Environmental protection and investment costs as factors of road placement

Okolje in investicijski stroški kot dejavnika za umeščanje cestne trase v prostor

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Abstract: In the article, a methodology to aid the choice of the most appropriate road corridor from the standpoint of environmental protections and investment costs is presented. The methodology enables road planners to first define the route or so called corridor, which according to the selected factors is most acceptable and expert grounded, and in the next phase work out multiple combinations of previously "pure" scenarios. On the basis of additional evaluations, political preferences, financial capabilities and social acceptability, the most appropriate corridor for placement of a new road is chosen. Inside of the corridor, the most technically feasible route of new road is then drawn. The advantage of such an approach is foremost in the objectivity of the methodology and the simultaneous command of multiple factors when choosing the most appropriate corridor. The classic method of route placing has its roots in technical placement; and these alternatives are evaluated between each other from multiple perspectives.

Izvleček: V prispevku je prikazana metodologija določitve najugodnejšega cestnega koridorja z vidika varovanja okolja in investicijskih stroškov gradnje ceste. Metodologija omogoča načrtovalcu najprej definirati t.i. koridorje, ki so glede na izbrane vplive najugodnejši ter strokovno in objektivno čim bolj utemeljeni. V naslednji stopnji se lahko izdela tudi različne kombinacije prejšnjih »čistih« koridorjev. Med vsemi predlaganimi koridorji se na podlagi dodatnih vrednotenj, političnih preferenc, finančnih zmožnosti in družbene sprejemljivosti izbere tistega, ki je najbolj ustrezen. Znotraj koridorja se nato izriše tehnično najbolj ugodna trasa ceste. Prednost takega pristopa je predvsem v objektivnosti metodologije in v hkratnem obvladovanju več dejavnikov, ko izbiramo najugodnejši koridor. Klasična metoda umeščanja cestne trase v prostor namreč izhaja najprej iz tehnične umestitve, šele kasneje pa se različne variante, določene na tak način, med sabo vrednoti z različnih vidikov.

Review paper

Key words: road planning, environmental vulnerability, investment costs, GIS, methodology
Ključne besede: načrtovanje cest, ranljivost okolja, investicijski stroški, GIS, metodologija

Introduction

The construction of an infrastructure network is an important task that enables development of individual parts of the country as well as of the state as a whole. In road network planning – the largest in scope and complexity in infrastructure – we generally find many different approaches. The most frequent, and also the most commonly used, is the so-called »technical« approach[1]. With this approach, the alternative individual routes according to technical criteria are chosen first, and then are judged in view of the environmental and spatial impact later. Adequate protection measures are included in this approach. The second approach, originally introduced in Germany, and now utilized in Slovenia, is the so called "spatial" approach[1]. The purpose of this approach is to determine the spatial and environmental vulnerability of a particular route chosen. First, the narrow, spatially acceptable corridor is chosen. Then within the corridor alternative routes are designed according to technical criteria.

A choice of factors to include in route selection modelling methodology, depend on the goals we wish to achieve. In most cases environmental vulnerability is the only factor. Environmental protection is becoming an increasingly important issue in today's world. Besides an increased public awareness of the need for environmental protection, Slovenia has with joining the EU in 2004 adopted European legislation, which places an even greater emphasis on environmental protection. It is important that the construction of new road connections does not harm the natural state of the environment, or cultural heritage. With project planning it is therefore paramount that the construction of the road connection itself impacts on the environment as little as possible.

The second most important factor that influences road placement and construction are investment costs. Usually, the available funds are smaller than requested, so the goal is to find the solution which enables the greatest benefit for road users and society as a whole at the lowest cost possible.

This article represents a useful introduction to the application of GIS methodologies to solve a transportation problem. In this paper appropriate methodology which allows optimal route determination in space, with regard to both environmental protection, and investment costs is utilized. The optimization of all different constrains is very important in road design, because a suitable initial approach results in substantial savings (in terms of both money and the environment) when it comes to further realization of plans and projects.

Methodology

In a broader sense the geographic information system (GIS) is an information system specializing in the input, storage, manipulation, analysis and reporting of geographical (spatially related) information[2]. Information in GIS is often stored and represented as layers, which are sets of geographical features linked with their attributes. Before a GIS can be use to solve the problems, data must be properly chosen and represented in a digital computing environment.

Route selection or road planning is an example of the impact of multiple geographical constraints in nature. The route selection process is in fact a multi-criteria decision making process where a final decision is made by considering different types of information.

The task is to define a route linking the previously identified start and end points. The goal is to insure that the road route chosen is the shortest, least expensive (i.e. presents minimum investment costs), and does the least harm to the environment (i.e. maximum environmental preservation). Some criteria are self reinforcing, such as road length and investment costs, while others are mutually exclusive, such as road length and environmental damage. An appropriate balance which tries to satisfy divergent interests must be found.

The methodology for the optimal corridor or route selection can be divided into 5 steps. The first three are used for new data layer synthesis, for each factor separately (environment, costs, etc.), while the last two are used for optimal corridor modelling of all the factors combined (Figure 1).

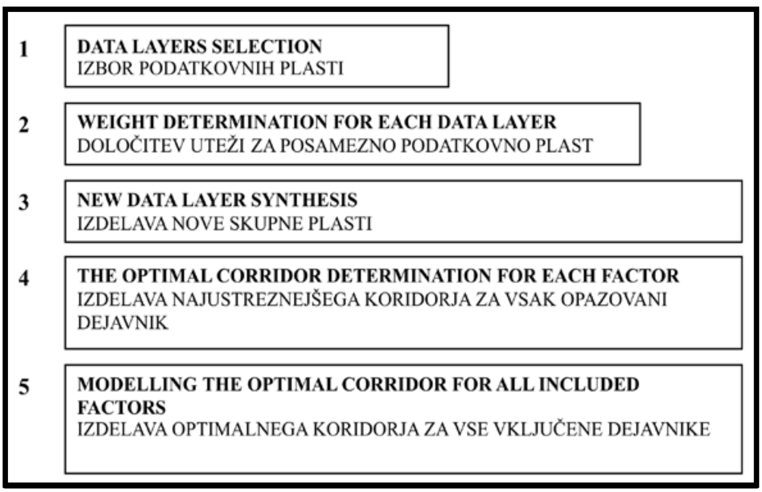

Figure 1. Schematic representation of methodology for route selection
Slika 1. Shematska predstavitev metodologije za umeščanje cestne trase v prostor

In the first stage data layer selection on an environmental protection basis is performed. The layers represent protected areas as defined by legislation or otherwise designated as protected. At this point, digital data layers of the space in question are collected and modified with the use of GIS tools. Areas where protection of the environment is called for are generally areas less (or not at all) appropriate for the placement of new road.

In the second stage, depending on the meaning of a particular area, the weights for each individual layer are assigned. The more that a certain area needs to be protected, the larger the weight assigned to that layer. The weight actually shows how much longer a route between two points will be drawn, as opposite to the most direct path of the route. If too large weight is assigned, the environment is more protected (because the route will take the path across less protected areas); however the investment costs will be significantly higher, and the new road too long.

In the third stage, vector data is converted to raster data. Every point is assigned a value, which represents the sum of the values of individual layers (layers, selected in the first stage and weights, assigned in the second). Areas with the highest values are least appropriate for new road determination from the standpoint of protection of the environment.

Cost analysis is performed in a similar way as the environmental protection analysis. In the first stage, layers which lead to increased costs of construction of the new road are determined. For example, a large change in above sea level elevation (influence on the construction of tunnels and viaducts), potential avalanche areas or other geologically and hydrologically inappropriate areas on which the construction of roads is much more difficult. At this stage the expert geological opinion and judgement is very important. Individual layers are weighted in the second stage, with an eye as to how much they increase the total costs of construction of the new road connection. In the third stage, individual layers in raster form are combined and the values of individual overlapping areas summarized.

In the fourth stage, the most environmentally appropriate corridor is placed. The new road is placed in a location which cumulatively has the least negative impact on the environment. This is determined with the help of appropriate GIS tools. In the same way a corridor which from a construction standpoint is lowest in cost is drawn.

The two corridors determined in the fourth stage can have a similar path or can be considerably different. In the case of a considerable difference, a new corridor is determined, which represents the most optimal route between the two, in other words the most appropriate route of the new road, which would attain the lowest possible cost while not neglecting protection of the environment. In this process, every factor (environmental, cost analysis) can be assigned a weight, which is an expression of the degree of importance we assign to each perspective. Differing weights can fundamentally alter the placement of the new road route.

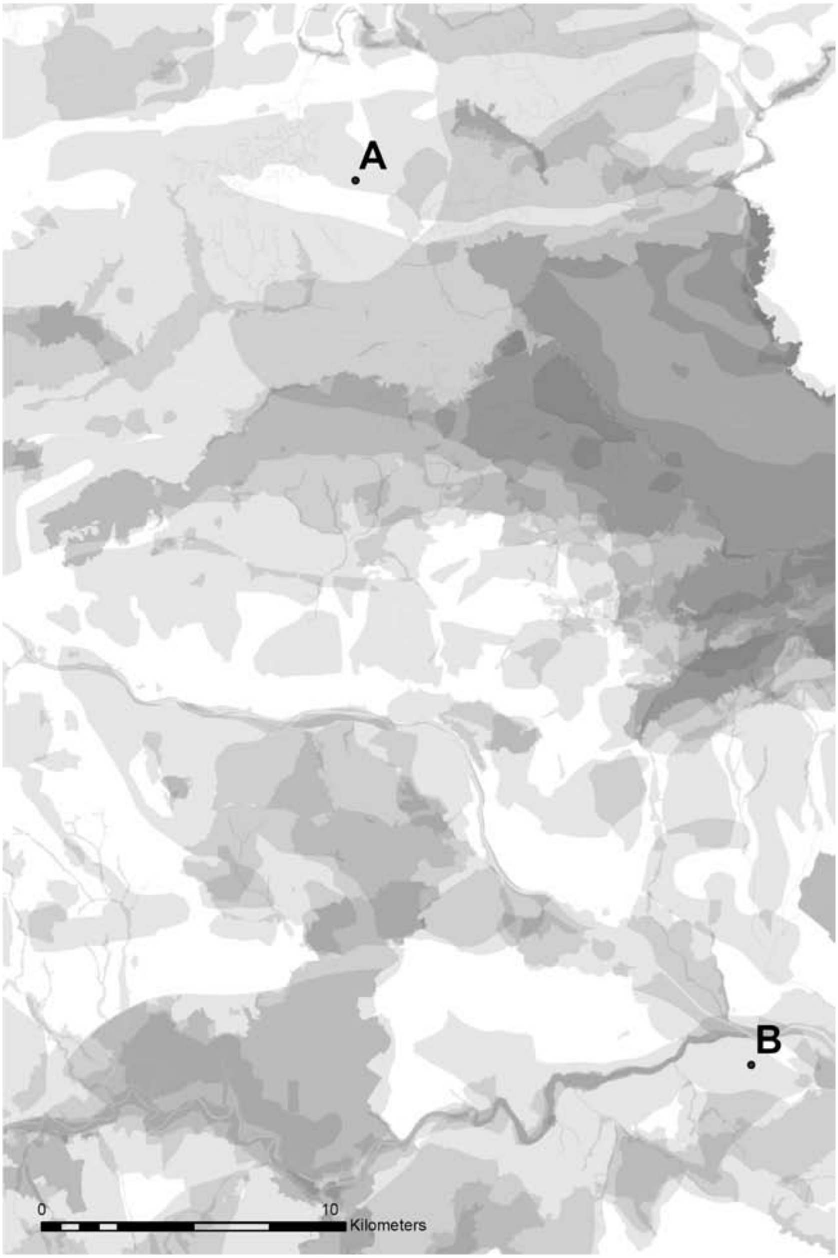

Figure 2. Composite map of environmental layers
Slika 2. Karta, sestavljena iz posameznih plasti varovanih delov okolja

Results and Discussion

For the presentation of the introduced methodology, a portion of southeast Slovenia was chosen. Selected digital layers for the environmental protection analysis included:

- Natura 2000 areas,
- protected areas of nature,
- valuable natural features,
- ecologically important zones,
- water protection zones,
- cultural heritage.

For definition of a favourable corridor with regard to road construction cost analysis, the following layers were applied:

- relief (slope),
- sensible regions (flooded areas, erosion areas, landslide areas),
- waters and lakes,
- objects (buildings etc.).

In this paper, all selected data layers have equal weight. If the importance or influence of certain data is determined to be greater than that of other data, the assigned weight should be heavier. In Figure 2, the composite map of all environmental layers is presented. The darker zones correspond to several protected areas. These are the areas less suitable for new road construction. The most appropriate areas for new road placement are in white.

In the next stage, data is converted from vector format into raster format, and the most appropriate new road corridor from the environmental protection as well as cost perspective is drawn with the help of appropriate GIS tools. In Figure 3, the first picture on the top left is environmentally the most appropriate corridor, while the last picture on the bottom right is the most appropriate route from a cost perspective. The goal of the new road planner is to find a solution which will protect the environment to the highest degree possible at the lowest possible cost.

Because two conditions that aren't directly comparable need to be satisfied in the final and most optimal corridor, there are many solutions which can be represented graphically (Figure 4 - gray and black points). The best solutions are the black points, which lay along the Pareto[3] curve. The Pareto trade-off curve is the curve made up of Pareto points that represent possible solutions. For all the points on the curve it holds true that in giving more importance to one factor it is automatically assigned less importance to the other. All the points present an equal solution to the problem - no particular one is better than any other.

If we apply the Pareto model to the display of determination of the most appropriate corridor for road placement from an investment costs as well as environmental protection perspective (Figure 3), it can be determined that all the solutions displayed correspond to points on the Pareto curve. The next goal is to find the solution, which will be utilized in actual practice.

Comparison of the individual pictures in Figure 3 show that the model of proportions varies from costs 80 %: environment 20 % to costs 10 %: environment 90 % show territory which is in common to all the models. This territory can thus be tak-

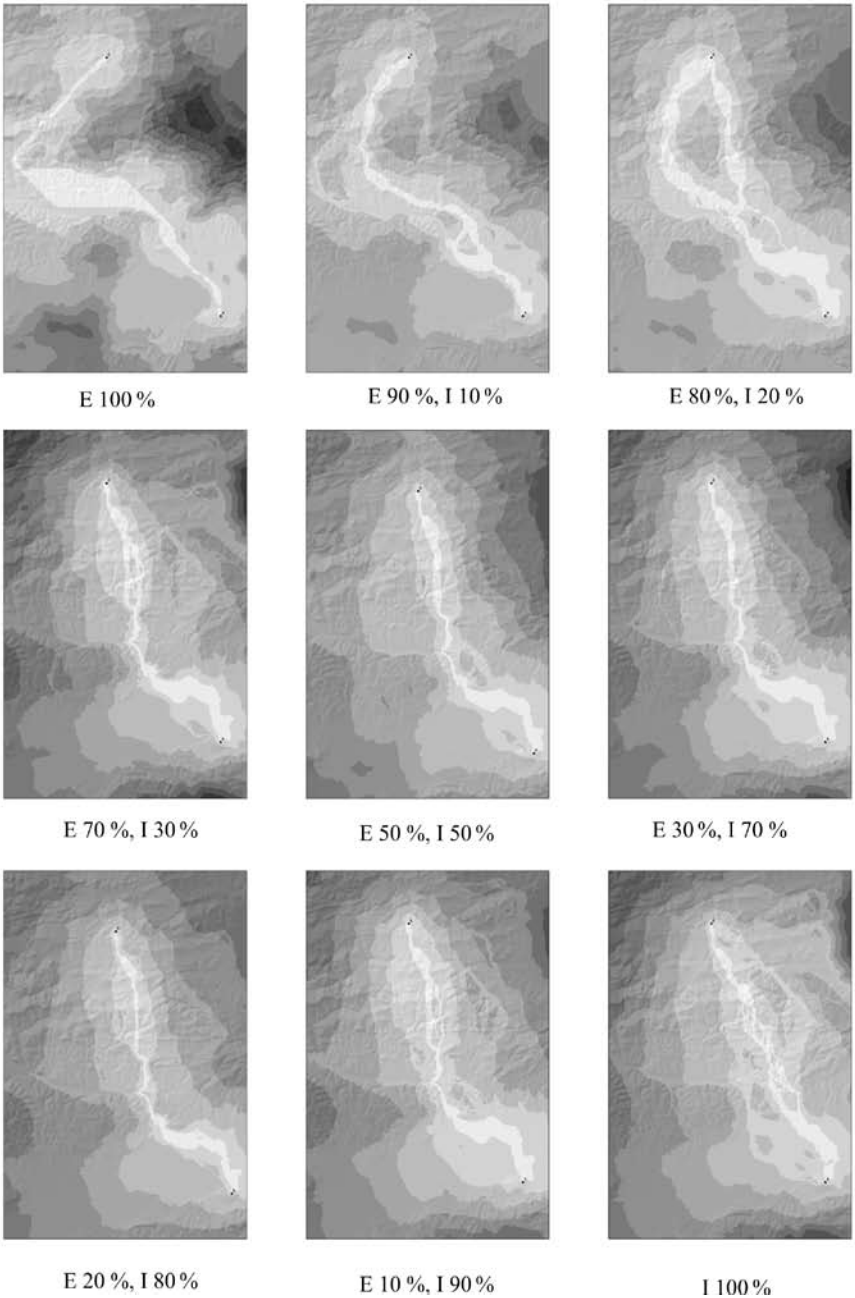

Figure 3. Optimal road corridors as a result of the corridor modelling (E – environment, I – investment)
Slika 3. Modelsko določeni optimalni koridorji poteka ceste (E – okolje, I – investicija)

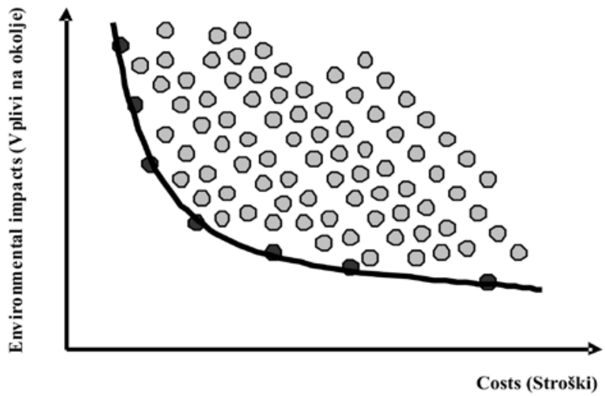

Figure 4. Pareto optimality curve
Slika 4. Paretova optimizacijska krivulja

en as the most convenient corridor for the construction of a new road. Inside of this corridor various alternatives can be determined, evaluated and compared with each other in classic approach.

The choice of the most optimal route for a new road as demonstrated above is not always simple. In a way it is a political decision, because it entails deciding how important protection of the environment is in financial terms. Social acceptance plays an important role within this process, as does the influence the new road would have on the development of a particular area. The methodology demonstrated allows for individual alternatives which enter the political foray to be expertly and objectively supported to the maximum extent possible.

In the demonstrated model two groups of limitations (environmental protection and investment costs) are included, even though more groups could be included. Possible limitations, which could also be included in the model, are:

- limitations of space (for example, neighbourhoods - limiting factor regarding the construction of road, though at the same time also a factor of attractiveness in space),
- physical barriers (unfavourable terrain, geological or hydrological conditions, water streams, lakes),
- economic potential (industrial zones, tourist zones, accessibility and the connectedness of town centres),
- political limitations and social acceptance.

Conclusions

In construction of transport infrastructure the question of how to intervene with minimal impact on the environment yet at the same time in a technically most feasible and cost effective way is a common problem. Every intervention into nature affects the environment. The planner's task is to pick the solution which will do the least harm to the environment while providing the greatest economical benefit.

In the article, a methodology to aid the choice of the most appropriate road corridor from the standpoint of the environment protections and investment costs is presented. The methodology enables road planners to determine the route or corridor, which according to the selected factors is most acceptable, and in the next phase work out multiple combinations of previously »pure« scenarios. On the basis of additional evaluations, political preferences, financial capabilities and social acceptability, the most appropriate corridor for placement of a new road is chosen. Inside of the corridor, the most technically feasible route of new road is then drawn.

In spite of computer support importance for methodology execution, preparing the input data needs an expert knowledge and cooperation of different specialists. Selection and data layers synthesis needs the knowledge of geology, hydrology, civil engineering, environment, legislation, land use, etc. Only professional prepared and grounded input data enable optimal results.

The advantage of such an approach is foremost in the objectivity of the methodology and the simultaneous command of multiple factors when choosing the most appropriate corridor. The classic method of placing the road route in space has its roots in technical placement; only later are alternatives evaluated between each other from multiple perspectives.

Povzetki

Okolje in investicijski stroški kot dejavnika za umeščanje cestne trase v prostor

Pri gradnji prometne infrastrukture se vedno srečujemo z dilemo kako poseči v prostor, da bo okolje kar najmanj prizadeto, in hkrati najti tehnično najugodnejšo rešitev, ki bo tudi stroškovno ugodna. Vsak poseg v okolje prizadene tudi naravo. Načrtovalčeva naloga je, da izbere tako rešitev, ki ponuja ob najmanjši prizadetosti okolja, največjo ekonomsko korist.

Izbor posameznih dejavnikov, ki jih vključimo v metodologijo za določitev sprejemljivega infrastrukturnega koridorja, je lahko zelo različen, odvisno od cilja, ki ga želimo doseči. Večinoma je tak dejavnik samo eden, to so različna varovana območja okolja. V tem primeru projektant izriše traso ceste tako, da poteka čim manjši meri čez varovana območja. V metodologijo pa lahko vključimo tudi druge dejavnike. V prispevku je prikazana metodologija določitve najugodnejšega cestnega koridorja z vidika varovanja okolja in investicijskih stroškov gradnje ceste.

Predlagana metodologija za umeščanje cestne trase v prostor vsebuje več stopenj (slika 1):

1. Določi se področja, ki so povezana z varovanjem okolja. To so varovana območja, določena v zakonskih ali podzakonskih aktih, ali pa jim je na kakšen drug način pripisan varovalni pomen. Na tej stopnji se zbere plasti digitalnih prostorskih podatkov in se jih ustrezno obdela z orodji GIS (slika 2).

2. Glede na pomen posameznega področja se določi uteži za posamezno plast. Bolj ko želimo neko območje ali dobrino varovati, večjo utež dobi. Če določimo preveliko utež, okolje sicer bolj varujemo (ker bo izrisana pot prečkala malo varovanih območij), a bo nova cesta daljša in investicijski stroški bistveno višji.

3. Vektorske podatke pretvorimo v rastrske. Vsaki točki pripišemo vrednost, ki predstavlja vsoto vrednosti posameznih plasti (plasti, izbranih v prvi stopnji in uteži, izbranih v drugi stopnji). Področja z najvišjo vrednostjo so najmanj primerna za izdelavo nove cestne povezave z vidika varovanja okolja.

Na podoben način kot okoljski vidik se izdela tudi stroškovnega. V prvi stopnji se določi plasti, ki vplivajo na povečanje stroškov pri izgradnji cestne povezave. To so na primer velika sprememba nadmorske višina (vpliva na gradnjo tunelov in viaduktov), plazovita območja oz. geološko in hidrogeološko neugodna območja, na katerih je gradnja ceste bistveno zahtevnejša. V tej stopnji je zelo pomembna tudi strokovna geološka ocena. Posamezne plasti se v drugem delu ustrezno uteži. V tretji stopnji se posamezne plasti v rastrski obliki združi in vrednosti na posameznih prekrivajočih področjih sešteje.

4. Na podlagi ovrednotenih površin iz tretje točke se s pomočjo ustreznega GIS orodja izdela najustreznejši koridor z vidika varstva okolja in koridor, ki je z vidika stroškov izgradnje cestnega odseka najugodnejši.

5. Koridorja, dobljena v četrti stopnji, sta si po poteku lahko podobna ali pa se bistveno razlikujeta. V primeru bistvene razlike se izdela še koridor, ki predstavlja optimum med obema »čistima« koridorjema, torej kje je najprimernejši potek cestne trese, ko bi z najnižjimi stroški dosegli največje varovanje narave. Pri tem postopku lahko vsakemu od vidikov (okolje, stroški) določimo poljubno utež, ki je odraz tega, kateremu vidiku dajemo večji pomen. Različne uteži lahko bistveno spremenijo potek trase.

Na sliki 3 je na prvi sliki prikazan okoljsko najprimernejši koridor, na zadnji sliki pa investicijsko najugodnejši koridor. Cilj načrtovalca cestne povezave je najti tako rešitev, ki bo ob najnižjih stroških najbolj okoljsko ugodna. Ker v končnem koridorju združujemo dve lastnosti, ki nista neposredno primerljivi, obstaja veliko rešitev, kar lahko ponazorimo tudi grafično (slika 4 - sive in črne točke). Najboljše rešitve so črne točke, ki ležijo na t.i. Paretovi krivulji[3]. Za vse točke na tej krivulji je značilno, da če hočemo eno lastnost izboljšati, se pri tem druga poslabša. Pri tem vse te točke predstavljajo enakovredne rešitve problema - nobena ni boljša od druge.

Če prenesemo Paretov model na prikaz izdelave najbolj ugodnega koridorja izgradnje cestne povezave tako s stroškovnega kot tudi okoljskega vidika (slika 3), lahko ugotovimo, da vse prikazane rešitve ustrezajo točkam na Paretovi krivulji. Naslednji cilj je torej najti rešitev, ki jo bomo uporabili v praksi. Primerjava posameznih slik pokaže, da vsebujejo vsi modeli od razmerja okolje: stroški 80 %:20 % do razmerja 10 %:90 % v okviru najugodnejšega koridorja tudi ozemlje, ki je vsem tem modelom skupno. To ozemlje lahko zato pojmujemo kot najbolj ugodni koridor za izgradnjo ceste. Znotraj tega koridorja pa kasneje projektant izriše več variant, ki jih vrednotimo in primerjamo med sabo na klasičen način.

Kljub pomembnosti računalniške podpore pri izpeljavi metodologije je potrebno pri pripravi vhodnih podatkov veliko strokovnega znanja in sodelovanje strokovnjakov z različnih področij. Izdelava in izbira podatkovnih plasti zahteva znanja s področja geologije, hidrogeologije, gradbeništva, okolja, poznavanja zakonodaje, rabe tal, urejanja prostora itd. Le strokovno pripravljeni in utemeljeni vhodni podatki omogočajo optimalne rezultate.

Zgoraj prikazana izbira najugodnejšega koridorja ni vedno enostavna. Dejansko je to »politična« odločitev, saj se moramo odločiti, koliko nam pomeni varovanje okolja v denarnem smislu. Pri tem igra pomembno vlogo tudi družbena sprejemljivost in pa vpliv, ki bi ga imela nova cesta na razvoj območja. Prikazana metoda pa omogoča, da so posamezne različice, ki pridejo v »politično« presojo, čimbolj strokovno in objektivno utemeljene.

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