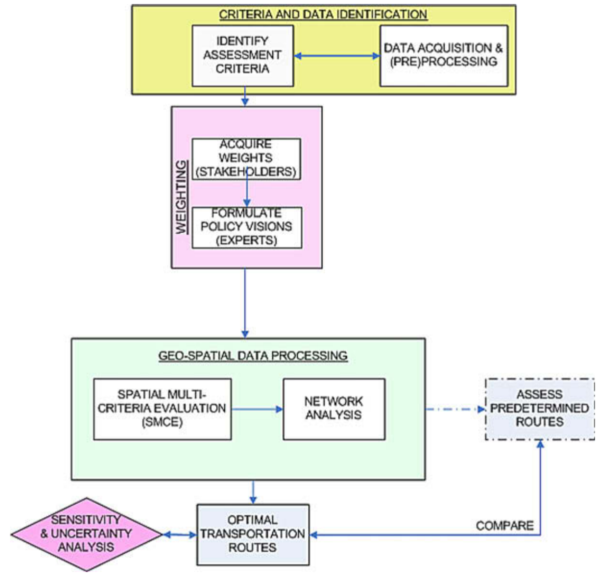

Fig. 2. Conceptual diagram of the method.

The method consists of 3 main components,

1. the criteria and data identification module where assessment criteria relevant to stakeholders are listed and the raw spatial data representing these criteria are assimilated into the model;
2. the weighting module, which weighs the various assessment criteria based on stakeholder preferences and policy visions;
3. the geospatial data-processing module is the core module which takes data from the above two modules and generates optimal route maps. This is where the SMCA and network analysis are performed.

If required a sensitivity analysis of the weights and scores may be performed. In the next sections each component is elaborated in more detail.

5. Criteria and data identification

Assessment criteria reflect the stakeholder concerns and a wide variety of impacts arising from an infrastructure development. For the Via Baltica study specifically a range of stakeholders were consulted to provide a list of criteria relevant to the planning. They ranged from representatives of environmental NGOs such as World Wildlife Fund (WWF) Poland, CEE Bankwatch Network and Polish society for protection of birds (OTOP), to Polish government bodies such as Ministry of Environment, National Park Authorities and the General Directorate of National Roads and Motorways (GDDKiA) to independent research institutes such as the Institute for Sustainable Development, and several other experts and professionals such as from the University of Warsaw. These criteria are grouped according to overall sustainable development objectives into themes. The themes that have been selected in this project are (1) transport efficiency, (2) ecology, (3) social impact and safety and (4) economic costs and benefits. Such themes are typically considered in an EIA process for transport, as listed in for example Goodenough and Page (1994), Fischer (1999) and UN ESCAP (2001). For each criterion within a theme a corresponding criterion score has to be defined, which is associated with a (raster) map in the SMCA process within with each pixel has a suitability value.

For the Via Baltica case study, the raster dataset is shown in Table 1. The raster maps are the input for the SMCA analysis

Table 1
List of themes, criteria and the explanation for use in the Via Baltica corridor study

Theme	Criteria	Explanation
Transport efficiency	Proximity to existing rail network	Spatial benefit. The closer the expressway is built to an existing rail network, the better the future intermodality
	Proximity to the proposed Rail Baltica	Spatial benefit. The closer the expressway is built to the proposed rail route, the better the future intermodality
	Current traffic density	Spatial benefit. The higher the current traffic density, the more is the reason to upgrade the road
Ecology	Internationally protected natural areas (Natura 2000 sites)	Spatial constraint. Natura 2000 sites are strictly protected under EU regulations
	Nationally protected areas, such as National and Landscape Parks (and Reserves)	Spatial cost. May be passed through but at a high cost
	Forests and semi natural areas	Spatial cost
	Wetlands and peat bogs	Spatial cost
	Water courses and lakes	Spatial cost
Social impact and safety	Proximity to urban areas	Spatial benefit. The closer the route is to an urban area, the greater the accessibility
	Risk of accidents in urban areas	Spatial cost. The closer the route is to an urban area, the greater are the incidences where resettlement of homes and establishments will be required
	Population served	Spatial benefit. The larger the population served, the more reasons to upgrade the road
	Hazardous areas	Spatial cost. The closer it is to a hazard prone area, the more will be the cost associated with providing safety features
Economic costs and benefits	Current agriculture land-use	Spatial cost. Current livelihood
	Economic zones	Spatial benefit. The more the economic activity in the area, the more reasons to upgrade the road
	Best agricultural soils	Spatial cost. Potentially productive areas
	Current status of the road (Category of the road)	Spatial benefit. The higher the current category of the road, the lower will be the engineering cost of upgrading it
	Intersections with water bodies	Spatial cost. Bridges, viaducts, culverts etc involve the construction of expensive structures. Also, the longer the bridge, the higher the cost
	Intersections with secondary roads	Spatial cost. All intersections with secondary roads need to be upgraded. This involves the construction of expensive structures such as flyovers
	Problem soils for construction	Spatial cost. Soils like peat are prone to differential settlement and pose a potentially high construction cost and/or a high maintenance cost
	Ancillary structures for urban areas	Spatial cost. The closer the route is to an urban area, the higher will be the engineering costs associated with building acoustic barriers, pedestrian subways and other ancillary structures

further in the process. In a SMCA, criteria are usually classified into factors or constraints, based on the type of impact. A factor can be a benefit or a cost. Poor performance of a factor can be compensated by good performance of another factor, which can lead to a good overall performance in the cumulative suitability map. A spatial benefit is defined as a criterion that contributes positively to the output; the higher the value, the better it is. A spatial cost is defined as a criterion that contributes negatively to the output; the lower the value, the better it is. A spatial constraint is accordingly defined as a criterion that determines which areas in the final output map are considered as absolutely not suitable for the proposed development. As opposed to factors, poor performance of a constraint cannot be compensated by good performance of another factor or constraint. These areas will always obtain value 0 for that pixel in the final output. Criteria that represent legally protected – or otherwise unavailable – areas are usually made constraints. For example, Natura 2000 sites, which are internationally protected under EU laws for example, are considered a spatial constraint in the Via Baltica case study.

6. Weighting of criteria and themes

With the assignment of weights the importance of a criterion or group of criteria for the purpose of the proposed activity and for decision making is emphasized. For the Via Baltica case study, the same stakeholders representing NGOs, government bodies and academia as mentioned in previous section were asked to assign weights for the collected criteria.

In weight assignment a distinction is made between 'expert' weights and 'policy' weights. The assignment of weights to criteria within a theme is often based on expert knowledge. The expert determines with objective arguments the importance of criteria, often backed up by scientific knowledge (Bonte et al., 1998; Brouwer and van Ek, 2004). The importance can be determined using

Table 2
Different visions, themes and their weights used in the Via Baltica corridor study

Themes	Visions			
	Equal vision	Social vision	Ecology vision	Economy vision
Transport efficiency	0.25	0.27	0.27	0.27
Ecology	0.25	0.06	0.52	0.06
Social impact and safety	0.25	0.52	0.15	0.15
Economic costs and benefits	0.25	0.15	0.06	0.52

e.g. the magnitude, extent, duration and significance of an effect (and the criterion derived from it). For example, in the Via Baltica case study, within the theme 'safety', the criterion 'displacement of people' gets more weight than the criterion 'fire hazard due to peat'.

The proponent(s), affected people and decision makers have often complete different interests. They assign different priorities to different environmental themes with more 'subjective' or political' arguments. Taking these different political weights into account is an important element of multi-criteria assessment and is called assessing different perspectives or policy visions.

In the Via Baltica case study, four policy visions (scenarios) were formulated and are summarised in Table 2. The equal vision represents the neutral (or reference) vision, wherein all themes have the same weight. In the social vision the highest weight is given to the theme 'social impact and safety, in the ecology vision the highest weight is given to the theme 'ecology', and in the economy vision the highest weight is given to the theme 'economic costs and benefits'. The weights were assigned according to the expected value method in which the weight vector is calculated based on a ranking of the four themes (Janssen and Van Herwijnen, 1994; Saaty, 1980). In the case study, the use of these policy visions enables the comparison of different routing scenarios, representing the interests and perspectives of different stakeholders and policy makers.

7. Spatial multi-criteria analysis (SMCA)

In the SMCA process the geo-spatial datasets representing the different criteria and weights described above, are combined to prepare routing suitability maps for the four policy visions. Such a suitability map provides a continuous geographic surface. Each pixel value of this surface indicates the overall suitability value for routing the highway through that pixel. This type of continuous surface is similar to a friction map or an impedance map, as described in Yusof and Baban (2004) and Grossardt et al. (2001).

The software used for this study is ILWIS 3.3 (ITC, 2007), which is a free open-source software having a strong SMCA module. For rasterizing all the layers representing the different geo-spatial datasets a pixel size of 1000 metres was chosen. This was done for three reasons:

1. A road layer as a vector represents a shape having no lateral dimension, whereas in real life a road does have width. Moreover environmental effects are felt more in the width direction, than along the length. Hence, the width dimension is very important to the analysis. Referring to Polish road impact studies, such as Cyglicki (2005), and personal communication with Polish EIA experts, it was found that the minimum direct impact distance, also based on the European Union's Birds Directive, for existing roads is 500 m from the centreline of the road.
2. Only 2% of all the road segments used in this analysis are less than 1 km in segment length, hence this will not cause a significant error in the analysis.
3. All the three raster sources used in this case study, i.e. the LandScan (2006) ambient population dataset, night-time light satellite imagery and European Soil Database (ESDB) (JRC, 2006a) data use a pixel resolution of 994 m–1 km, hence accuracy loss during re-sampling is avoided.

Based on the defined themes, spatial criteria and weights, as identified in Tables 1 and 2, a criteria tree is built in ILWIS for each of the four policy visions. Each criterion is represented by its own map. Once all the criteria and maps are inserted in position in the criteria tree, standardization of all the criteria is done using either an (1) attribute function (for standardising according to certain class data), (2) goal function (for standardising according to a predefined minimum/maximum value) or (3) maximum function (for standardising according to the maximum value of the map), depending on the type of data represented in each criterion. As such all the input maps are standardised to utility values between 0 (not suitable) and 1 (highly suitable). An example of a completed criteria tree for the economy vision in ILWIS is depicted in Fig. 3.

Following this procedure four suitability maps for routing of the highway could be produced, one for each policy vision, as is depicted in Figs. 4–7.

In these raster maps, areas of low suitability (valued 0) are symbolized by the colour red[1], while areas of highest suitability (valued 1) by the colour green. Areas of intermediate suitability are shown by intermediate colours of the gradient between red and green. The suitability values in the four final raster maps are accordingly transferred to the network and converted to impedance values to be used in a transport network analysis using ArcGIS software.

[1] For interpretation of colour in Figs. 4–7, the reader is referred to the web version of this article.

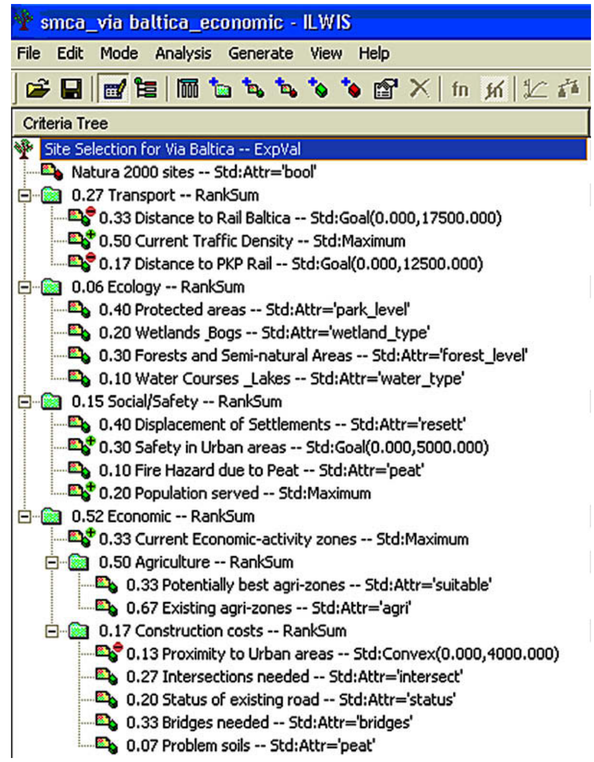

Fig. 3. A screenshot of the completed SMCA table in ILWIS.

8. Transport network analysis

To commence the transport network analysis sub-component of the method, the suitability maps of the four visions and a pre-processed road vector layer have to be brought into the GIS. The line-raster extraction algorithm of Beyer (2004) is used to extract the line weighted means from each resultant raster map to the road vector layer. This procedure attributes the mean suitability value of each resultant vision to each segment of the line layer based on its location. In Beyer (2004) the line weighted mean (LWM) is defined as

$$\mathrm{LWM} = \frac{\sum_{i=1}^{n}(l_i \cdot v_i)}{L} \tag{1}$$

with l_i is the length of a line segment i that is covering a certain raster cell, v_i is the suitability value of the raster cell from the SMCA suitability underlying that line segment, and L is the total length of the polyline of which the line segments forms part.

To find the path of least cost in the network, all the obtained values are then inverted by subtracting them from 1 (maximum suitability). Furthermore, since the pixel size in this case is 1 km, this then gives the impedance per kilometre of road. In order that the total impedance of each segment (from node to node) is obtained, the impedance per kilometre value is multiplied by the corresponding length of the line in kilometres covering the raster cell. These value fields are then used as vision specific-impedances to build the network in the ArcGIS Network Analysis module. Using the LWM values, the impedance (Ω_j) of each polyline j within the road network layer is then formulated as

$$\Omega_j = (1 - \mathrm{LWM}) \cdot L. \tag{2}$$

It should be noted that the LWM values are based on the underlying pixels alone. However, given the pixel size of 1 km, the pre-processing steps that result in a continuous impedance surface and the line-raster algorithm itself, the possibility of having large differences between adjoining cells, for example having a pixel of high

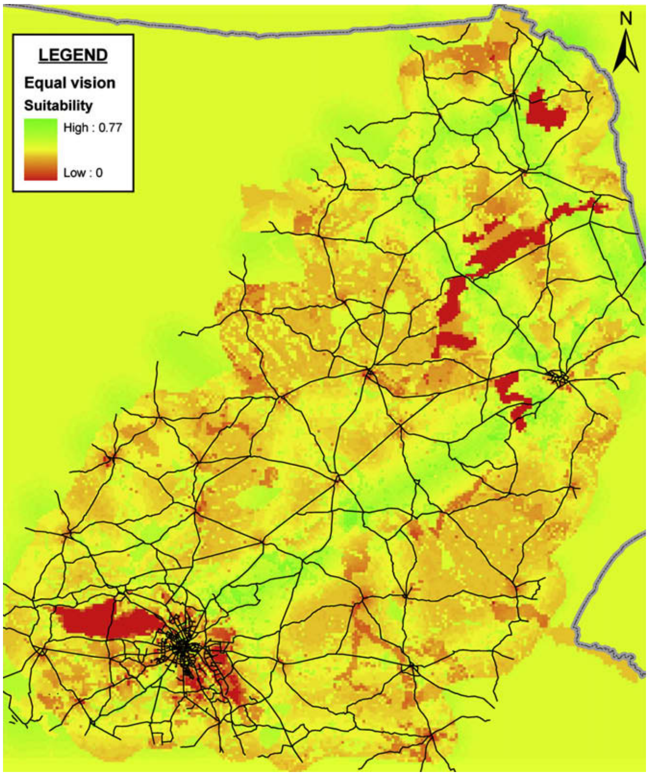

Fig. 4. Suitability map for equal vision.

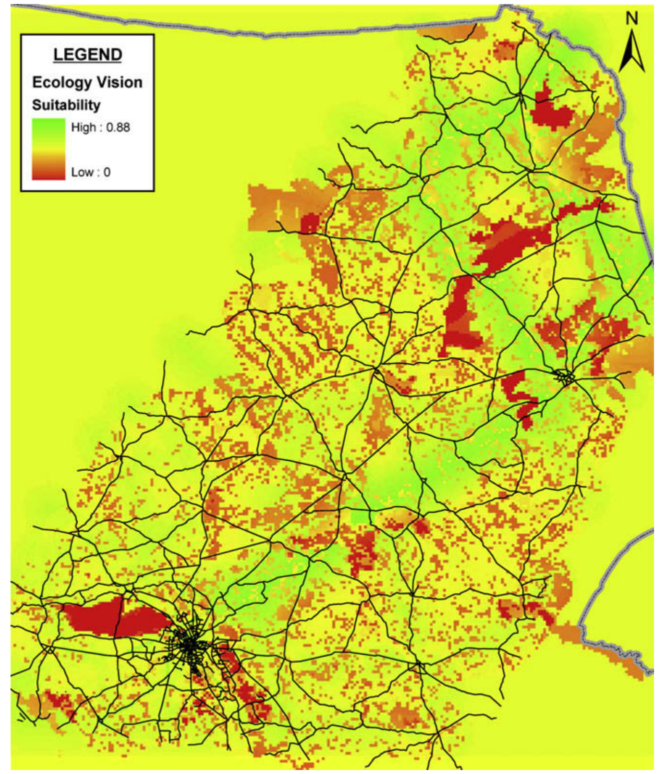

Fig. 6. Suitability map for ecology vision.

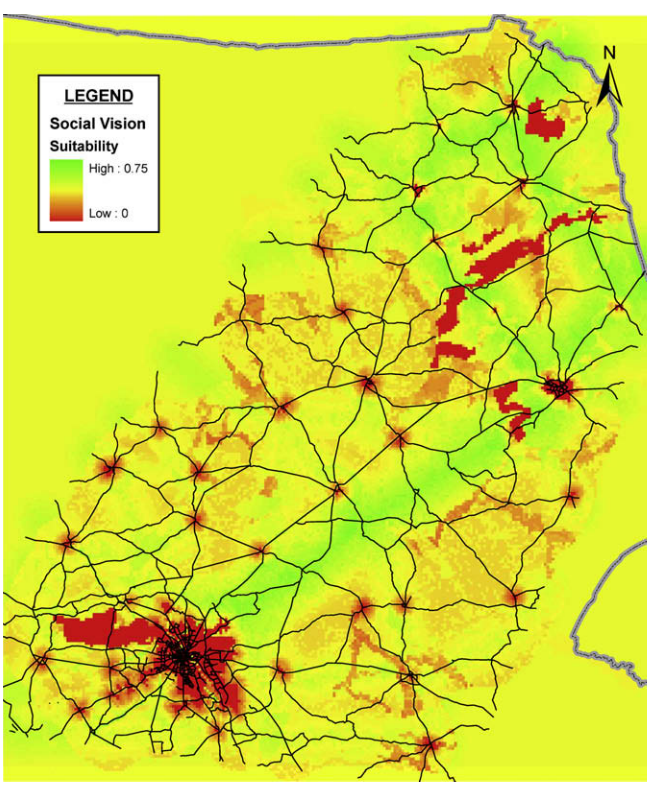

Fig. 5. Suitability map for social vision.

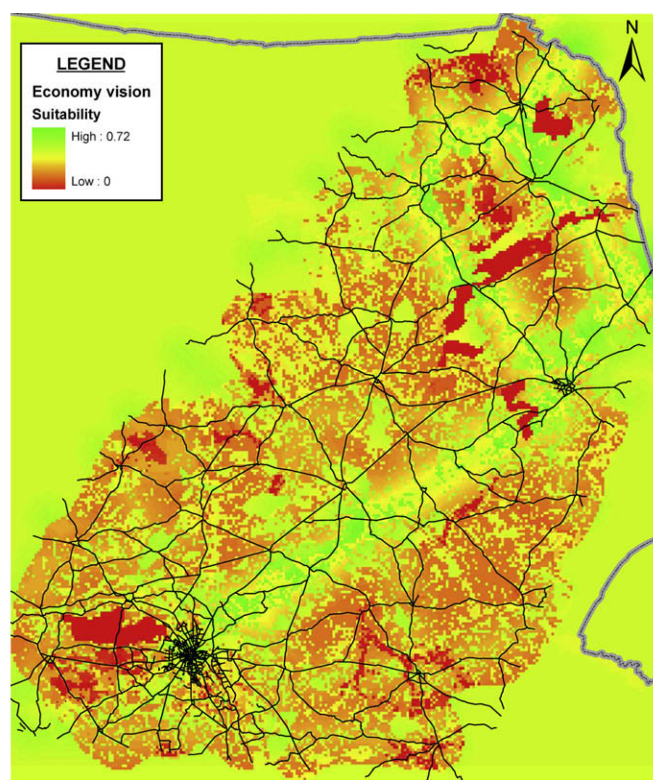

Fig. 7. Suitability map for economy vision.

suitability underneath the line segment, and a non-suitable cell directly adjoining the underlying pixel, is tested to be highly unlikely.

Thereafter, the well-known Dijkstra's algorithm for shortest path calculations was used in ArcGIS to find the path of least total, vision specific, impedance. This procedure was repeated for all four visions, i.e. the equal-vision impedance, economy-vision impedance, ecology-vision impedance and social-vision impedance, respectively. Thus four different routes having the same origin and destination have been generated. The total impedance accumulated by each route, is defined as the total route impedance (Ω_R), and can be expressed as

$$\Omega_R = \sum_{j=1}^{m} \Omega_j \tag{3}$$

with Ω_j the impedance value of polyline j, and m the number of polylines comprising the optimal route.

The higher the Ω_R value, the greater are the costs associated with the route and/or the lower are the benefits attained by it.

9. The optimal routes and their characteristics

Using the methodology set out before, the network is solved for the path of least impedance for each of the four visions, using Warsaw as the origin and Budzisko as the destination, thus yielding four optimal routes. The properties of each optimal route show the numerical values of total route length and the total route impedance (Ω_R) for each generated route. The four route alternatives generated as such, their lengths and total route impedances, are depicted in Figs. 8–11 and Table 3.

From these figures and the table the geographical and quantitative characteristics for each optimal route can be seen. The equal-vision route and the social-vision optimal route have the same geographical routing but have different impedance values. They also have the shortest length of the four optimal routs generated herein. The ecology-vision optimal route has the highest impedance, while the economy-vision optimal route has the highest length of all the four routes. All four routes overlap with each other for almost 70% of total trajectory, diverging only from the city of Grajewo forward.

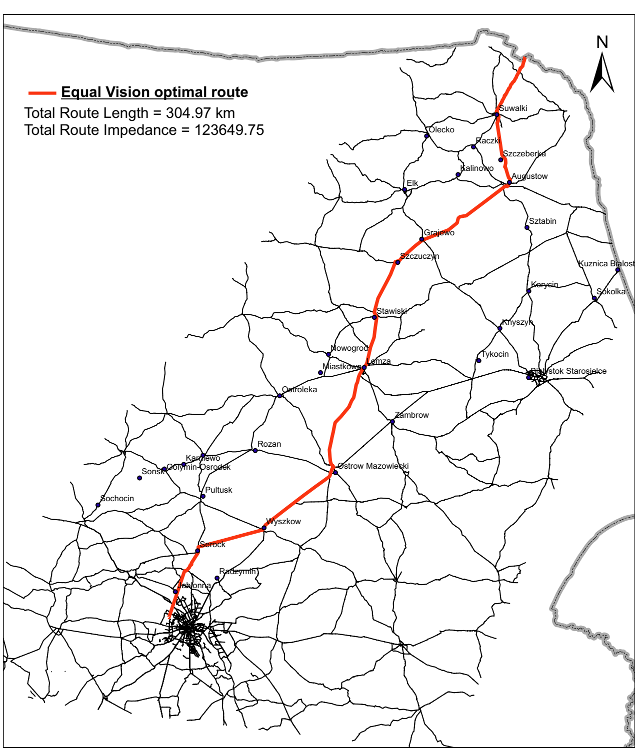

Fig. 8. The Via Baltica expressway – the equal vision route.

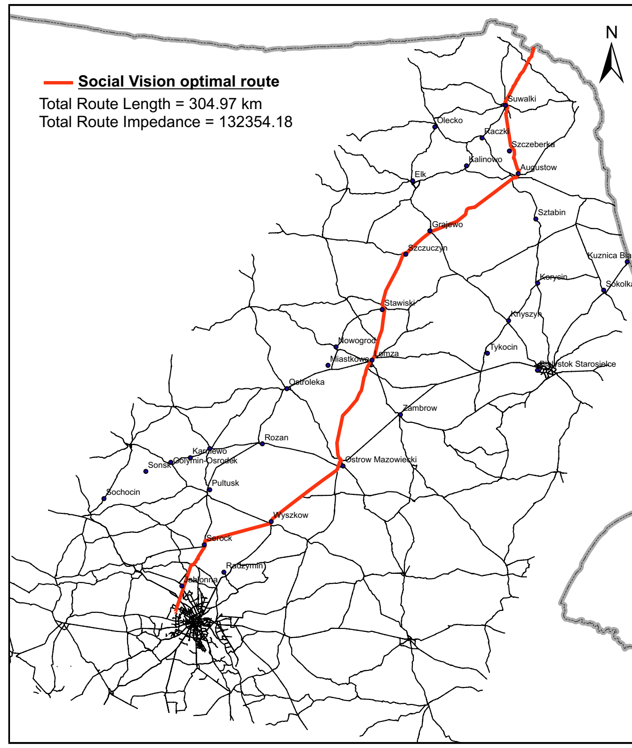

Fig. 9. The Via Baltica expressway – the social vision route.

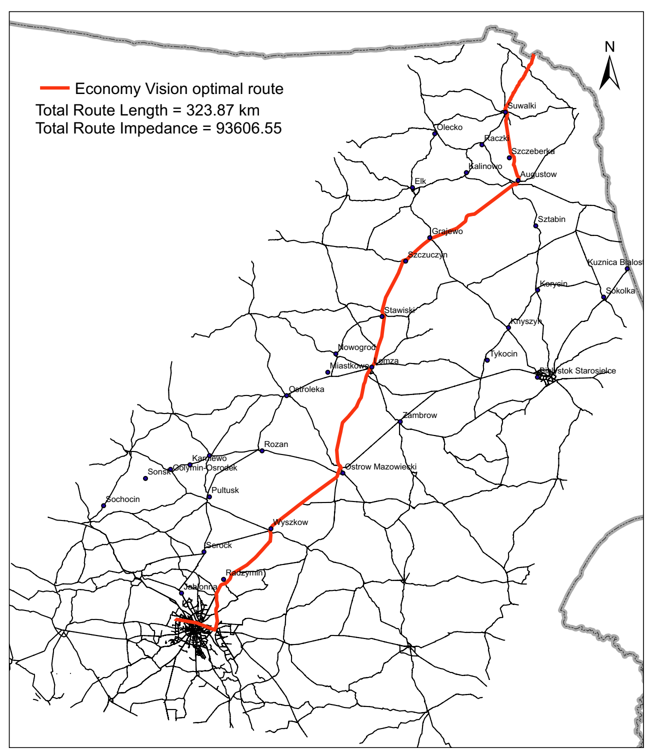

Fig. 10. The Via Baltica expressway – the economy vision route.

10. Assessing and comparing a predetermined and preferred route alternative

As has been discussed before, the practice of predetermining of route alternatives, and subsequent assessment of impacts, is

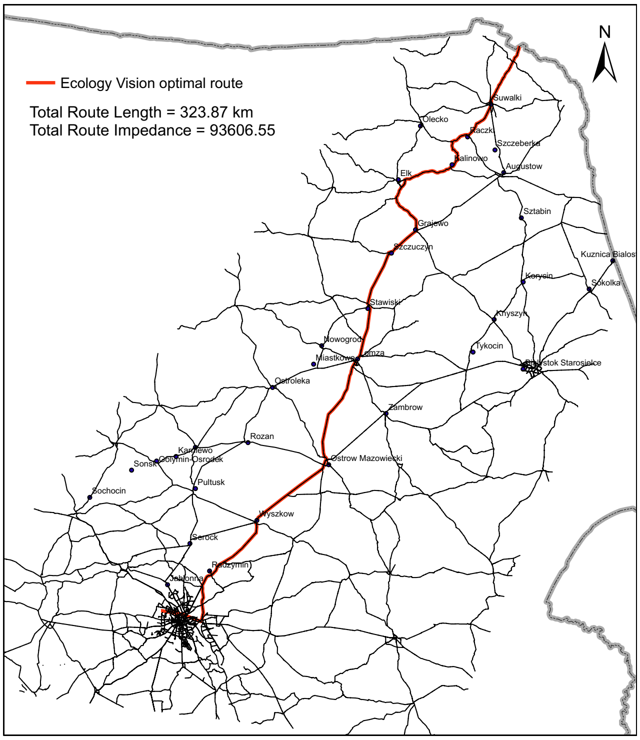

Fig. 11. The Via Baltica expressway – the ecology vision route.

prone to stakeholder dissatisfaction, see also Valve (1999). However, in addition to objectively comparing the four vision optimal routes, this methodology can also be extended to assess a predetermined route, e.g. the Via Baltica route alternative, as preferred by the Polish Government through its implementing agency called the General Directorate of National Roads and Motorways (GDDKiA).

The Polish Government preferred route alternative, as used in this case study, is shown in Fig. 12 below. In this case, the assessment procedure uses the same built network and transport network analysis algorithm as before, but with the use of "fixed stops" and "barriers" in order to reproduce the preferred route alternative in each vision. The total route length and total route impedance (Ω_R) of the Government preferred route are compared with those of the four policy visions (Table 3).

From this table, it can be seen that for each vision, the Government preferred route has much higher impedance than its corresponding vision's optimal route. In addition, it can be seen that the government preferred route alternative is always longer by 20–40 km, which is about 6–13% more as compared to the four optimal routes. This will significantly increase the construction and operation costs. A visual comparison, of Figs. 13–15 (optimal routes) with Fig. 12 (government preferred route), indicates consistent:

1. avoidance of ecologically sensitive areas and protected areas;
2. accessibility to economically active areas;
3. avoidance of hazardous areas;
4. optimisation of financial costs, such as construction of ancillary structures and total length.

11. Discussion

The methodology described and demonstrated in this paper can be applied to any linear transport infrastructure project (such as highway or rail), which is destined for upgrade rather than for entirely new construction. Though this case study was restricted to a network covering about one-fourth of Poland, the methodology and model can be used for any scale and size, but is particularly advantageous for geographically large-scale projects, thus relatively coarse network structures.

The transport network analysis procedure used in this method is a vector-based approach, using an existing road network. A greater weighting is given to higher category roads in the procedure. Therefore, mainly higher categories of roads, i.e. a coarse network, are selected for use in the transport network analysis. As such, the method limits extraneous loops and detours, thus keeping the total route length under control. Furthermore, the impedance for each road segment is calculated by using the length of the segment as a multiplier, thus the total route length continues to play an important role, although not a predominant one. This way, the number of vehicle-kilometres continues to be accounted for.

For this case study in particular, and increasingly in many other infrastructure projects, where it is mandated that, 'no new roads should be created, only upgrading of existing roads is allowed', the final route can only follow existing roads. Therefore only a vector-based network analysis can serve the purpose. Another advantage of this method is that the final routes that are generated continue to be polyline shapes; hence they can be used for further GIS-based analysis (if needed) without requiring any additional processing.

This methodology improves upon previous scientific research in the field, by building a comprehensive methodology that integrates the use of SMCA and transport network analysis in these kinds of studies. It also improves on the research of Grossardt et al. (2001) by selecting a pixel size designed as per the effect-range of the highway and, most importantly, using the vector based network analysis.

A visual test done by overlaying the optimal routes on the original criteria layers shows that the spatial logic of each vision is firmly (and unambiguously) asserted throughout the entire route for that vision, despite it not always being obvious at first glance. This firmly proves the authors' assumption that the existing (and popular) methodology of predetermining various route alternatives and conducting impact assessments on them can often overlook other route alternatives that may be more suitable from environmental, social and economic impact points of view.

Table 3
Comparison of the total route impedances and total route lengths of the various vision-optimal routes and the Polish Government's preferred route

	Equal vision		Social vision		Economy vision		Ecology vision	
	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)	Total route impedance Ω_R	Total route length (km)
Optimal route	123649.75	304.97	132354.18	304.97	93606.55	323.87	155823.24	313.10
Government preferred route	140437.06	343.34	149698.00	343.34	110032.71	343.34	174378.13	343.34
Decrease over government preferred route (%)	13.58	12.58	13.10	12.58	17.55	6.01	11.91	9.66

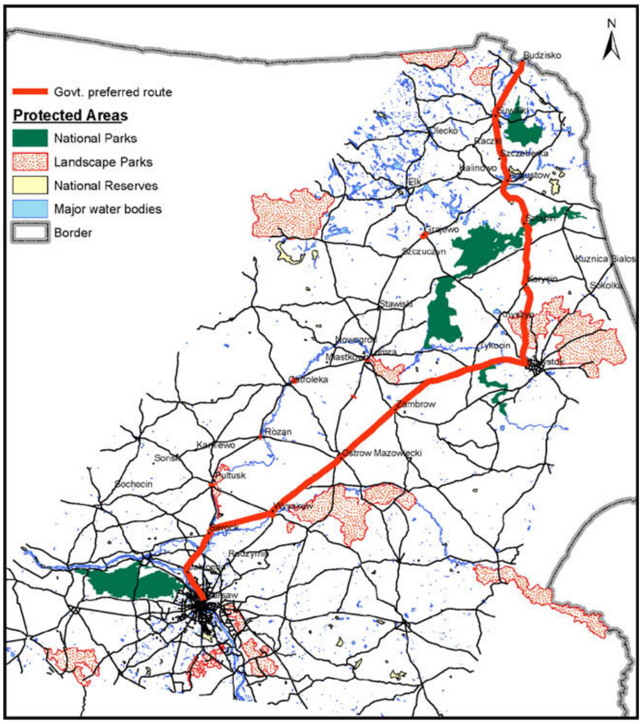

Fig. 12. The government preferred alternative.

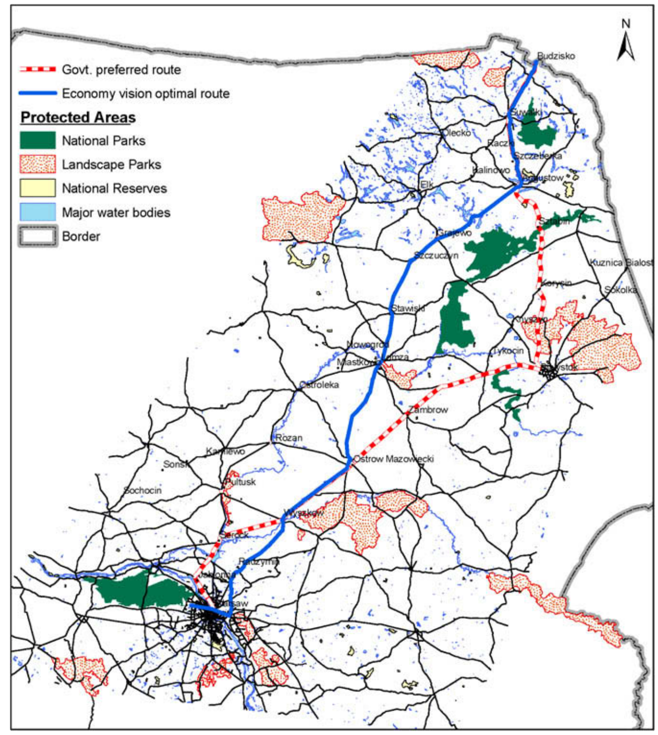

Fig. 14. Government preferred route (red) vs. economy vision route (blue).

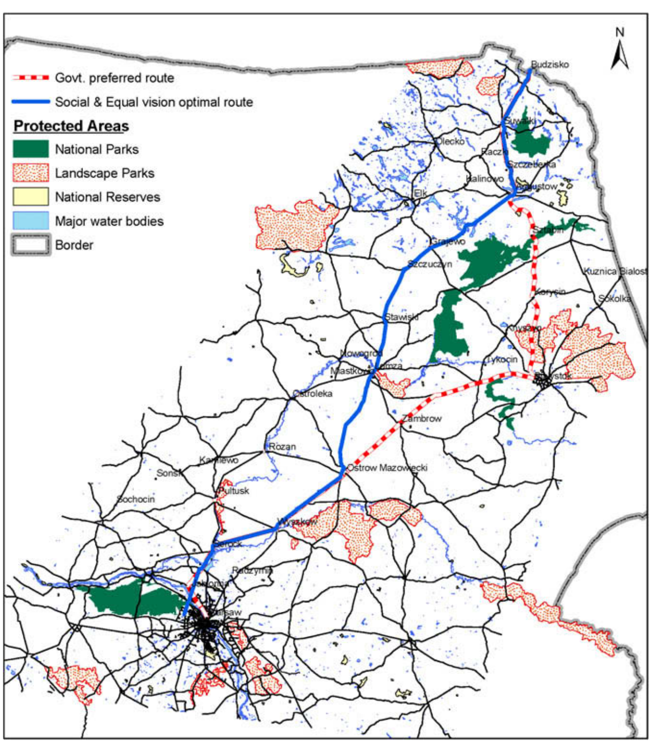

Fig. 13. Government preferred route (red) vs. equal/social route (blue).

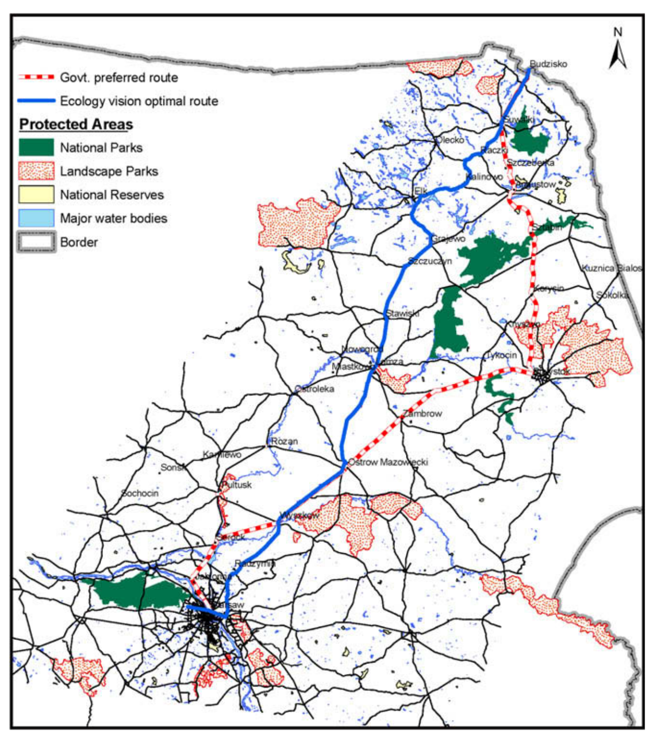

Fig. 15. Government preferred route (red) vs. ecology vision route (blue).

12. Conclusions and recommendations

Large transport infrastructure projects such as the recent Via Baltica highway project in Poland intend to stimulate regional economic development, but are also known to have negative impacts on the local environment. The assessment of bio-physical, social and economic impacts of available routing alternatives is required to improve decision-making in the planning stages of infrastructure projects. If not done adequately, only one or a few sub-optimal alternatives are being short-listed in the end. This was also the case for the Government preferred route of the Via Baltica, which was criticized by local stakeholders and finally suspended by the EU.

The concept presented in this paper emphasises that if stakeholder concerns and expert knowledge are coupled to the highway planning at the route alternative determination stage itself, unnecessary biophysical, social and economic damage can be easily avoided and the benefits enhanced. At the same time, a substantial increase in the utility of the project and also, increase of stakeholder confidence in the planning process can be induced.

Based on this concept, a systemic and geo-information based methodology that can formulate and assess effect-based transport route alternatives is presented. This methodology integrates environmental regulations and concerns without ignoring the equally important considerations of transport system efficiency, safety, socio-economic demands, financial and engineering viability, as well as policy considerations.

These results show that spatial multi-criteria assessment and network analysis can be coupled together to create a system of route generation based on cumulative impacts. These assessment criteria are derived from bio-physical, social and economic parameters but also involve weighting, which is obtained from stakeholder concerns, policies and expert knowledge. It is also shown that designing the pixel size as per the highway effect range works better even though the resolution is much coarser than in previous methods. The use of geospatial data including remote sensing imagery helps to fill in the spatial information gaps in the spatial decision support system presented here.

In the Via Baltica case study four optimal routes were generated for different policy visions. As compared to the Polish government's preferred route, it was shown that all four optimal routings have less impedance and are also shorter than the government preferred route. In addition, these alternatives would also satisfy the EU's environmental laws and provide a high degree of stakeholder satisfaction.

The method can be enhanced by the use of other relevant criteria such as migratory corridors, slope regimes, environmentally susceptible soils, engineering properties of soils, traffic noise, air pollution, etc. which could increase the versatility of the method.

The results of the case study demonstrate that a GIS-based spatial decision support system can support authorities and planners worldwide to better respond to stakeholder demands for transport route alternatives more systematically, transparently and objectively. The ultimate decision on which route alternative is chosen rests in the hands of political authorities. However, the methodology presented in this paper provides decision makers with a tool that enables them to be more rational and transparent if they so wish. Hence the presented method can be used to improve the practice of Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) for transport planning, a mandatory requirement in many countries, and thus it enables sustainable transport planning.

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Appendix A

A.1. Description of datasets

Thematic raster layer	Dataset
Proximity to existing rail network	Vmap0 dataset (rail).
Proximity to the proposed Rail Baltica	CodeTen Rail Baltica feasibility report mapped on Vmap0 dataset (rail).
Current Traffic density	Annual Average Daily Traffic data for 2005 from the GDDKiA.
Internationally protected natural areas (Natura 2000 sites)	World Database of Protected Areas (WDPA) database.
Nationally protected areas	Vector Data of National Parks, Landscape Parks and National Reserves from the Polish Ministry of Environment.
Forests and semi-natural Areas Wetlands and bogs Water courses and lakes	CORINE 2000 land classification database confirmed with ASTER satellite image (dated July 2006).
Proximity to urban areas	Derived from Vmap0 dataset (urban areas).
Risk of accidents in urban areas	Derived from Vmap0 dataset (urban areas).
Peat areas (fire hazard)	European Soil Database (ESDB) version 2.0.
Population served	LandScan® 2004 population database.
Economic zones	DMSP-OLS Radiance-Calibrated night light satellite imagery (Composite image for 2003).
Potentially prime agriculture areas	Derived from European Soil Database (ESDB) version 2.0.
Existing agriculture	Derived from European Soil Database (ESDB) version 2.0.
Construction in urban areas	Derived from Vmap0 dataset (urban areas).
Intersections needed	Derived from Vmap0 dataset (roads).
Current status of the road (Category of the road)	Derived from Vmap0 dataset (roads) confirmed with GDDKiA roads dataset.
Bridges needed	Derived from intersection of Vmap0 datasets (roads and perennial water courses).
Construction on Peat	Derived from European Soil Database (ESDB) version 2.0.

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