MULTI-CRITERIA DECISION MAKING IN PUBLIC TRANSPORT WITH THE AHP METHOD: THEORY AND PRACTICE

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Wien, 4th of December 2019

Content

- Universiti of Zagreb Faculty of Transport and Traffic Sciences
- Methods for Evaluation Projects in Transportation
- Multi-criteria decision making
- AHP method - background
- AHP method – application
- Case study – Examples
- Quiz!

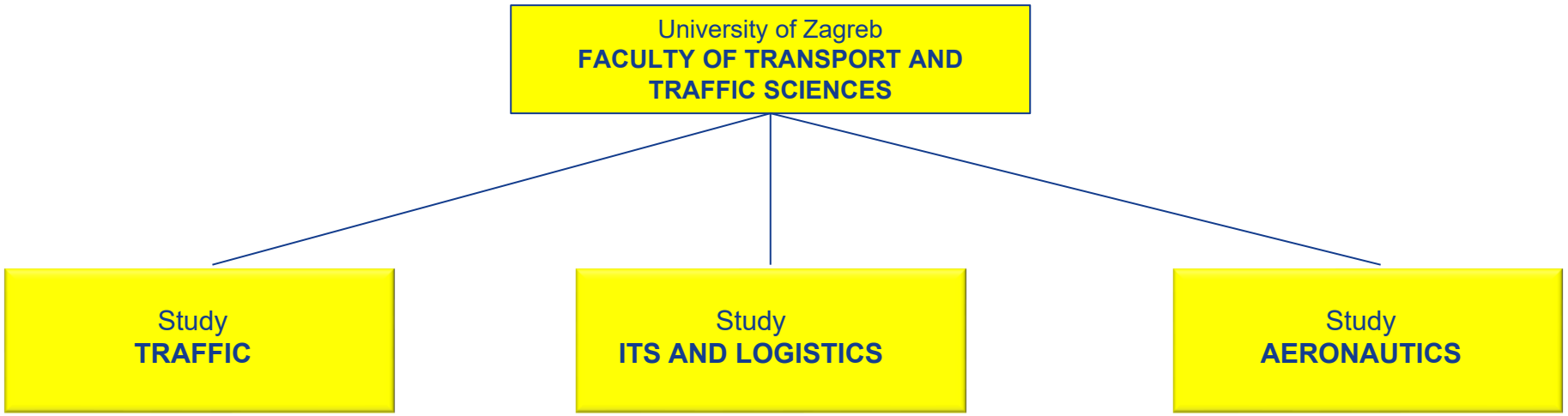
UNIVERSITY OF ZAGREB / BASIC FACTS

- Public University
- Established: 1669
- Oldest and biggest in South-East Europe
- Research oriented, contributing over 50% to the total research output of the country
- 29 faculties + 3 art academies
- Bachelor's, Master's and Doctoral degrees
- Arts, Biomedicine, Biotechnology, Engineering, Humanities, Natural and Social Sciences
- Students: 70,000
- Academic staff: 8,000

FACULTY OF TRANSPORT AND TRAFFIC SCIENCES (FTTS) / BASIC FACTS

- Public institution of higher education, scientific and educational unit of the University of Zagreb
- Established in 1984
  - professional studies from 1962
  - university studies from 1968
- Bologna system (3+2+3) introduced in 2005
- Undergraduate, graduate and postgraduate study programmes
- Academic staff: 120
  - Professors: 50
  - Assistants/Researchers: 70
- Students: 2,200

Undergraduate and graduate study programmes



orientation:
- ROAD TRAFFIC
- URBAN TRAFFIC
- INFORMATION AND COMMUNICATION TRAFFIC
- POSTAL TRAFFIC
- WATER TRAFFIC
- AIR TRAFFIC
- RAILWAY TRAFFIC

orientation:
- INTELLIGENT TRANSPORT SYSTEMS
- LOGISTICS

module: PILOT
- orientation : MILITARY PILOT
- orientation: CIVIL PILOT

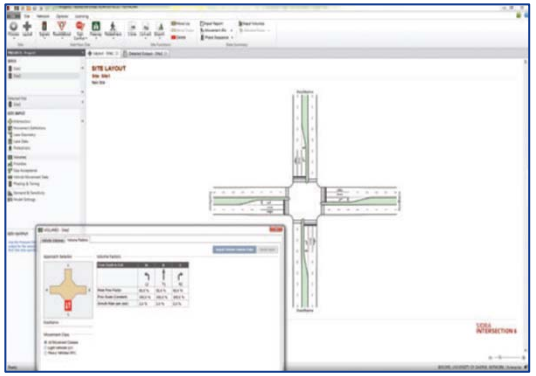
module: AIR TRAFFIC CONTROLER

Undergraduate study – 6 semesters / 180 ECTS
Graduate study – 4 semesters / 120 ECTS

Road and urban traffic flow analysis and prediction

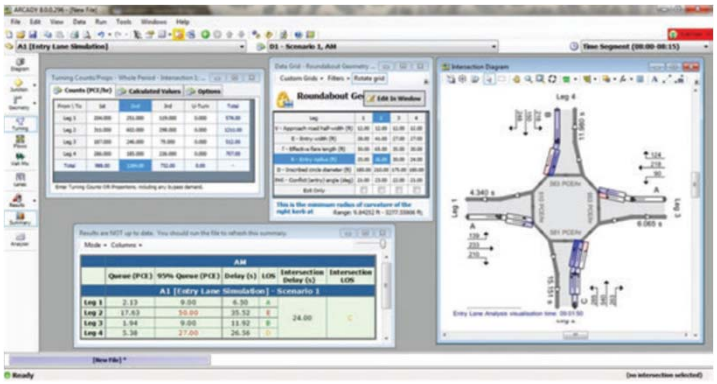
Program za makrosimulaciju prometa **Visum** **PTV AG**, Karlsruhe, Germany

Program za mikrosimulaciju prometa **Vissim** **PTV AG**, Karlsruhe, Germany



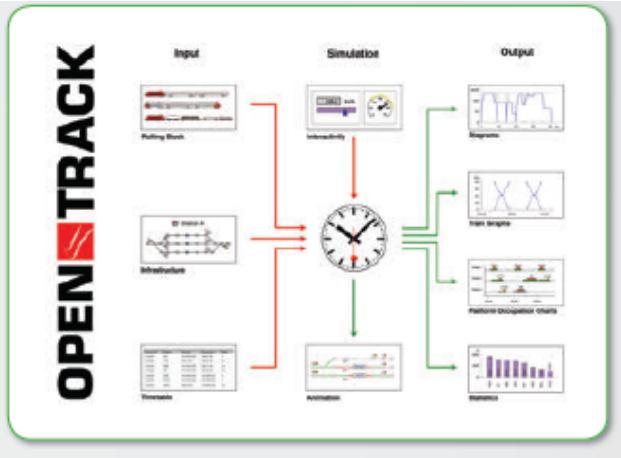
Program za analizu prometa u raskrižju **Sidra Intersection** - Akcelik & Associates Pty Ltd, Greythorn, Australia

Program za projektiranje raskrižja i prometnica **AutoTURN Pro 3D** - Transoft Solutions, Richmond, Canada



Program za modeliranje prometnog toka na raskrižju **JUNCTION - ARCADY**

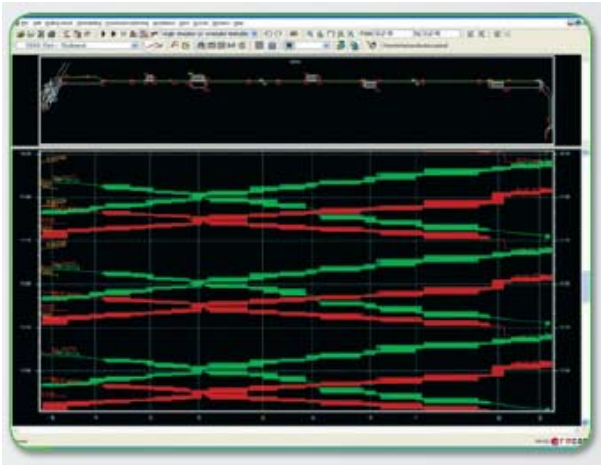
Railway system simulation and railway traffic safety analysis



Program za modeliranje i simulacije u željezničkom prometu **OpenTrack**
Swiss Federal Institute of Technology, Zürich, Switzerland

Autostop uređaj **RAS 8385**

Digitalno upravljiva maketa željezničkog sustava



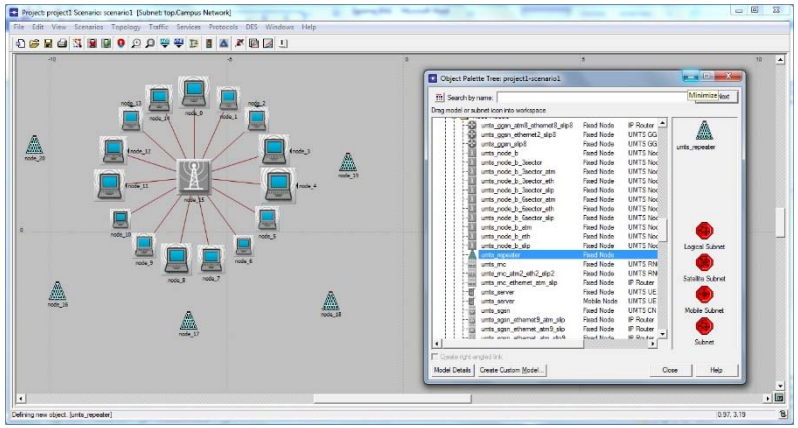
Program za modeliranje i simulacije u željezničkom prometu **RailSys**
Rail Management Consultants GmbH (RMCon), Hannover, Deutschland

Information and communication systems, networks and services forensic and optimisation

Komutacijski čvor **ERICSSON BP 50**

Sustav za cjelovitu forenzičnu analizu
Cellebrite-UFED-Touch

CISCO aktivna mrežna oprema



OPNET Wireless Module

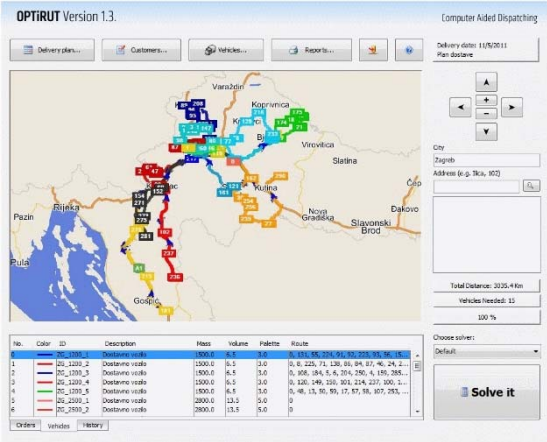
Intelligent transport system technologies

Komplet za robotiku **Mindstorms LEGO** Group, Billund, Denmark

Sučelje za komunikaciju čovjeka s računalom korištenjem električnih aktivnosti mozga **EPOC Emotiv Systems**, San Francisco, California, USA

Komplet mikrokontrolera s osjetilima **Arduino**, China

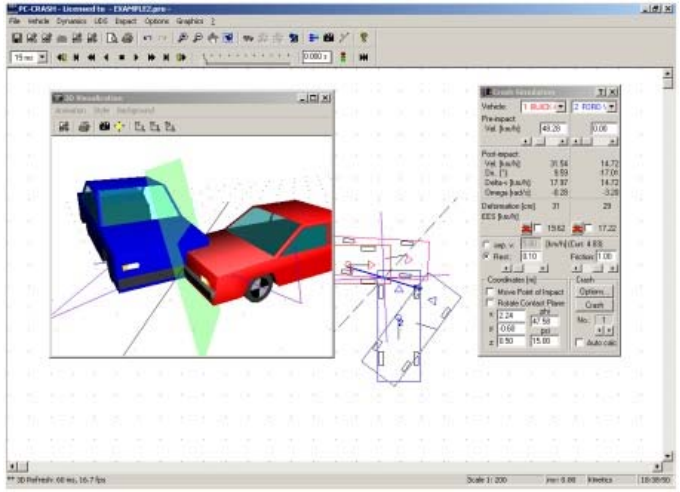
Uređaj za praćenje pokreta **Kinect Microsoft**, Redmond, Washington, USA



Aplikacija za optimizaciju usmjeravanja dostavnih vozila, Fakultet prometnih znanosti

Sustav za vizualizaciju prividnog svijeta **Oculus Rift DK2**

Techical crash analysis (crash test)



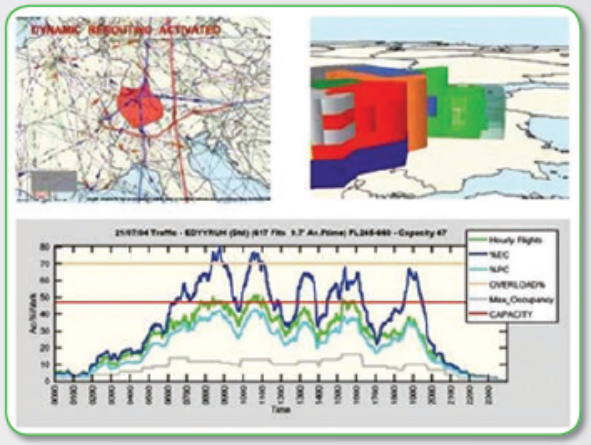
Traffic signalisation inspection

Measuring vehicle with road markings retroreflection detection and analysis

Air traffic simulation and airport system design

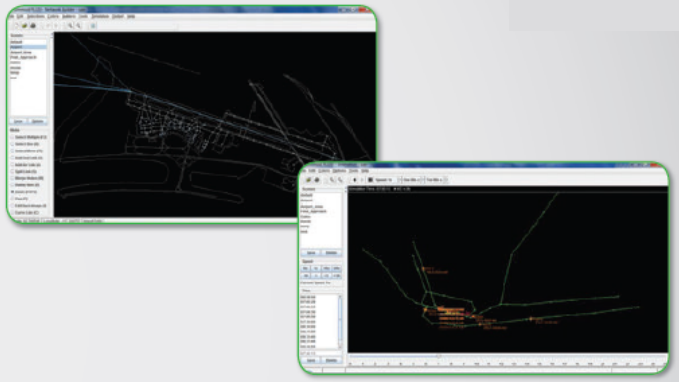
Naziv opreme / Equipment name
Program za modeliranje i simulaciju zračnog prostora
System for traffic Assignment and Analysis at a Macroscopic level (SAAM)

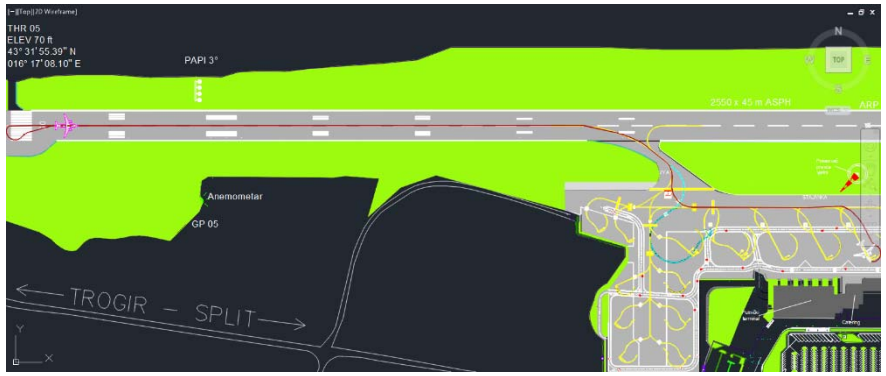
Proizvođač / Manufacturer
EUROCONTROL, Brussels, Belgium



Naziv opreme / Equipment name
Program za planiranje aerodromskog sustava
SIMMOD PLUS
Airport and Airspace Simulation Model
SIMMOD PLUS

Proizvođač / Manufacturer
ATAC Corporation, Santa Clara, California, USA





Pathplanner Airside

Flight and flight control simulator

Simulator letenja za rad višečlane posade, jednomotorni i višemotorni zrakoplov i turbo-prop zrakoplov
Elite FNTP II S923

Faculty expertise

- Planning, analysis, design, modeling, optimisation and implementation of systems and processes, feasibility studies preparation, cost-benefit analysis, project management and knowledge dissemination
- Smart, safe, green, efficient transport and traffic
  - road, urban, railway, water, information and communication, postal, air, aeronautics, air traffic control, intelligent transport systems, logistics
- Undergraduade, graduade and postgraduade (doctoral) education, lifelong learning

DECISION MAKING IN TRANSPORT

DECISION MAKING IN TRANSPORT

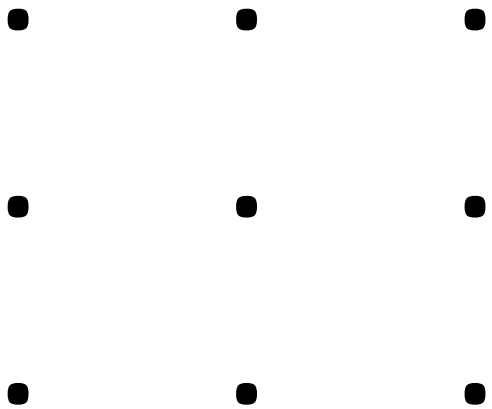
- **Decision making is based on the results of evaluation of the proposed alternative solutions of the project**
- Decision making – transport knowledge, creative thinking

- Creative people are driven by a feeling that something new and different needs to be done, and are passionate about transforming inner vision into external reality. (Thomas L. Saaty)
- In practicing creativity we need to be big in heart, generous in spirit, and both imaginative and logical in mind.
- None of us is perfect, but there is no harm in trying.

DECISION MAKING IN TRANSPORT

- Creative thinking – numerous exercise examples
- Exercise 1:

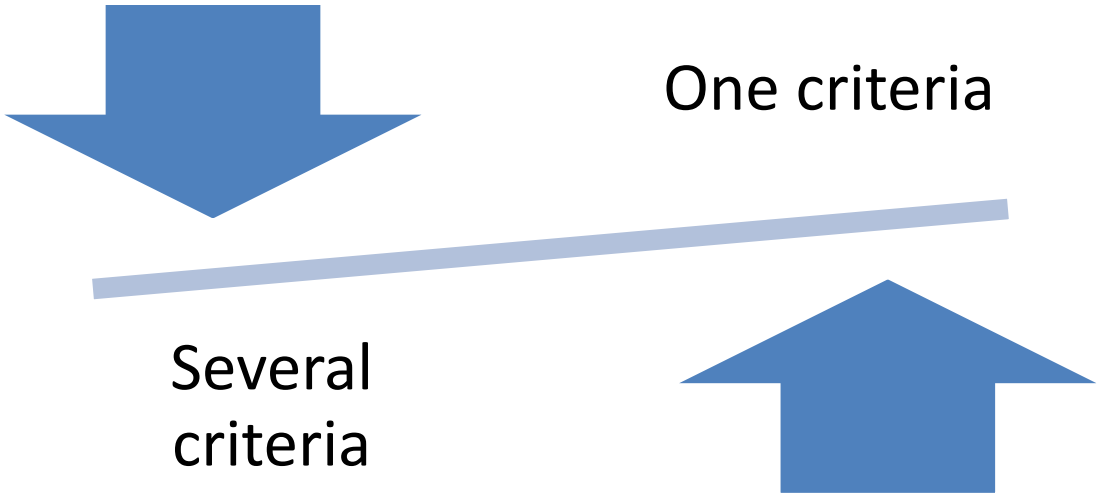
  Connect the following dots, using four straight lines. Do not lift your pencil from the page. This is a calssic example of creativity.



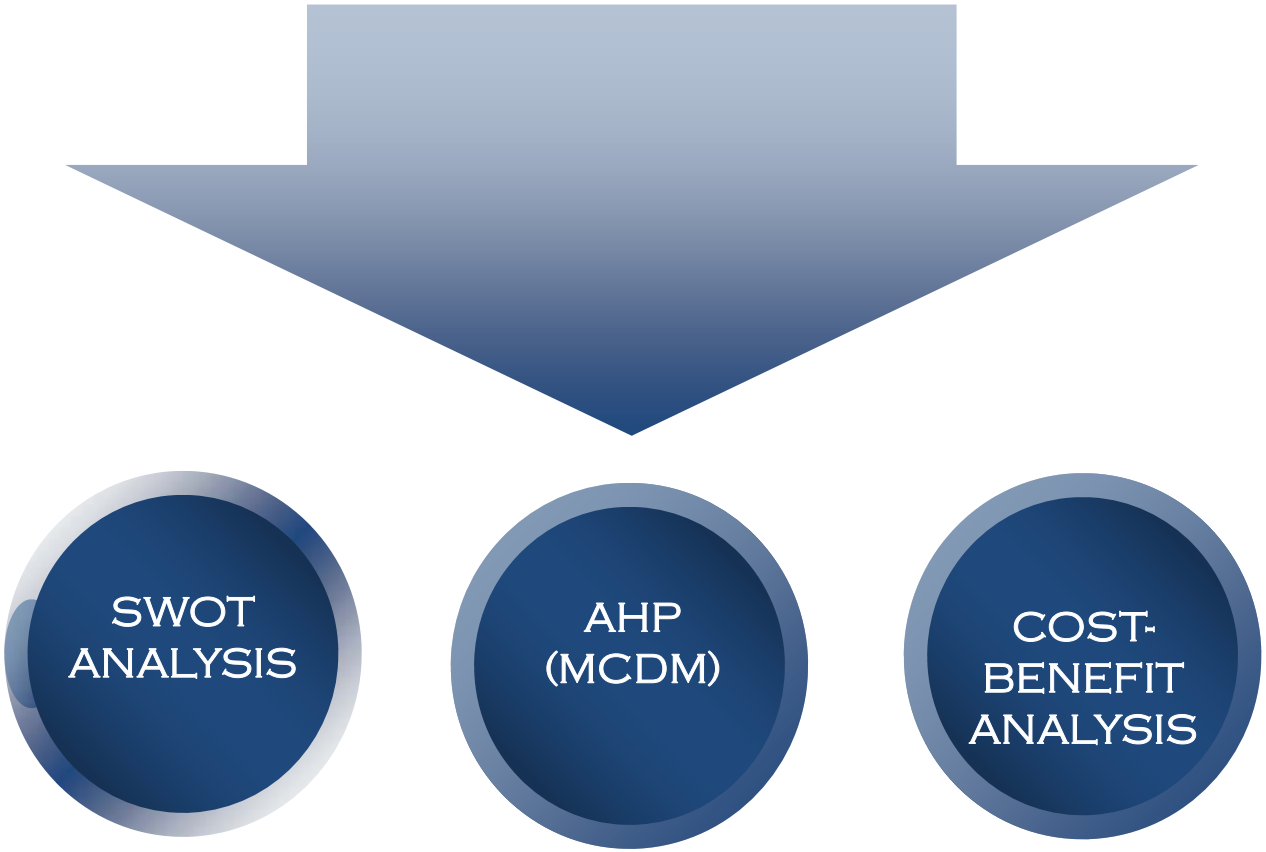
METHODS WTH NO SCIENTIFIC BACKGROUND

- **The method of perseverance:** habit or inertia supports attitude, belief in a claim
- **Method of authority**: a reference to the authority of a person regardless of his own opinion, or the result of research
- **The method of intuition**: trying to be guaranteed for a belief which is based on decision maker attitudes, and attitudes that are "obviously true".

METHODS FOR PROJECT EVALUATION



SELECTED METHODS



SWOT ANALYSIS

Strengths
Weaknesses
Opportunities
Threats

Main characteristics:

- an advanced method for analyzing the selected strategies and situations,
- rrepresents a comprehensive description of the characteristics of the object of analysis and as such it can be part of analytical decision-making,
- it is used to analyze the factors that determine the strength of the object of analysis, its weaknesses, unused opportunities and possible threats, i.e. dangers, and their critical analysis gives the basis for developing a strategy,
- the answers obtained by the SWOT analysis should be used in the next phase to make important strategic decisions, define the mission and vision, future objectives, and the strategy which will all help in realizing the set objectives,
- simple way of communicating and is an excellent choice for organize information from studies or surveys
- the data are organized in the so-called SWOT matrix.

THE BASIC SWOT MATRIX

Internal factors / External factors	STRENGTHS (S)	WEAKNESSES (W)
OPPORTUNITIES (O)		
THREATS (T)		

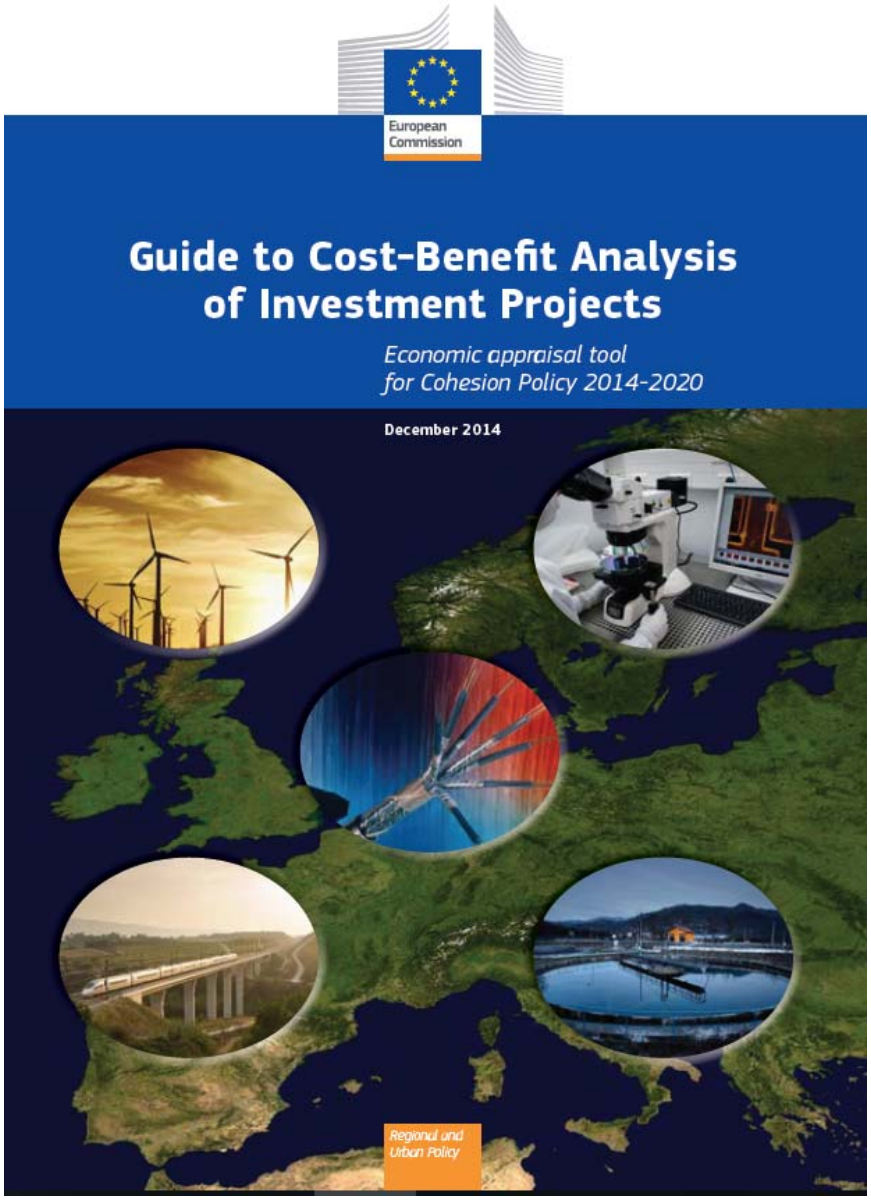
STRATEGIES - SWOT MATRIX

Internal factors / External factors	**STRENGTHS** **(S)**	**WEAKNESSES** **(W)**
OPPORTUNITIES **(O)**	**S – O** (Maxi-Maxi strategy) Using a strength to maximise an opportunity	**W – O** (Mini-Maxi strategy) Improving capability to maximise an opportunity
THREATS **(T)**	**S – T** (Maxi-Mini strategy) Minimising a threat with a strength	**W – T** (Mini-Mini strategy) Minimising weaknesses and threats at same time

COST BENEFIT ANALYSIS

- The cost-benefit analysis is a methodological procedure for making rational investment decisions and represents a procedure of determining the social costs and social benefits in the public sector.
- The function of objective is usually the growth of social product, national revenue or raising of quality of the public good.
- The focus is on maximizing social benefits. It is used to methodologically examine the costs, benefits and risks of all the options, and to determine the cost-most efficient methods of achieving the set goals.
- The basic characteristic of this method is to determine, harmonise and evaluate all the advantages and drawbacks of a project, in order to use this basis to determine the outcome of the investment project, which allows making of the decision about the realization of the project.
- The relation between the costs and benefits should be the criterion of making the decision about the economic justification of the project.
- The cost-efficiency of several years of investments, i.e. long-term investments, is evaluated by means of several indicators which are usually:
  - B/C ratio,
  - internal rate of return (IRR),
  - net present value (NPV),
  - relative net present value,
  - payback period.

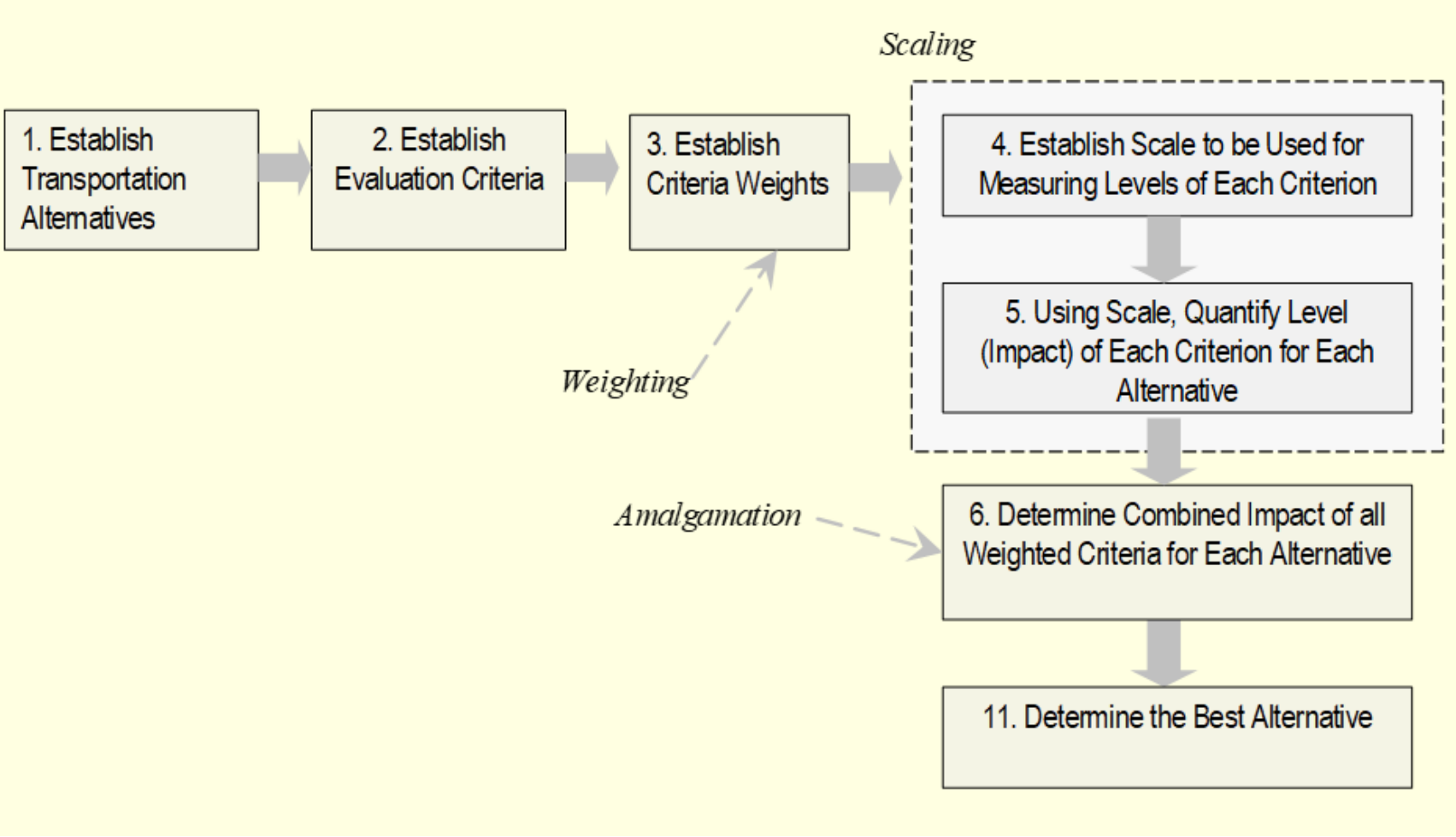
Cost benefit analysis means simply that costs and benefits will be summarized and weighed against each other.



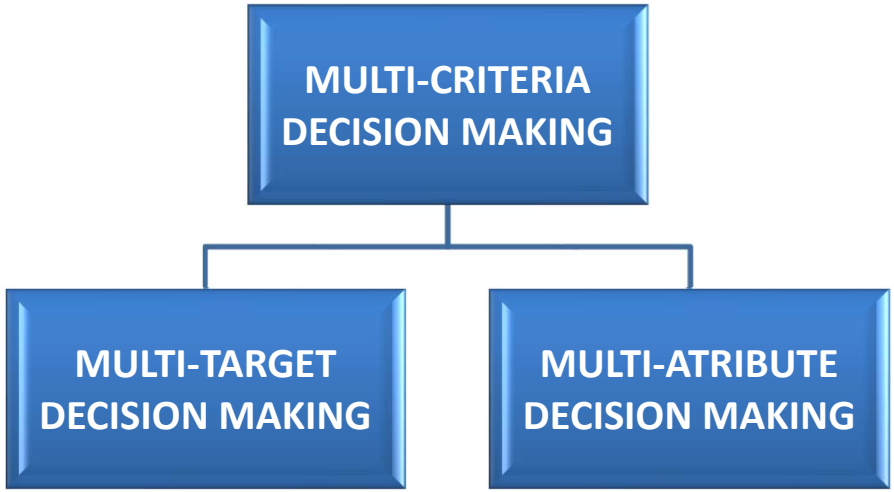
https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

MULTI-CRITERIA DECISION MAKING

Typical steps in Multi-Criteria Decision Making



MULTI-CRITERIA DECISION MAKING



The Analytic Hierarchy Process (AHP method)

MULTI-TARGET DECISION MAKING – methods

- multicriteria simplex method
- Zionts–Walleniusova method
- method STEM
- Etc.

MULTI-ATRIBUTE DECISION MAKING – methods

- method of domination
- ELEKTRE I–IV
- PROMETHEE I–IV
- AHP
- VIKOR
- etc.

Main characteristic of AHP method)

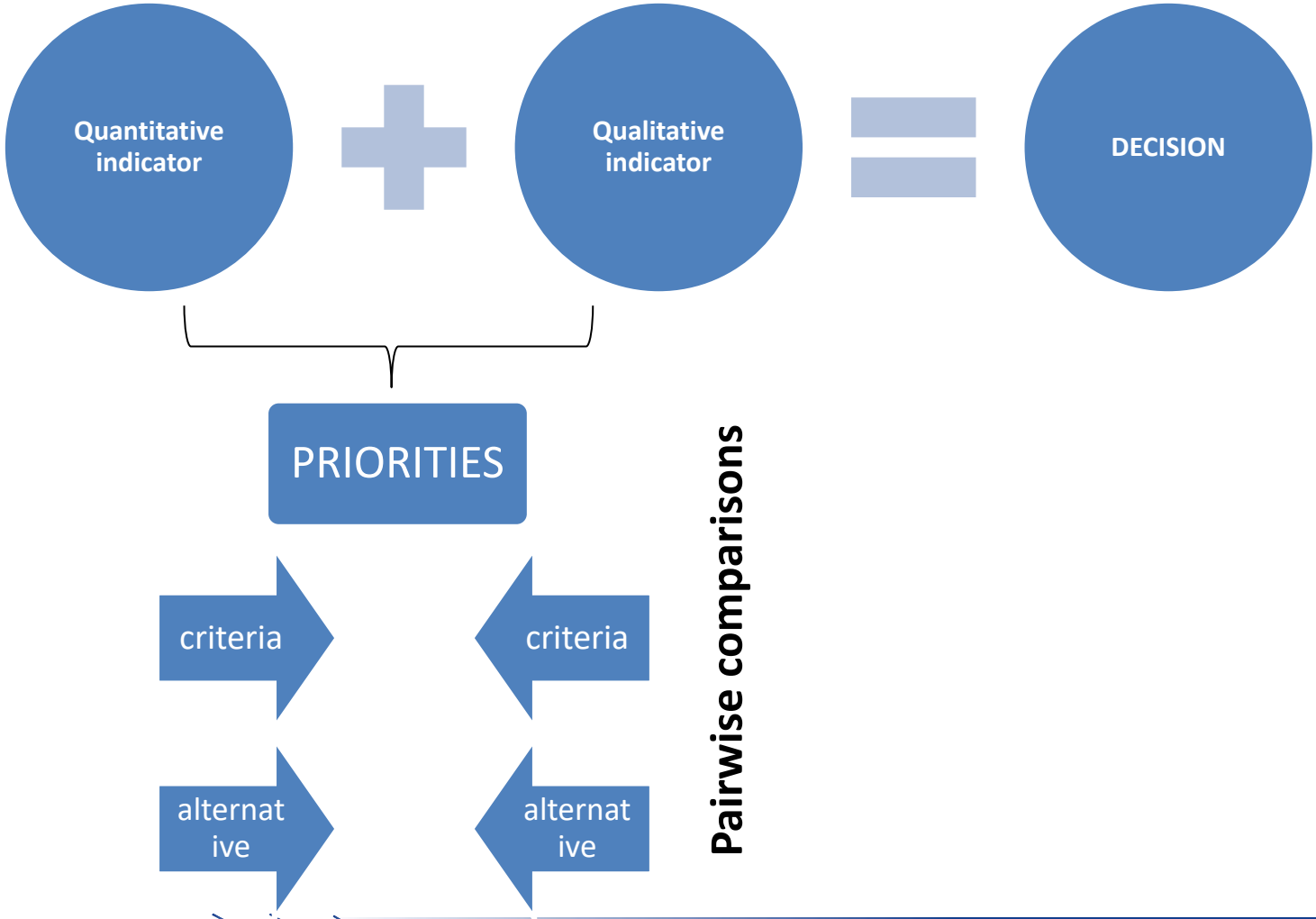
- Method for multi-criteria decision making.
- Founded and developed by Thomas L. Saaty in 1970.
- It allows the use of qualitative, as well as quantitative criteria in evaluation.
- It is a popular and widely used method applied in variety of decisions and planning projects.
- Best known and widely used Multi Criteria Analysis (MCA) approach
- Real world decision problems.
- Wide range of applications to solve complex decision-making problems in transportation.
- AHP is implemented in the software *Expert Choice* .

Founder of Analytic Hierarchy Process

Name	Thomas L. Saaty
Born	Mosul, Iraq
DOB	July 18, 1926 - August 14, 2017 Pittsburgh
Degrees	PhD, Mathematics, Yale University, 1953 Post-graduate study, University of Paris, 1952-53 MA, Mathematics, Yale University, 1951 MS, Physics, Catholic University of America, 1949 BA , Columbia Union College, 1948
Hobbies	Collecting jokes and maintaining his world-wide joke list, caring for his garden (coffee-grounds are his latest find as the best fertilizer ever), and collecting new stories and ideas about the creative process.

Thomas L. Saaty is the creator of the Analytic Hierarchy Process (AHP), a method for measuring intangibles by making judgments on pairs of elements with respect to a property they have in common. In multi-criteria problems these measures are combined using a hierarchical or network structure to choose the best of several alternatives. By using the AHP, multi-criteria performance measures can be developed to measure the potential benefits of projects and initiatives so that resources can be deployed where they are most likely to achieve the greatest return. The strength of Dr. Saaty's method is its ability to measure intangibles. It brings mathematical precision and science to answer the murky, complex, multi-dimensional decisions that occur during constantly changing conditions. In essence, his method quantifies the value of different choices, and creates a framework in which people can prioritize the factors in a decision without becoming overwhelmed by the tradeoffs.

MAIN CHARACTERISTIC - AHP



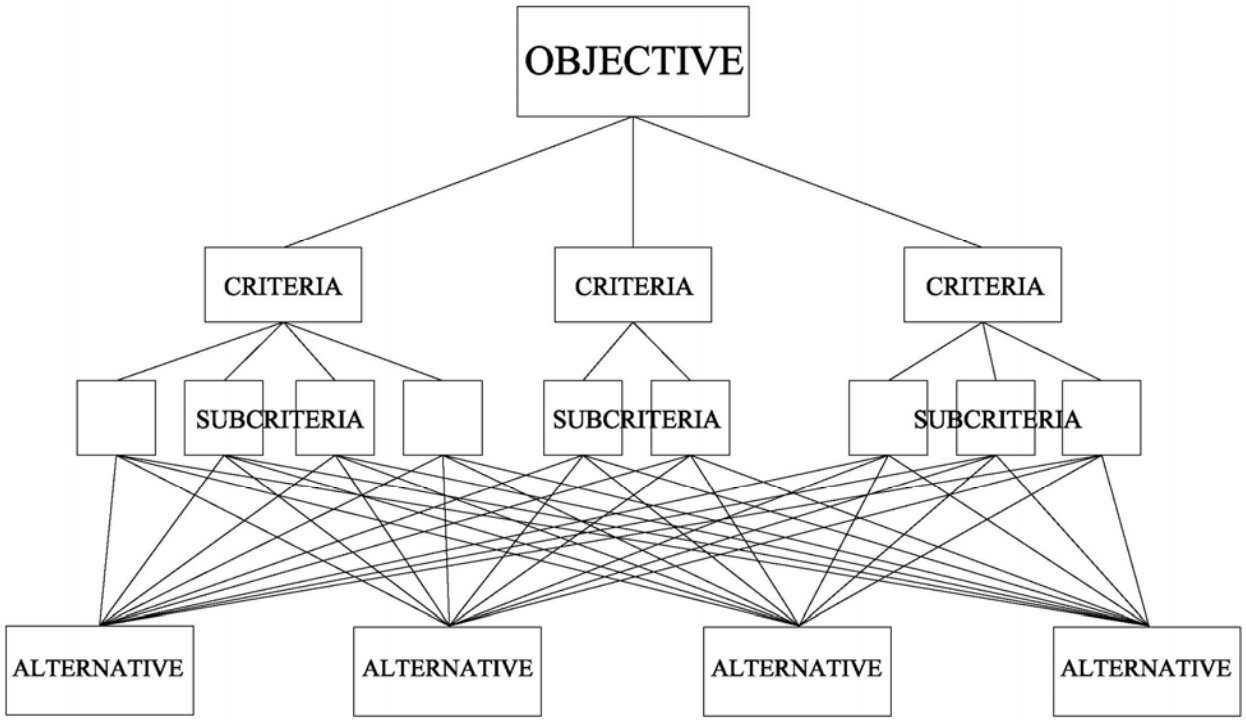
Key steps of the AHP

Three key steps of the AHP:

1. **Decomposing the problem into a hierarchy** – one overall goal on the top level, several decision alternatives on the bottom level and several criteria contributing to the goal
2. **Comparing pairs** of alternatives with respect to each criterion *and* pairs of criteria with respect to the achievement of the overall goal
3. **Synthesising judgements** and obtaining priority rankings of the alternatives with respect to each criterion and the overall priority ranking for the problem

Key steps of the AHP

Decomposing the problem into a hierarchy – one overall goal on the top level, several decision alternatives on the bottom level and several criteria contributing to the goal



Key steps of the AHP

Comparing pairs of alternatives with respect to each criterion *and* pairs of criteria with respect to the achievement of the overall goal.

Synthesising judgements and obtaining priority rankings of the alternatives with respect to each criterion and the overall priority ranking for the problem

Pairwise comparisons:

to	A1	A2	A3
Alternative 1 (A1)	a_{11}	a_{12}	a_{13}
Alternative 2 (A2)	a_{21}	a_{22}	a_{32}
Alternative 3 (A3)	a_{31}	a_{32}	a_{33}

→ Pairwise Comparison Matrix $A = (a_{ij})$

For all i and j it is necessary that:

(a) $a_{ii} = 1$ a comparison of criterion i with itself: *equally important*

(b) $a_{ij} = 1/ a_{ji}$ a_{ji} are reverse comparisons and must be the reciprocals of a_{ij}

SAATY SCALE

Type of Scales:

- ✓ **Nominal** - used for labeling variables, without any quantitative value; could simply be called "labels"
- ✓ **Ordinal** - order of the values is what's important and significant
- ✓ **Interval** - numeric scales in which we know not only the order, but also the exact differences between the values
- ✓ **Ratio** – tell us exact value between units

Intensity of Importance	Definition	Explanation
1	**Equal** Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	**Moderate** importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	**Strong** importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	**Very strong** or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	**Extreme** importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Comparison Matrix

Given: Three Vienna-Trams of different sizes.

Tram A

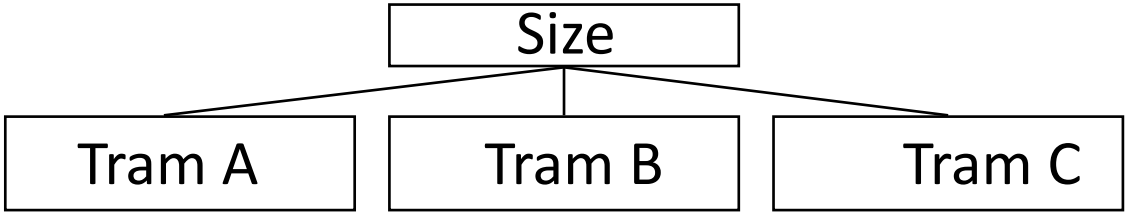
Tram B

Tram C

We Assess Their Relative Sizes By Forming Ratios

Size Comparison	Tram A	Tram B	Tram C
Tram A	S_1/S_1	S_1/S_2	S_1/S_3
Tram B	S_2 / S_1	S_2 / S_2	S_2 / S_3
Tram C	S_3 / S_1	S_3 / S_2	S_3 / S_3

Pairwise Comparisons



Size Comparison	Tram A	Tram B	Tram C	Resulting Priority Eigenvector	Relative Size of Tram
 Tram A	1	2	6	6/10	A
 Tram B	1/2	1	3	3/10	B
 Tram C	1/6	1/3	1	1/10	C

When the judgments are consistent, as they are here, any normalized column gives the priorities.

Estimating Consistency

- ***Consistency Index*** is defined as follows:

$$CI = (\lambda_{max} - n) / (n - 1)$$

(Deviation λ_{max} from *n* is a measure of inconsistency.)

- λ_{max}=maximal eigenvalue

- ***Random Index*** (***RI***) is the average consistency index of 100 randomly generated (inconsistent) pairwise comparisons matrices. These values have been tabulated for different

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

Estimating Consistency

- ***Consistency Ratio*** is the ratio of the consistency index to the corresponding random index:

$$CR = CI / RI(n)$$

- *CR* of **less than 0.1** ("10% of average inconsistency" of randomly generated pairwise comparisons matrices) is usually **acceptable**.
- If *CR* is not acceptable, judgements should be revised. Otherwise the decision will not be adequate.

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives			
	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Having a comparison matrix, now we would like to compute priority vector, which is the normalized Eigen vector of the matrix.

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3
Tram 1	0,60	0,60	0,60
Tram 2	0,30	0,30	0,30
Tram 3	0,10	0,10	0,10
Σ	1,00	1,00	1,00

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3			
Tram 1	0,60	0,60	0,60	w_1	**0,60**	6/10
Tram 2	0,30	0,30	0,30	w_2	**0,30**	3/10
Tram 3	0,10	0,10	0,10	w_3	**0,10**	1/10
Σ	1,00	1,00	1,00		**1,00000**	

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

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Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3			
Tram 1	0,60	0,60	0,60	w_1	**0,60**	6/10
Tram 2	0,30	0,30	0,30	w_2	**0,30**	3/10
Tram 3	0,10	0,10	0,10	w_3	**0,10**	1/10
Σ	1,00	1,00	1,00		**1,00000**	

Step 3: Calculation of consistency index (CI)

a)	Calculate the weighted rating for each row in matrix 1
b_1	1,80
b_2	0,90
b_3	0,30

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3			
Tram 1	0,60	0,60	0,60	w_1	**0,60**	6/10
Tram 2	0,30	0,30	0,30	w_2	**0,30**	3/10
Tram 3	0,10	0,10	0,10	w_3	**0,10**	1/10
Σ	1,00	1,00	1,00		**1,00000**	

Step 3: Calculation of consistency index (CI)

a)	Calculate the weighted rating for each row in matrix 1
b_1	1,80
b_2	0,90
b_3	0,30
b)	Approximation of Lambda(max)
λ_1	3,00
λ_2	3,00
λ_3	3,00
$\lambda max =$	3,00

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3			
Tram 1	0,60	0,60	0,60	w_1	**0,60**	6/10
Tram 2	0,30	0,30	0,30	w_2	**0,30**	3/10
Tram 3	0,10	0,10	0,10	w_3	**0,10**	1/10
Σ	1,00	1,00	1,00		**1,00000**	

Step 3: Calculation of consistency index (CI)

a)	Calculate the weighted rating for each row in matrix 1	
b_1	1,80	
b_2	0,90	
b_3	0,30	
b)	Approximation of Lambda(max)	
λ_1	3,00	
λ_2	3,00	
λ_3	3,00	
$\lambda max =$	3,00	
c)	Calculate consistency index (CI)	CI=(λmax -n)/(n-1)
n=	3	n is the number of elements that we compared in matrix 1
$\lambda max =$	3,00	
CI=	0,00	

Estimating Consistency – example 3 trams

Step 1: Pairwise comparison for all alternatives

	Tram 1	Tram 2	Tram 3
Tram 1	1	2	6
Tram 2	1/2	1	3
Tram 3	1/6	1/3	1
Σ	1,67	3,33	10,00

Step 2: Calculation of priority (i.e., normalized eigenvector)

	Tram 1	Tram 2	Tram 3			
Tram 1	0,60	0,60	0,60	w_1	**0,60**	6/10
Tram 2	0,30	0,30	0,30	w_2	**0,30**	3/10
Tram 3	0,10	0,10	0,10	w_3	**0,10**	1/10
Σ	1,00	1,00	1,00		**1,00000**	

Step 3: Calculation of consistency index (CI)

a)	Calculate the weighted rating for each row in matrix 1		
b_1	1,80		
b_2	0,90		
b_3	0,30		
b)	Approximation of Lambda(max)		
λ_1	3,00		
λ_2	3,00		
λ_3	3,00		
λmax =	3,00		
c)	Calculate consistency index (CI)	CI=(λmax -n)/(n-1)	
n=	3	n is the number of elements that we compared in matrix 1	
λmax =	3,00		
CI=	0,00		

Step 4: Calculation of consistency ratio (CR) CR=CI/RI

CI=	0		
RI=	0,52		
CR=	0,000	< 0,1	OK

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University of Zagreb
Faculty of Transport and Traffic Sciences

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
Tram 3	1/3	1/3	1	2	3
Tram 4	1/4	1/4	1/2	1	2
Tram 5	1/5	1/5	1/3	1/2	1

Estimating Consistency – example 5 trams

Estimating Consistency – example 5 trams

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
Tram 3	1/3	1/3	1	2	3
Tram 4	1/4	1/4	1/2	1	2
Tram 5	1/5	1/5	1/3	1/2	1

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	5,00000	3,40000	10,26667	17,30000	28,00000
Tram 2	13,00000	5,00000	24,66667	36,50000	52,00000
Tram 3	3,43333	1,83333	5,00000	8,16667	13,33333
Tram 4	2,31667	1,11667	3,16667	5,00000	8,00000
Tram 5	1,63611	0,67611	2,11667	3,26667	5,00000
Σ	25,39	12,03	45,22	70,23	106,33

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
Tram 3	1/3	1/3	1	2	3
Tram 4	1/4	1/4	1/2	1	2
Tram 5	1/5	1/5	1/3	1/2	1

Estimating Consistency – example 5 trams

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
Tram 1	5,00000	3,40000	10,26667	17,30000	28,00000	63,9667	w_1	0,2468	24,68%
Tram 2	13,00000	5,00000	24,66667	36,50000	52,00000	131,1667	w_2	0,5061	50,61%
Tram 3	3,43333	1,83333	5,00000	8,16667	13,33333	31,7667	w_3	0,1226	12,26%
Tram 4	2,31667	1,11667	3,16667	5,00000	8,00000	19,6000	w_4	0,0756	7,56%
Tram 5	1,63611	0,67611	2,11667	3,26667	5,00000	12,6956	w_5	0,0490	4,90%
Σ	25,39	12,03	45,22	70,23	106,33	259,20		**1,00000**	100,00%

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
Tram 3	1/3	1/3	1	2	3
Tram 4	1/4	1/4	1/2	1	2
Tram 5	1/5	1/5	1/3	1/2	1

Estimating Consistency – example 5 trams

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
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Σ	25,39	12,03	45,22	70,23	106,33	259,20		**1,00000**	100,00%

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
Tram 1	190,33833	91,07167	300,58333	472,41111	732,08889	1.786,4933	w_1	0,2426	24,26%
Tram 2	384,32500	190,33833	605,78333	961,21111	1.504,88889	3.646,5467	w_2	0,4952	49,52%
Tram 3	98,90093	48,14093	159,55444	251,53556	390,13333	948,2652	w_3	0,1288	12,88%
Tram 4	61,64444	30,25778	99,92889	157,83111	245,15556	594,8178	w_4	0,0808	8,08%
Tram 5	39,98556	19,85222	64,98593	102,93556	160,32444	388,0837	w_5	0,0527	5,27%
Σ	775,19	379,66	1.230,84	1.945,92	3.032,59	7.364,21		**1,00000**	100,00%

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
Tram 3	1/3	1/3	1	2	3
Tram 4	1/4	1/4	1/2	1	2
Tram 5	1/5	1/5	1/3	1/2	1

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
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Tram 2	13,00000	5,00000	24,66667	36,50000	52,00000	131,1667	w_2	0,5061	50,61%
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Σ	775,19	379,66	1.230,84	1.945,92	3.032,59	7.364,21		**1,00000**	100,00%

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
Tram 1	159.352,27	77.966,92	255.124,63	402.983,58	626.850,85	1.522.278,25	w_1	0,2428	24,28%
Tram 2	325.643,24	159.352,27	521.330,26	823.506,36	1.281.051,10	3.110.883,22	w_2	0,4961	49,61%
Tram 3	84.211,95	41.207,16	134.837,41	212.987,83	331.311,77	804.556,11	w_3	0,1283	12,83%
Tram 4	52.777,27	25.826,45	84.506,60	133.487,18	207.647,00	504.244,50	w_4	0,0804	8,04%
Tram 5	34.423,72	16.846,07	55.119,00	87.067,59	135.440,70	328.897,08	w_5	0,0524	5,24%
Σ	656.408,45	321.198,86	1.050.917,89	1.660.032,55	2.582.301,41	6.270.859,16		**1,00000**	100,00%

Step 1: Pairwise comparison for all criteria

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5
Tram 1	1	1/5	3	4	5
Tram 2	5	1	3	4	5
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Tram 4	1/4	1/4	1/2	1	2
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Σ	775,19	379,66	1.230,84	1.945,92	3.032,59	7.364,21		**1,00000**	100,00%

	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
Tram 1	159.352,27	77.966,92	255.124,63	402.983,58	626.850,85	1.522.278,25	w_1	0,2428	24,28%
Tram 2	325.643,24	159.352,27	521.330,26	823.506,36	1.281.051,10	3.110.883,22	w_2	0,4961	49,61%
Tram 3	84.211,95	41.207,16	134.837,41	212.987,83	331.311,77	804.556,11	w_3	0,1283	12,83%
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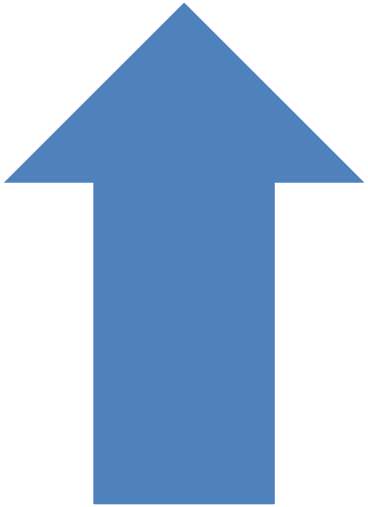
Σ	656.408,45	321.198,86	1.050.917,89	1.660.032,55	2.582.301,41	6.270.859,16		**1,00000**	100,00%

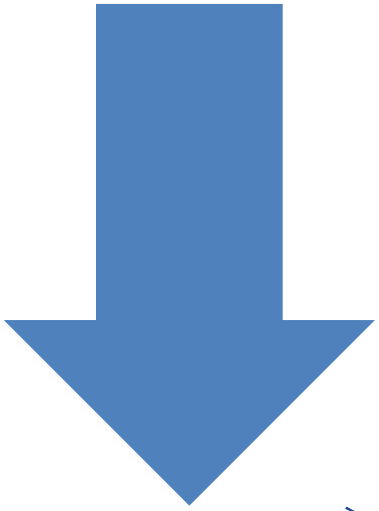
	Tram 1	Tram 2	Tram 3	Tram 4	Tram 5				
Tram 1	115.114.004.126,22	56.328.979.644,69	184.307.708.408,49	291.132.580.136,59	452.874.953.692,11	1.099.758.226.008,10	w_1	0,2428	24,28%
Tram 2	235.247.185.507,10	115.114.004.126,22	376.651.562.518,46	594.959.061.847,92	925.496.066.979,74	2.247.467.880.979,43	w_2	0,4961	49,61%
Tram 3	60.839.019.411,76	29.770.486.426,57	97.408.654.590,69	153.866.776.411,80	239.349.403.130,70	581.234.339.971,52	w_3	0,1283	12,83%
Tram 4	38.129.924.240,53	18.658.196.731,77	61.049.383.365,28	96.433.647.116,20	150.008.575.106,00	364.279.726.559,79	w_4	0,0804	8,04%
Tram 5	24.870.548.900,00	12.169.958.473,72	39.819.949.908,30	62.899.619.735,38	97.844.296.228,23	237.604.373.245,63	w_5	0,0524	5,24%
Σ	474.200.682.185,61	232.041.625.402,97	759.237.258.791,22	1.199.291.685.247,89	1.865.573.295.136,78	4.530.344.546.764,47		**1,00000**	100,00%

AHP: Pros vs. Cons



Pros

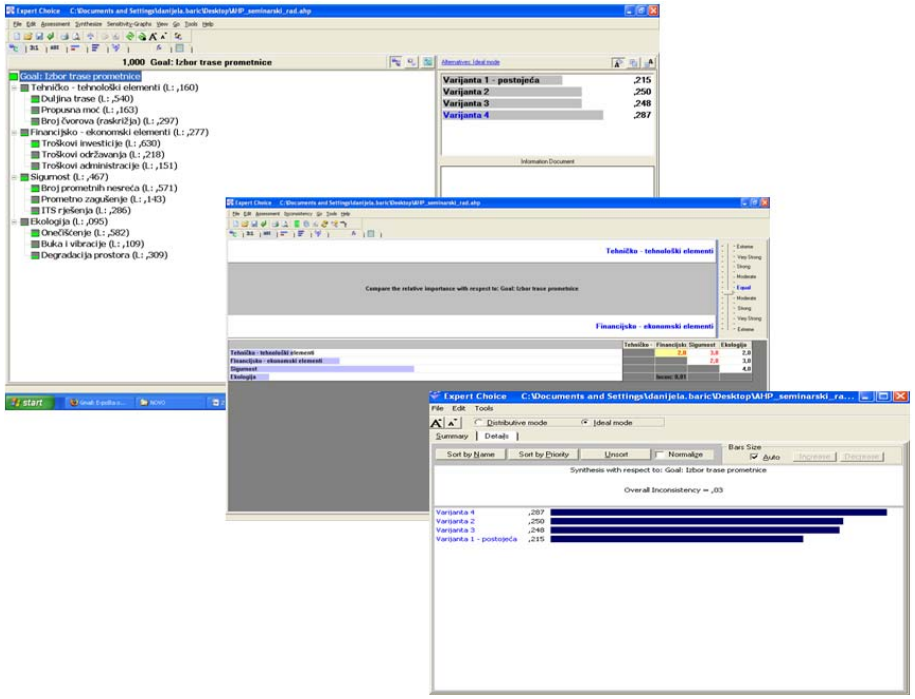
- simply to use
- allows multi criteria decision making
- it is applicable when it is difficult to formulate criteria evaluations, i.e., it allows qualitative evaluation as well as quantitative evaluation
- it is applicable for group decision making environments
- consistency in evaluation



Cons

- possibilities of subjective evaluation
- ddifficult to use when the number of criteria or alternatives is high, i.e., more than 7.
- conflict between decision makers
- decision makers capacity

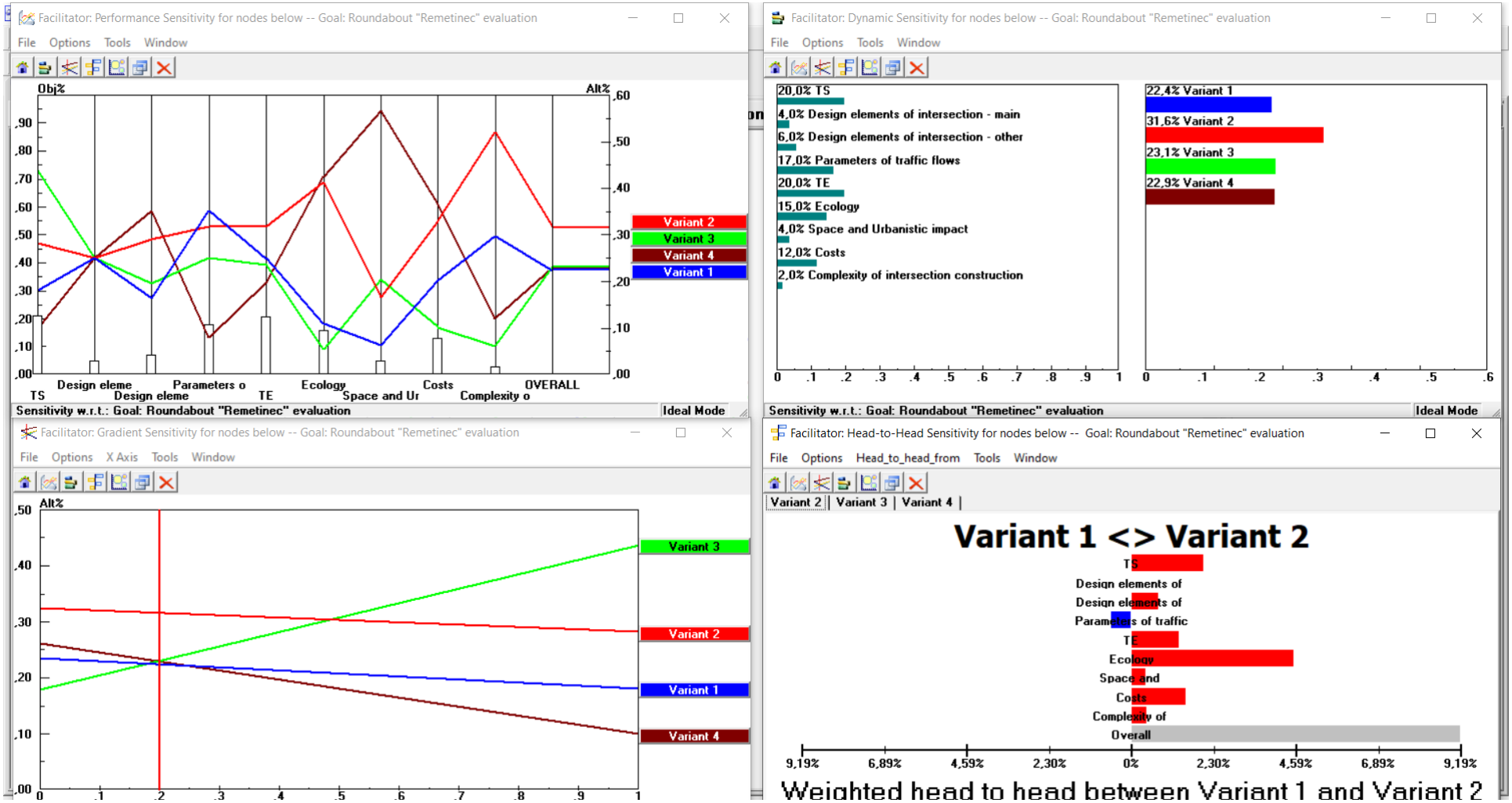
AHP → EXPERT CHOICE



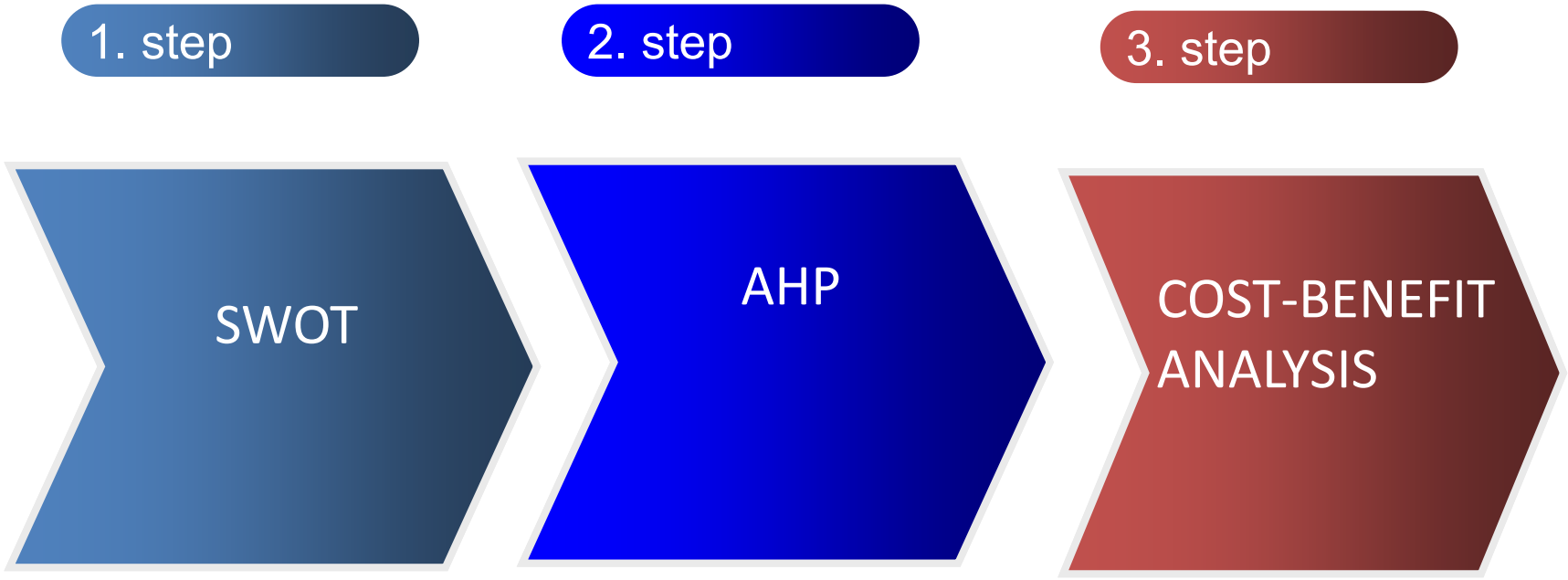
- Software package for making multi criteria decision making – AHP method
- EC helps you organize the various elements of a problem into a hierarchy.
- EC guides you in judging, via pair-wise comparisons, the relative importance of the objectives and the preference for the alternatives that you have defined.
- EC derives priorities by combining intangible information from decision makers experience and intuition, and tangible information such as data.
- Sensytivity analysis
- 4 graphs
- Survey

AHP: Sensitivity analysis

- The stability of the outcome to changes in the importance of the criteria is determined by testing the best choice against “what-if’ type of change in the priorities of the criteria.
- The sensitivity analysis in Expert Choice varies the weights of the criteria as input data.



Applying a methods



Application of the AHP method
- interesting cases -

An AHP model for Level crossing design in urban area of City of Zagreb

Goal:

Selection of the reconstruction design on the LC Trnava in Zagreb

Sveučilište u Zagrebu
Fakultet prometnih znanosti
University of Zagreb
Faculty of Transport and Traffic Sciences

METHODOLOGY

Analysis of the current condition of LCs

(characteristics of the current traffic network, collection of real data about the size and distribution of the current traffic load, traffic count, survey of LC users, determining the drivers' habits, and their traffic culture, etc.);

Development of simulation of the existing condition in the software tool PTV VISSIM;

Proposal of new variants of reconstruction;

Evaluation of the variants using MCDM and AHP method with the application of the software tools Expert Choice

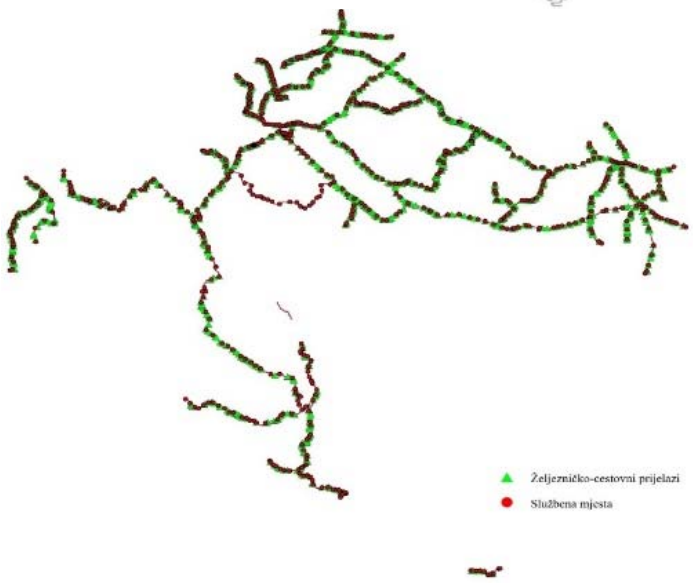
Development of simulation of the optimal variant in software tools PTV VISSIM.

Development of VR application

Testing the application

Education

LCs ON THE CROATIAN RAILWAYS



LEVEL CROSSING (LC)

- places of rail and road intersections
- areas with increased risk of accidents

RAILWAYS NETWORK (2018):

2,605km of railway tracks

1,512 LCs: 37% Active, 63% Passive

70 Pedestrian crossings

DAILY RAIL TRAFFIC:

649 passenger rails

192 cargo rails

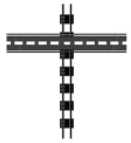
160 km/h max speed

Accidances **30**

5 on active LC
24 on psive LC
1 on pedestrians LC

2 injured on active LC
3 injured on pasive LC

Total fatalities **7**



5 fatalities on active LC
2 fatalitie on pasive LC

6 deads on active LC
2 dead on pasive LC

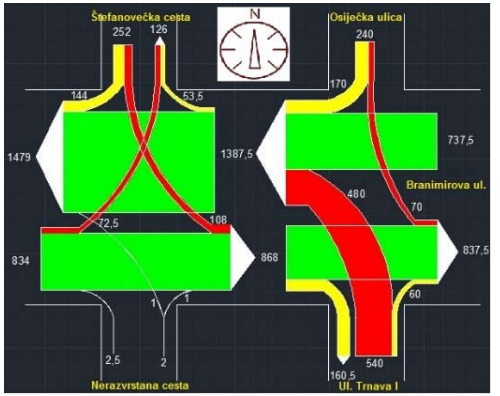
Broken barriers **452**

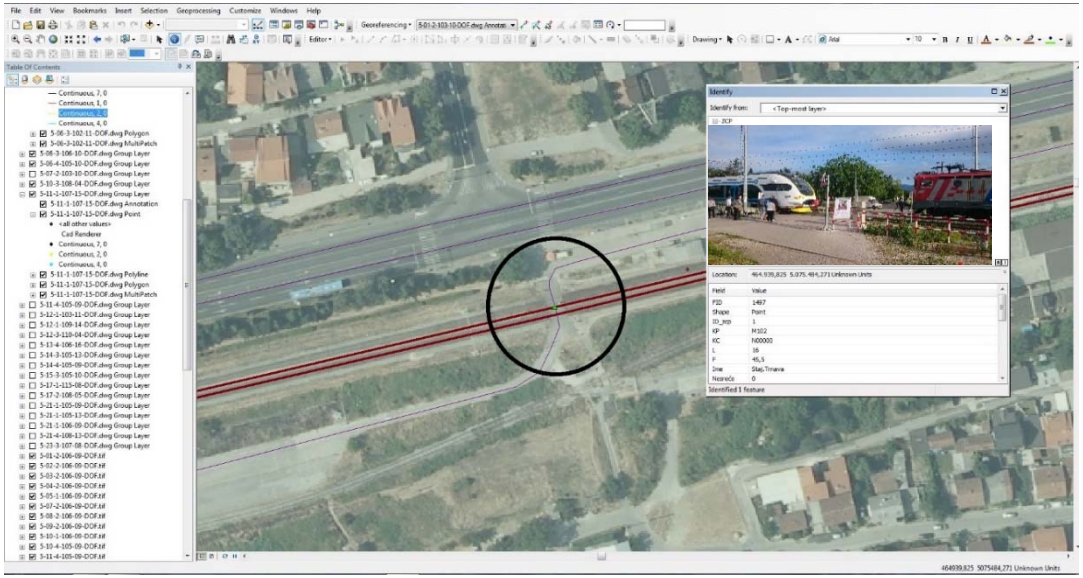
452 damaged or broken barriers

CASE STUDY ZAGREB

CASE STUDY - VR SCENARIO LOCATION - LC TRNAVA

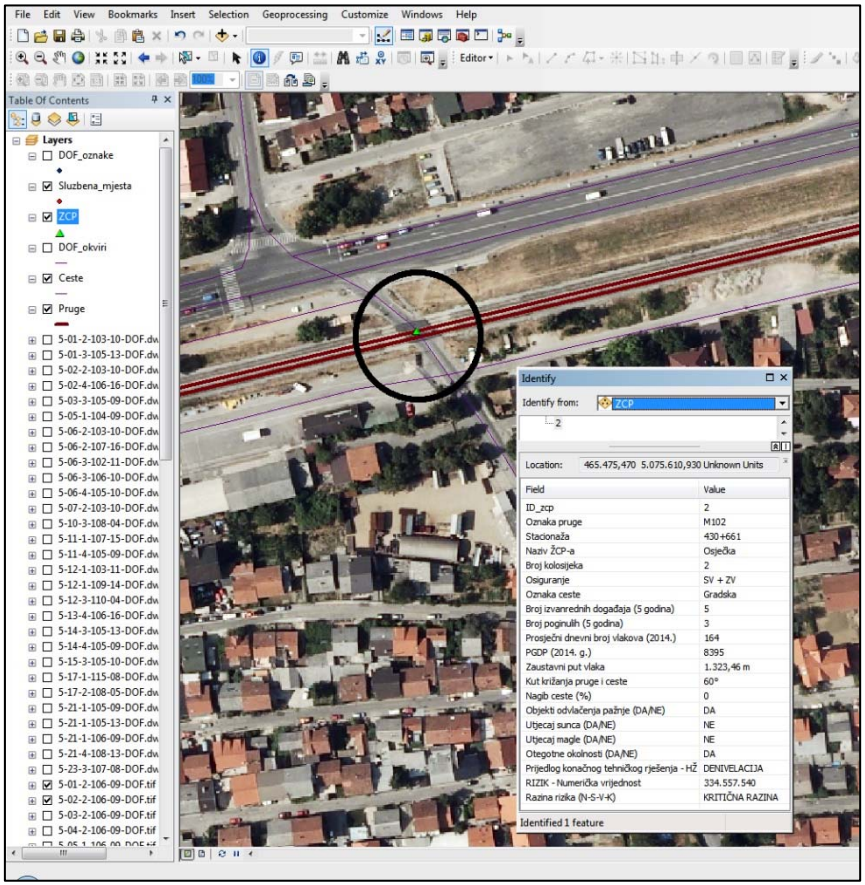
- Level crossing „Trnava” is located on the main international railwy line M102
- Two parallel railway tracks
- Close vicinty of Trnava railway station
- Secured with half-barriers and light&sound system





HOW LC-USERS BEHAVE AT LC?

- 8 fatalities in the last 10 years
- LC-users behaviour - main reason for accidents



LC LOCATIONS IN ZAGREB URBAN AREA

EQUIPMENT

METHODOLOGY FOR COLLECTING DATA

Day	Camera		Researcher		Police officer visible	Survey	Educational poster	HŽ gate keeper visible
	Hidden	Visible	Hidden	Visible				
Monday	✓		✓					✓
Tuesday	✓		✓					✓
Wednesday		✓		✓				✓
Thursday		✓		✓	✓	✓	✓	✓
Friday	✓		✓				✓	✓

SURVEY - LC TRNAVA

- **200** respondents – 55% F i 45% M
- the highest number of respondents belonged to the group of 26-60 years of age (**61%)**
- 84% of respondents use the LC Trnava every day
- **61%** live within 500 m of the LC
- **73%** of respondents do not know how much is the fine for illegal crossing
- **33%** of respondents indicate that the reason for illegal crossing is because they are in a hurry
- **93%** of respondents think that it is necessary to build an underpass (for pedestrians and for vehicles)

Reasons for legal and illegal crossing of the LC:

- **33%** of respondents stated that they are in a hurry
- **13%** of respondents think it is safe to pass because they do not see any train arriving
- **12%** of respondents think that the barrier stays lowered for too long
- **9%** say that they are tired of waiting
- **6%** estimate that it is safe
- Only **29%** of respondents cross the LC in a proper and legal way

SIMULATION – PTV VISSIM

LC Trnava
Queue: 240 m
The longest average waiting of vehicles: 19,8 s
The largest average vehicle delays: 26,06 s
The highest emission of harmful CO gases: 932 PPM
PPM
Fuel consumption: 13 L

LC Osječka - Trnava I
Queue: 143 m
The longest average waiting of vehicles: 69,7 s
The largest average vehicle delays: 80,44 s
The highest emission of harmful CO gases : 1182

Fuel consumption: 17 L

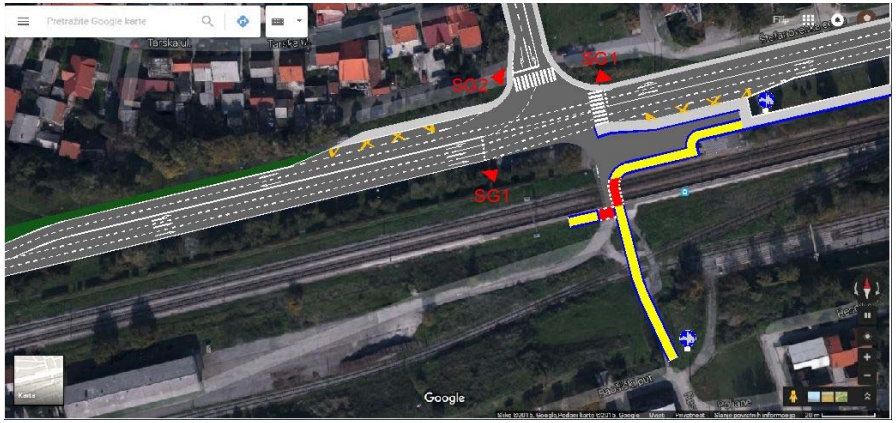
SIMULATION – PTV VISSIM

LC Trnava

- In peek-hour 254 pedestrians and 80 cyclists cross LC
- Queue: 50 LC users
- the average waiting time: 48 s
- the average delay of users: 51 s

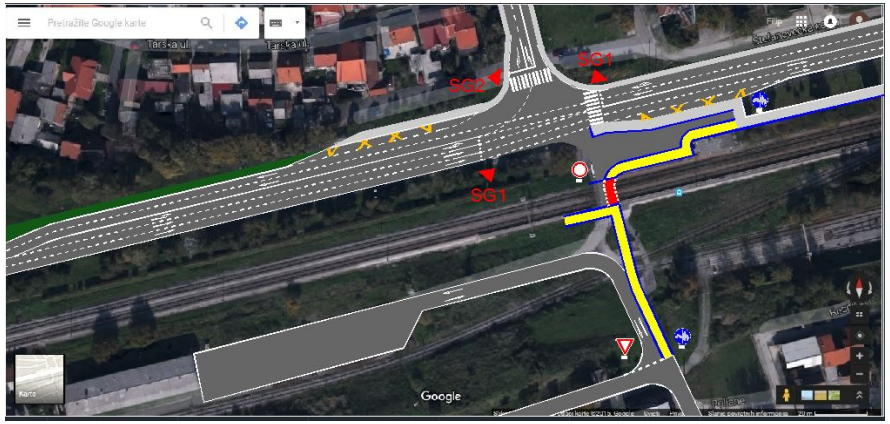
VARIANTS

To improve the level of traffic safety and capacity, four possible variant designs for reconstruction are proposed.



Variant 1

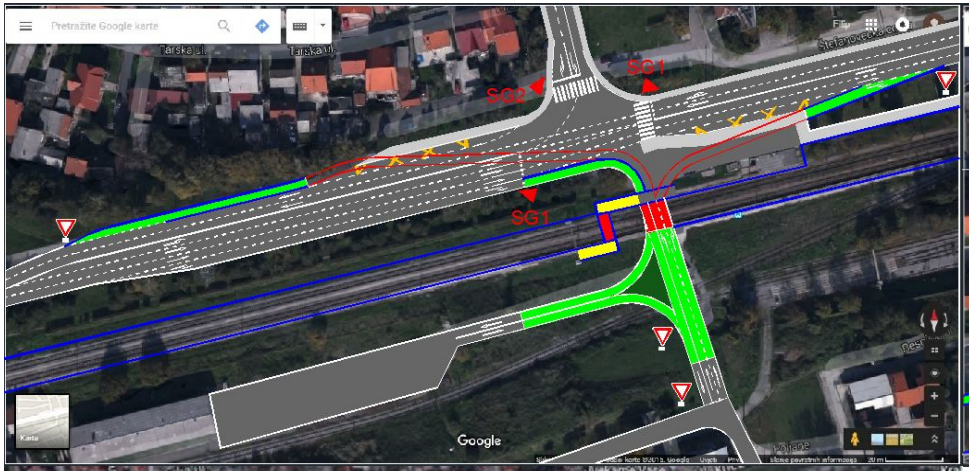
- construction of a pedestrian-cyclist underpass
- construction of an underpass would eliminate the conflict points between the road and rail traffic, i.e. primarily of pedestrians and cyclists and the rail vehicles.



Variant 2

- construction of a pedestrian-cyclist underpass the same as in the Variant 1 and the construction of an approach road towards the warehouse from the direction of Trnava and ban on the movement of road vehicles from the Branimirova Street towards LC.

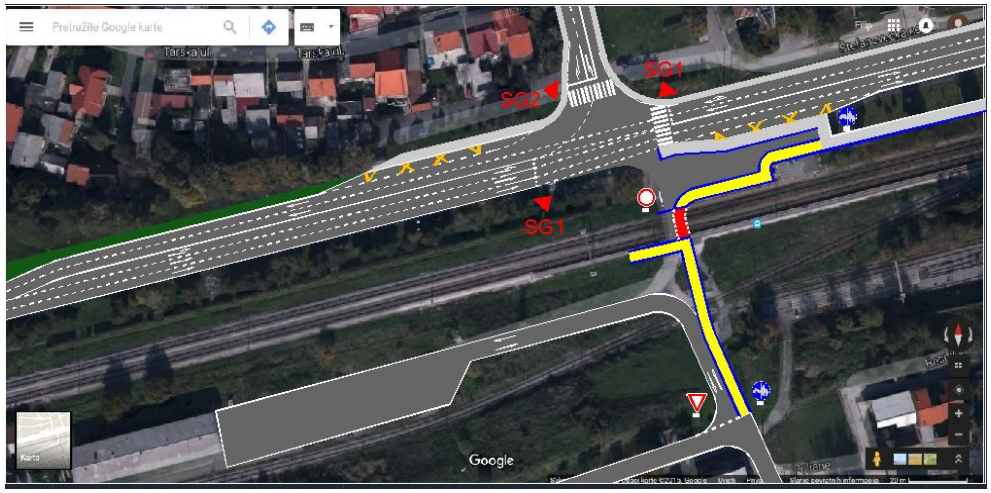
Variant 3 - Trnava



Variant 3 – Trnava I

Variant 3

- reconstruction of two adjacent LCs, LC Trnava and LC Osječka – Trnava I, at a distance of 500 metres between them
- This design solution proposes the construction of the underpass for the pedestrians and cyclists and the construction of an underpass for the drivers from Trnava who merge into the Branimirova Street eastwards (right turners) and westwards (left turners).
- the construction of an underpass for the right turners from the Branimirova Street towards Trnava is proposed

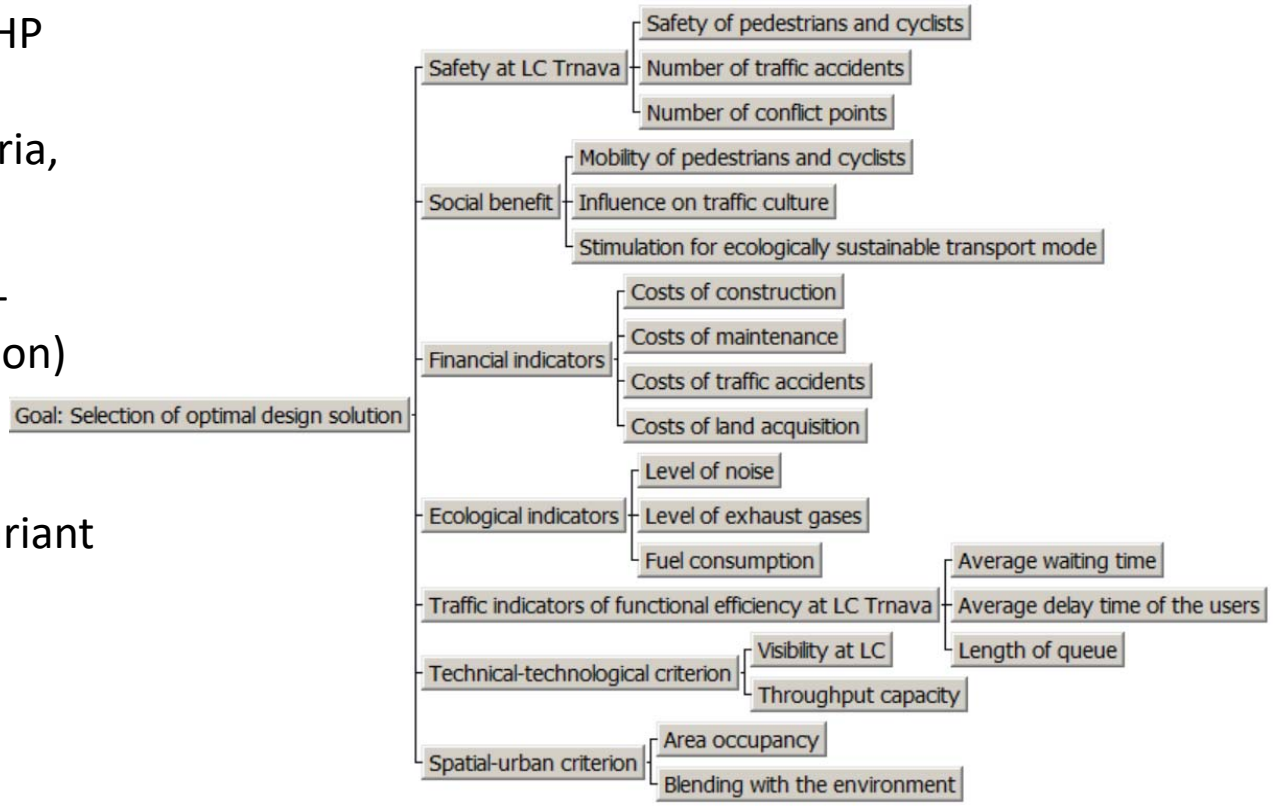


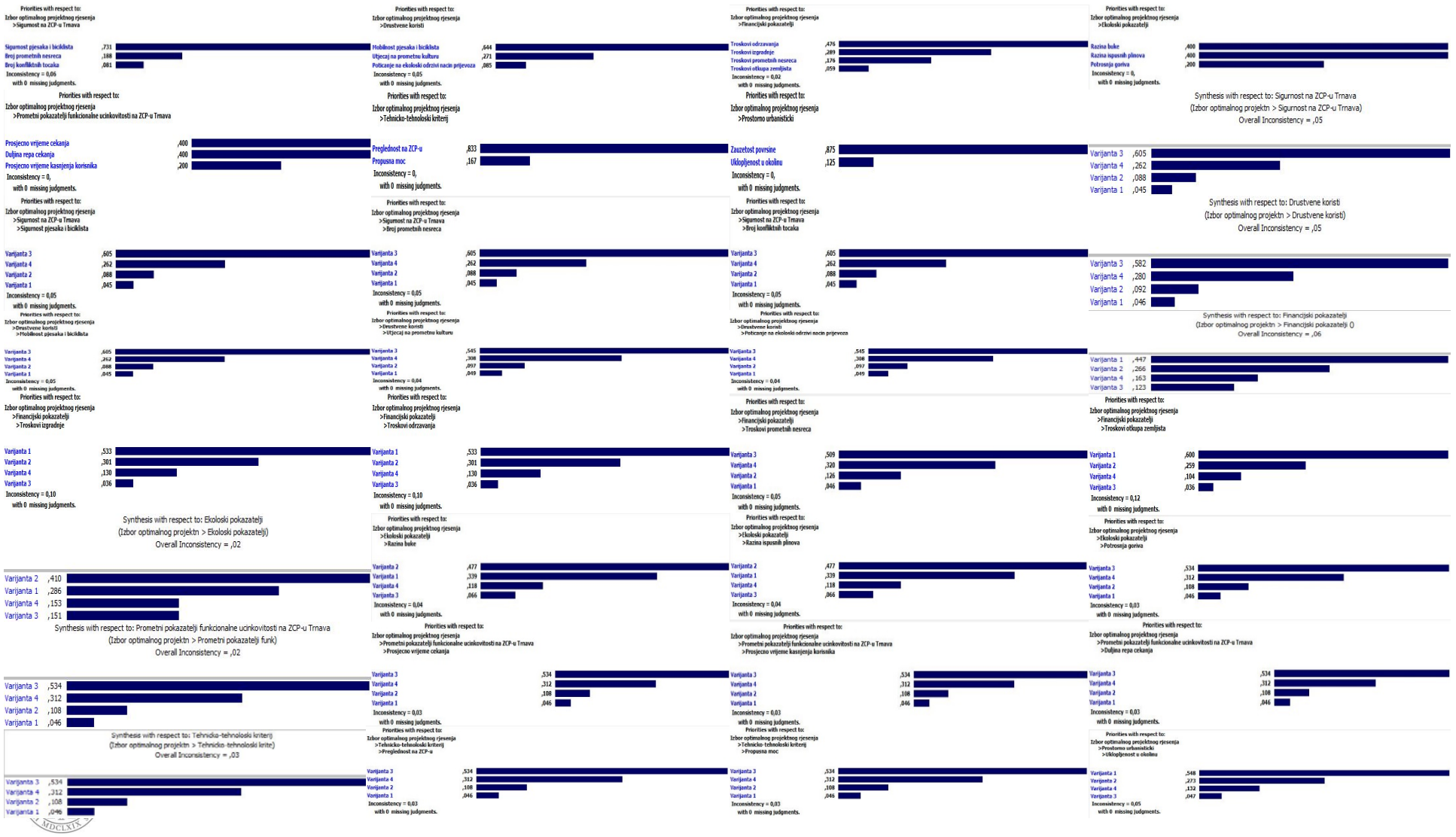
Variant 4

- combination of the proposal for the solution in Variant 2 and Variant 3.
- This proposal of the solution for the level crossing of Trnava and Osječka – Trnava I insures high safety level of the traffic flow.
- It completely eliminates the conflict points between the road vehicles and pedestrians, road vehicles and rail vehicles, and the pedestrians and rail vehicles at the mentioned LC
- The construction costs of these design solutions are somewhat lower than for the construction of elements from the previous variant.
- For the realisation of the mentioned design solutions less space is necessary for the construction than for the construction of the elements from the previous variant.

AHP MODEL

- hierarchical structure of AHP model (goal, alternatives/variants, criteria, sub-criteria)
- ranking of criteria and sub-criteria (pairwise comparison)
- evaluation of variants
- selection of the optimal variant
- sensitivity analysis




Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Sigurnost na ZCP-u Trnava
Sigurnost pjesaka i biciklista ,731
Broj prometnih nesreca ,188
Broj konfliktnih tocaka ,081
Inconsistency = 0,06
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Drustvene koristi
Mobilnost pjesaka i biciklista ,644
Utjecaj na prometnu kulturu ,271
Poticanje na ekoloski odrzivi nacin prijevoza ,085
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Financijski pokazatelji
Troskovi odrzavanja ,476
Troskovi izgradnje ,289
Troskovi prometnih nesreca ,179
Troskovi otkupa zemljista ,059
Inconsistency = 0,02
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Ekoloski pokazatelji
Razina buke ,400
Razina ispusnih plinova ,400
Potrosnja goriva ,200
Inconsistency = 0,
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prometni pokazatelji funkcionalne ucinkovitosti na ZCP-u Trnava
Prosjecno vrijeme cekanja ,400
Duljina repa cekanja ,400
Prosjecno vrijeme kasnjenja korisnika ,200
Inconsistency = 0,
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Tehnicko-tehnoloski kriterij
Preglednost na ZCP-u ,833
Propusna moc ,167
Inconsistency = 0,
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prostorno urbanisticki
Zauzetost povrsine ,875
Uklopljenost u okolinu ,125
Inconsistency = 0,
with 0 missing judgments.
Synthesis with respect to: Sigurnost na ZCP-u Trnava
(Izbor optimalnog projektn > Sigurnost na ZCP-u Trnava)
Overall Inconsistency = ,05
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Sigurnost na ZCP-u Trnava
>Sigurnost pjesaka i biciklista
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Sigurnost na ZCP-u Trnava
>Broj prometnih nesreca
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Sigurnost na ZCP-u Trnava
>Broj konfliktnih tocaka
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Synthesis with respect to: Drustvene koristi
(Izbor optimalnog projektn > Drustvene koristi)
Overall Inconsistency = ,05
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Drustvene koristi
>Mobilnost pjesaka i biciklista
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Drustvene koristi
>Utjecaj na prometnu kulturu
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Drustvene koristi
>Poticanje na ekoloski odrzivi nacin prijevoza
Varijanta 3 ,582
Varijanta 4 ,280
Varijanta 2 ,092
Varijanta 1 ,046
Synthesis with respect to: Financijski pokazatelji
(Izbor optimalnog projektn > Financijski pokazatelji ()
Overall Inconsistency = ,06
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Financijski pokazatelji
>Troskovi izgradnje
Varijanta 3 ,605
Varijanta 4 ,262
Varijanta 2 ,088
Varijanta 1 ,045
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Financijski pokazatelji
>Troskovi odrzavanja
Varijanta 3 ,545
Varijanta 4 ,308
Varijanta 2 ,097
Varijanta 1 ,049
Inconsistency = 0,04
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Financijski pokazatelji
>Troskovi prometnih nesreca
Varijanta 3 ,545
Varijanta 4 ,308
Varijanta 2 ,097
Varijanta 1 ,049
Inconsistency = 0,04
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Financijski pokazatelji
>Troskovi otkupa zemljista
Varijanta 1 ,447
Varijanta 2 ,266
Varijanta 4 ,163
Varijanta 3 ,123
Varijanta 1 ,533
Varijanta 2 ,301
Varijanta 4 ,130
Varijanta 3 ,036
Inconsistency = 0,10
with 0 missing judgments.
Synthesis with respect to: Ekoloski pokazatelji
(Izbor optimalnog projektn > Ekoloski pokazatelji)
Overall Inconsistency = ,02
Varijanta 1 ,533
Varijanta 2 ,301
Varijanta 4 ,130
Varijanta 3 ,036
Inconsistency = 0,10
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Ekoloski pokazatelji
>Razina buke
Varijanta 3 ,509
Varijanta 4 ,320
Varijanta 2 ,126
Varijanta 1 ,046
Inconsistency = 0,05
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Ekoloski pokazatelji
>Razina ispusnih plinova
Varijanta 1 ,600
Varijanta 2 ,259
Varijanta 4 ,104
Varijanta 3 ,036
Inconsistency = 0,12
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Ekoloski pokazatelji
>Potrosnja goriva
Varijanta 2 ,410
Varijanta 1 ,286
Varijanta 4 ,153
Varijanta 3 ,151
Synthesis with respect to: Prometni pokazatelji funkcionalne ucinkovitosti na ZCP-u Trnava
(Izbor optimalnog projektn > Prometni pokazatelji funk)
Overall Inconsistency = ,02
Varijanta 2 ,477
Varijanta 1 ,339
Varijanta 4 ,118
Varijanta 3 ,066
Inconsistency = 0,04
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prometni pokazatelji funkcionalne ucinkovitosti na ZCP-u Trnava
>Prosjecno vrijeme cekanja
Varijanta 2 ,477
Varijanta 1 ,339
Varijanta 4 ,118
Varijanta 3 ,066
Inconsistency = 0,04
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prometni pokazatelji funkcionalne ucinkovitosti na ZCP-u Trnava
>Prosjecno vrijeme kasnjenja korisnika
Varijanta 3 ,534
Varijanta 4 ,312
Varijanta 2 ,108
Varijanta 1 ,046
Inconsistency = 0,03
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prometni pokazatelji funkcionalne ucinkovitosti na ZCP-u Trnava
>Duljina repa cekanja
Varijanta 3 ,534
Varijanta 4 ,312
Varijanta 2 ,108
Varijanta 1 ,046
Inconsistency = 0,03
with 0 missing judgments.
Synthesis with respect to: Tehnicko-tehnoloski kriterij
(Izbor optimalnog projektn > Tehnicko-tehnoloski krite)
Overall Inconsistency = ,03
Varijanta 3 ,534
Varijanta 4 ,312
Varijanta 2 ,108
Varijanta 1 ,046
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Tehnicko-tehnoloski kriterij
>Preglednost na ZCP-u
Varijanta 3 ,534
Varijanta 4 ,312
Varijanta 2 ,108
Varijanta 1 ,046
Inconsistency = 0,03
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Tehnicko-tehnoloski kriterij
>Propusna moc
Varijanta 3 ,534
Varijanta 4 ,312
Varijanta 2 ,108
Varijanta 1 ,046
Inconsistency = 0,03
with 0 missing judgments.
Priorities with respect to:
Izbor optimalnog projektnog rjesenja
>Prostorno urbanisticki
>Uklopljenost u okolinu
Varijanta 1 ,548
Varijanta 2 ,273
Varijanta 4 ,132
Varijanta 3 ,047
Inconsistency = 0,05
with 0 missing judgments.

OPTIMAL VARIANT

After performing the entire analysis and evaluation of the variants according to each criterion and sub-criterion using AHP method Variant 3 (43.1%) has been proposed as the best traffic solution, and it includes a number of functional traffic solutions to increase the safety and urban mobility of the LC Trnava region.

LC TRNAVA

LC OSJEČKA-TRNAVA I

SIMULATION OF OPTIMAL VARIANT - VARIANT 3 -

- the queue length was reduced from 240 metres to 38 metres
- the average vehicle delay was reduced from 80 seconds to 16 seconds
- the share of CO has been almost halved and amounts to 578 PPM
- the average fuel consumption decreased from 17 litres to 8.2 litres
- by analysis of the pedestrian and cyclist flows no queues nor delays of the users have been recorded

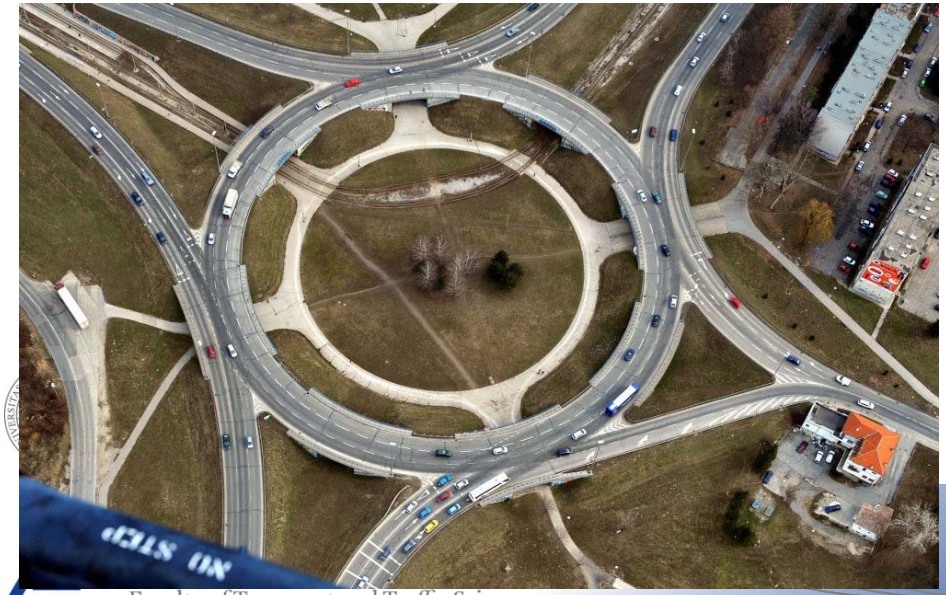
An AHP model for reconstruction of intersection in City of Zagreb

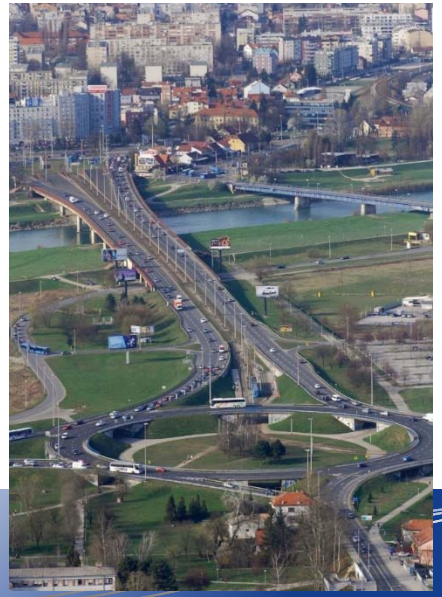
Goal:

NEW Roudabout „Remetinec”

CASE STUDY Roudabout „Remetinec" – previous situation

- located in the flatland without any major limitations, whereas four tangential approaches (1-Jadranska Avenue, 2-Remetinečka Road, 3-Avenue Dubrovnik and 4-Jadranski Bridge) are at longitudinal slope of 1% to 3%.
- inscribed circle diameter is 148 m and central island diameter is 124 m.
- the circulatory roadway has three lanes each 4,0 m wide.
- approaches are designed with three lanes each 3,5 m wide.
- Entry approach radius are 80 m except for the northern approach, which has radius of 200 m.



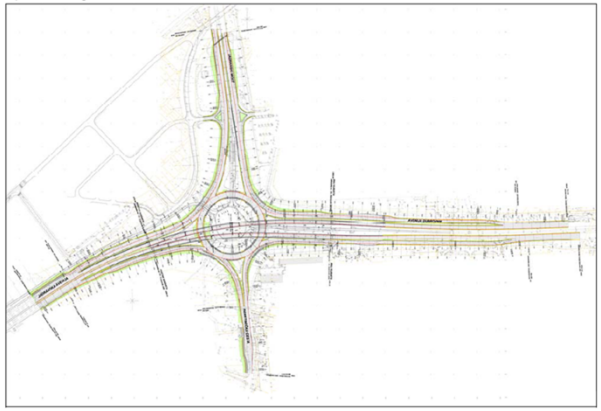


- the circulatory roadway has a 2% slope towards the centre because of the drainage.
- registered value of roundabout traffic volume ranges from 90.000 to 100.000 [veh/day], where Q_k = 99.023 [veh/day] has had more pronounced volumes on all approaches except on approach 2

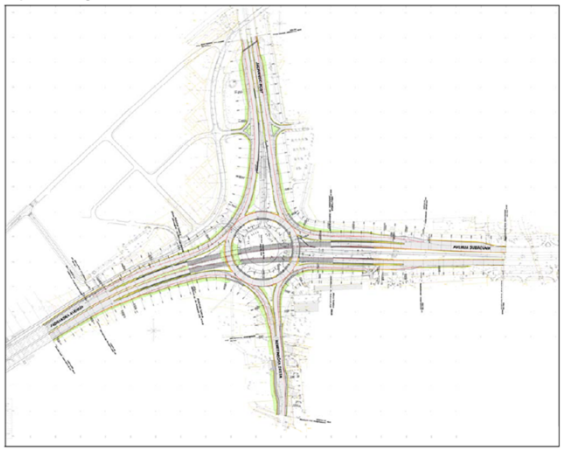
CASE STUDY Roudabout „Remetinec” – current situation - reconstruction

CASE STUDY Roudabout „Remetinec" – Alternatives

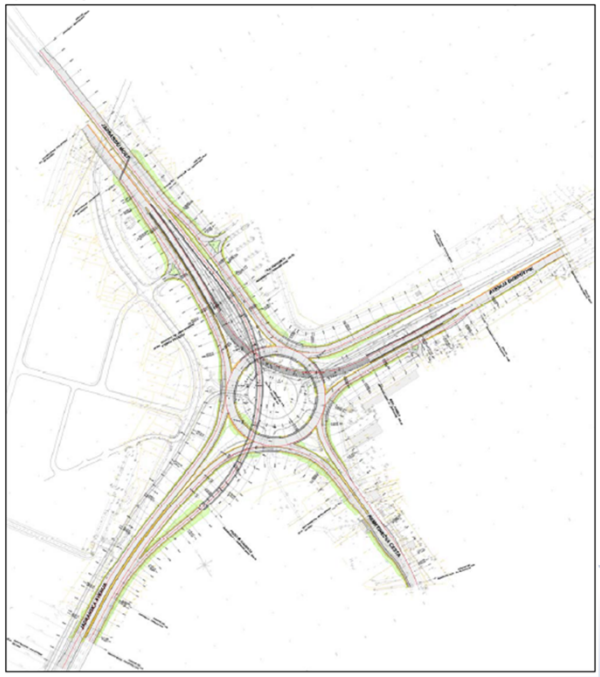
a) Layout of Variant 1



b) Layout of Variant 2



c) Layout of Variant 3

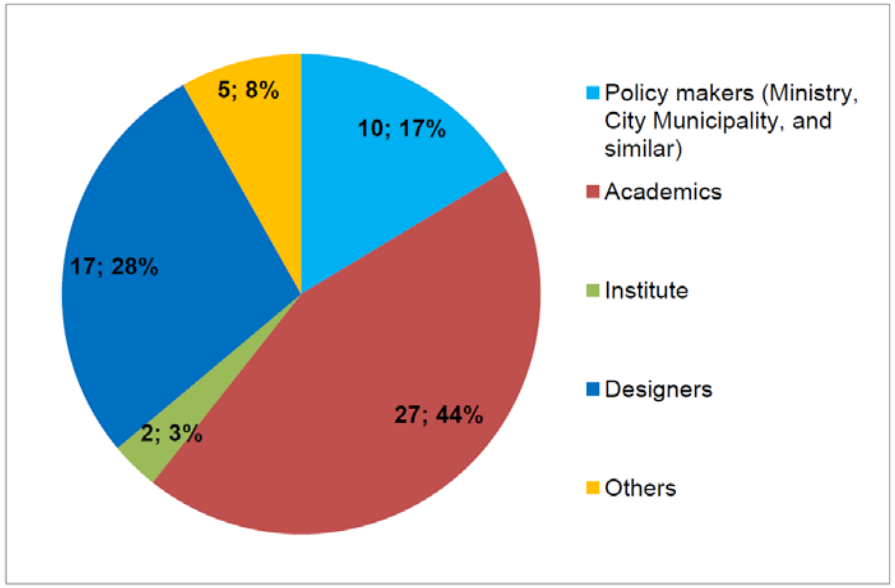


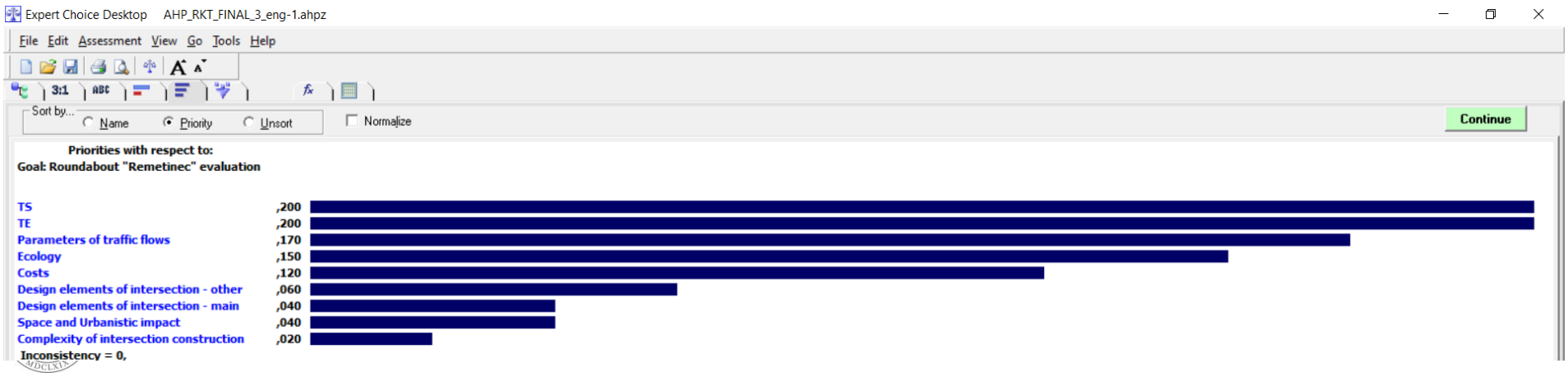
d) Layout of Variant 4

Four variants (alternatives) for reconstruction with particular focus on the safety-capacity and design geometry and their correlation are presented are proposed:

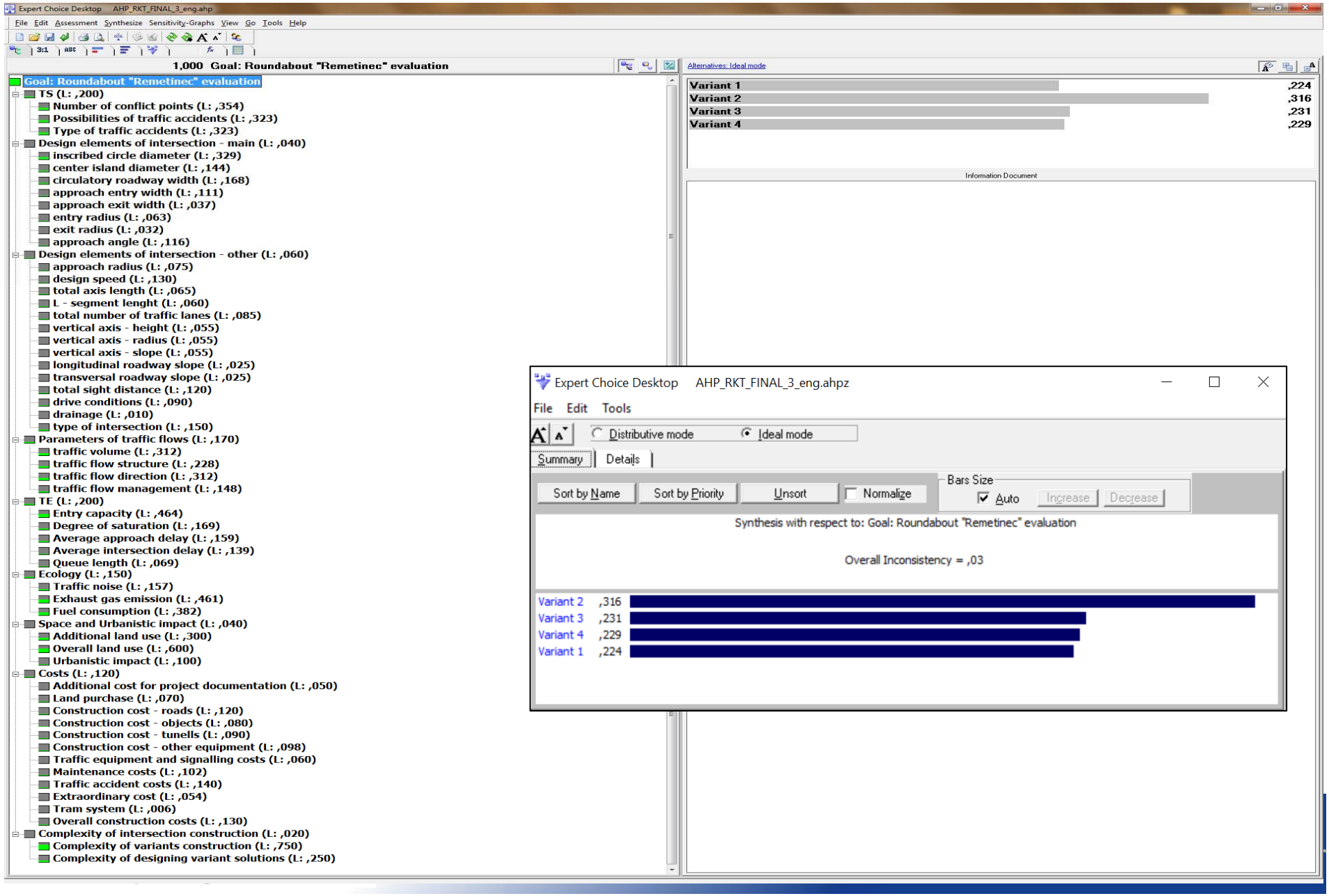
- Variant 1: traffic flows West – East are guided over viaducts at +2 level (Figure a)
- Variant 2: traffic flows West – East are guided through tunnels at -1 level (Figure b)
- Variant 3: traffic flow West – North is guided over viaduct at +2 level, traffic flow North – East is guided through the tunnels at -1 level (Figure c)
- Variant 4: traffic flow North – East is guided through tunnel at -1 level (Figure d)

CASE STUDY Roudabout „Remetinec" – criteria weights

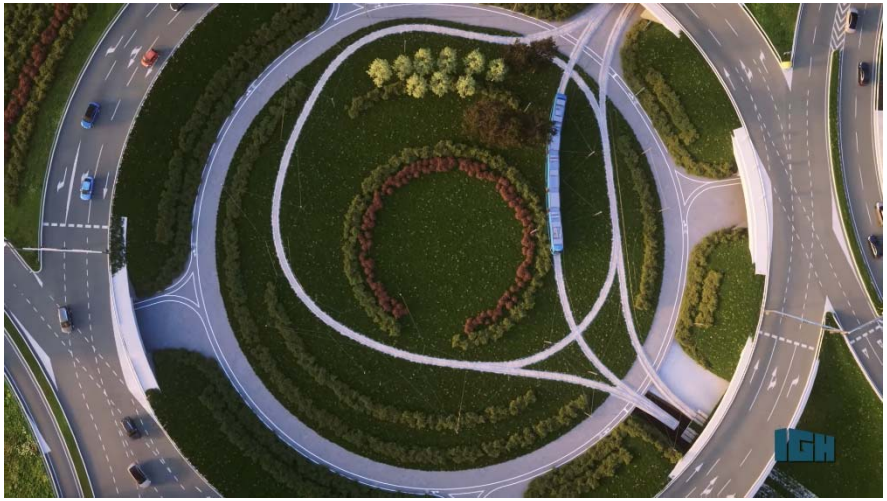




CASE STUDY Roudabout „Remetinec” – AHP model - results



CASE STUDY Roudabout „Remetinec” – final situation



Variant 2 - optimal

An AHP Model to Evaluate Road Section Design

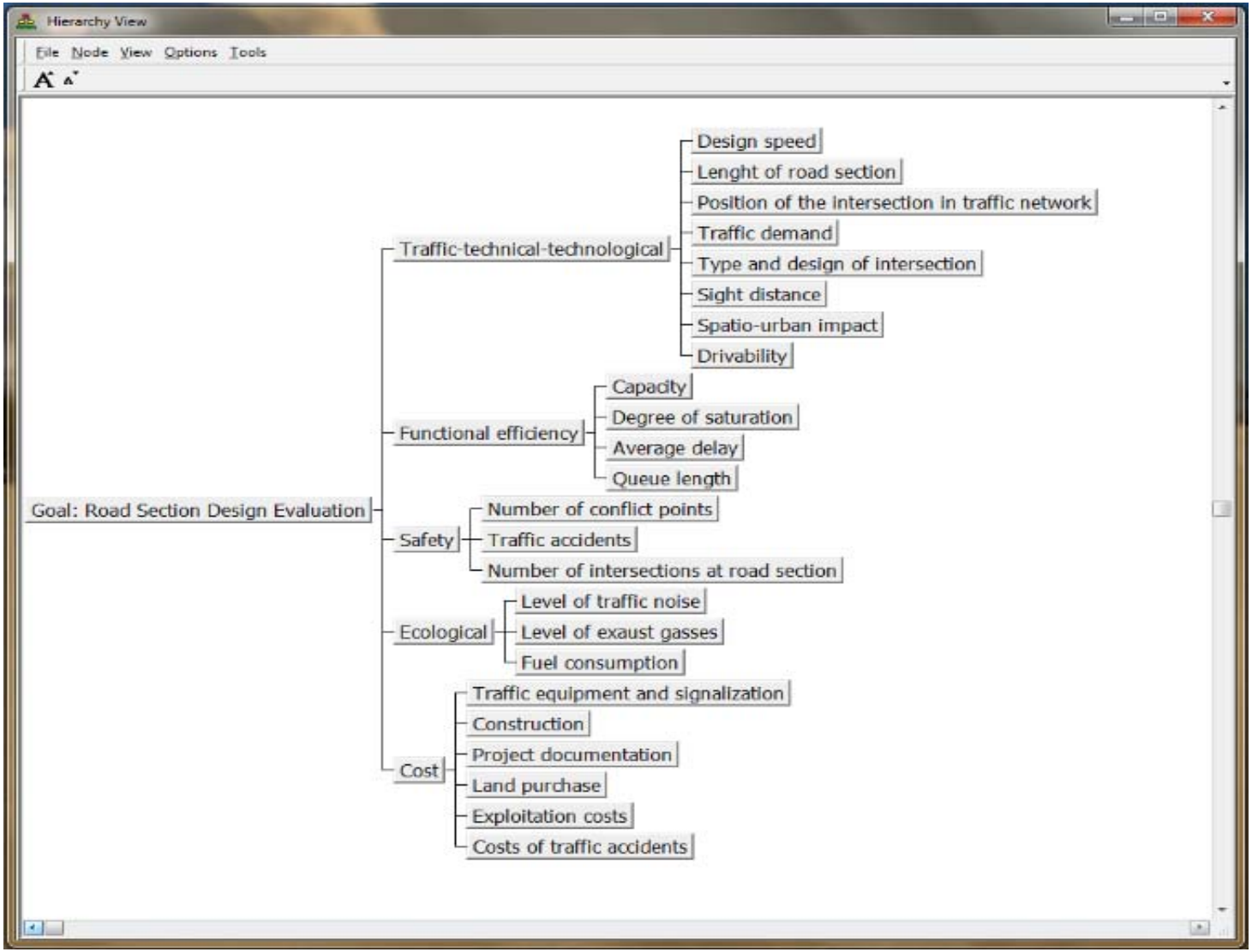
Goal:

Reconstruction of Road Section Design in suburban area of City of Split

PROBLEM

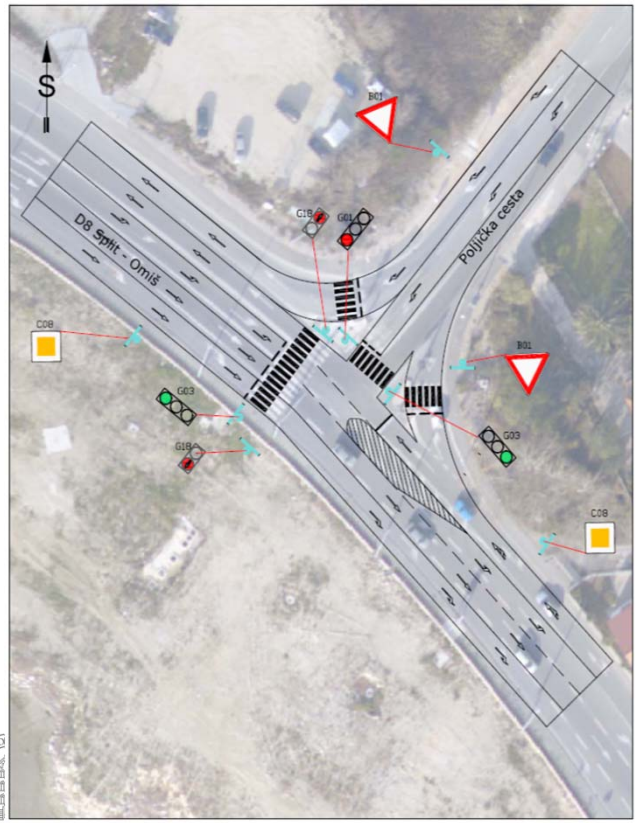
- The road stretch links the city of Split, the largest tourist destination in Dalmatia, with the smaller tourist city of Omiš to the east, the large tourist area on the Makarska Riviera and ultimately the tourist city of Dubrovnik.
- On the section of road extending from the direction of Split to the intersection of national road D8 and Poljička road, traffic runs in four lanes (two in each direction), and then in two lanes (one in each direction) after the intersection.
- Two partially signalised intersections (blinking yellow), labeled as intersection 1 (D8-Poljička road) and intersection 2 (D8-Street Gospe od Siti-Jurasova road), lie 100 m apart.
- Two unsignalised intersections, labeled intersection 3 (D8-Domovinskog rata street) and 4 (D8-Put Starog sela road) lie 300 m away from intersections 1 and 2.
- Analysis of traffic flows along this stretch of road during morning and afternoon peak hours, when commuters are traveling between the suburb and Split, has shown significant traffic jams.
- This is particularly true on weekends during the summer tourist season.
- From intersection 1 the traffic pile-up can extend for 2-3 km, even up to 10 km, causing delays of a few hours. In 2013, the traffic counter installed near intersection 1 recorded the highest average annual daily traffic (49,443 vehicles) and the highest average summer daily traffic (57,642 vehicles) of all counters installed in Croatia.

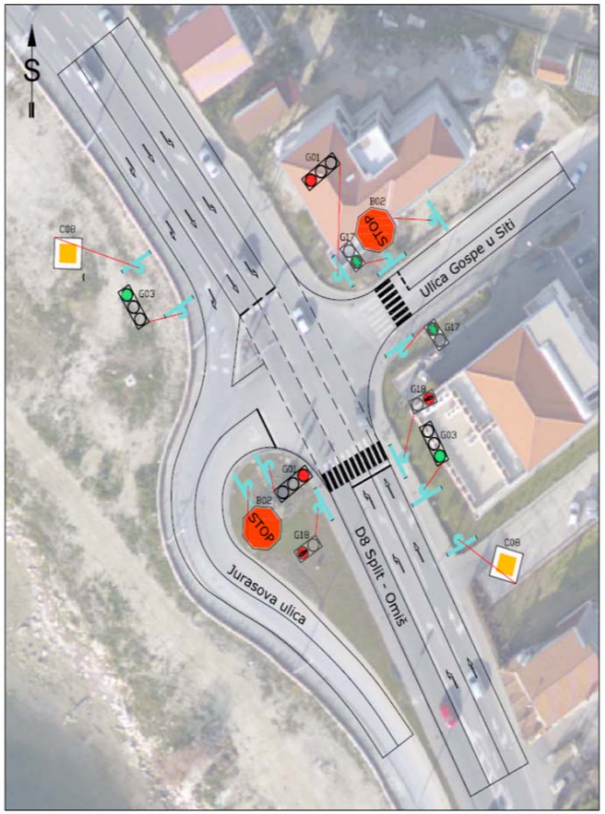
AHP MODEL


Hierarchy View
File Node View Options Tools
Goal: Road Section Design Evaluation
Traffic-technical-technological
Design speed
Lenght of road section
Position of the intersection in traffic network
Traffic demand
Type and design of intersection
Sight distance
Spatio-urban impact
Drivability
Functional efficiency
Capacity
Degree of saturation
Average delay
Queue length
Safety
Number of conflict points
Traffic accidents
Number of intersections at road section
Ecological
Level of traffic noise
Level of exaust gasses
Fuel consumption
Cost
Traffic equipment and signalization
Construction
Project documentation
Land purchase
Exploitation costs
Costs of traffic accidents

AHP MODEL - ALTERNATIVES

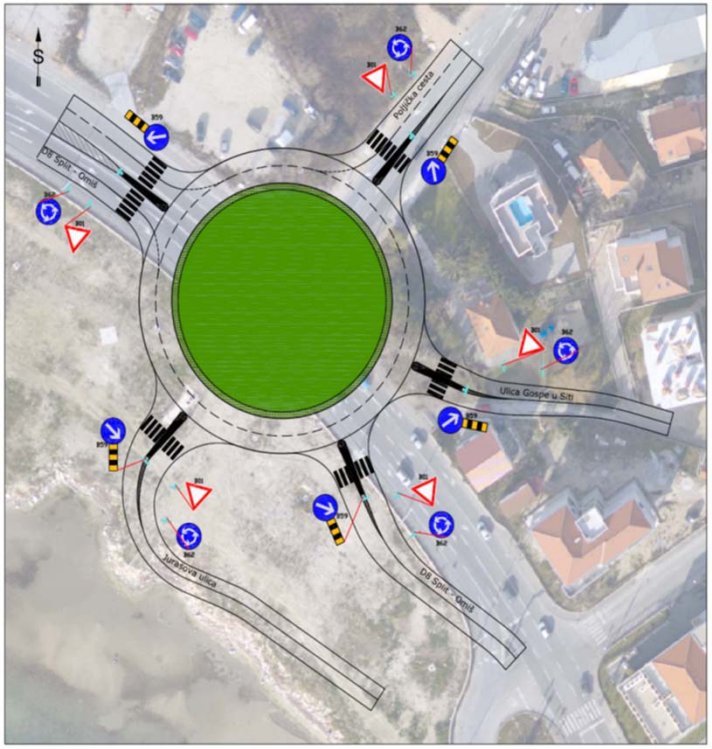
The first alternative (Variant 1) involved introducing and coordinating signaling at intersections 1 (D8-Poljička road) and 2 (D8-Street Gospe od Siti-Jurasova road), as well as adding a traffic lane for turning left from main road D8 at intersections 3 (D8-Domovinskog rata Street) and 4 (D8-Put starog sela road).

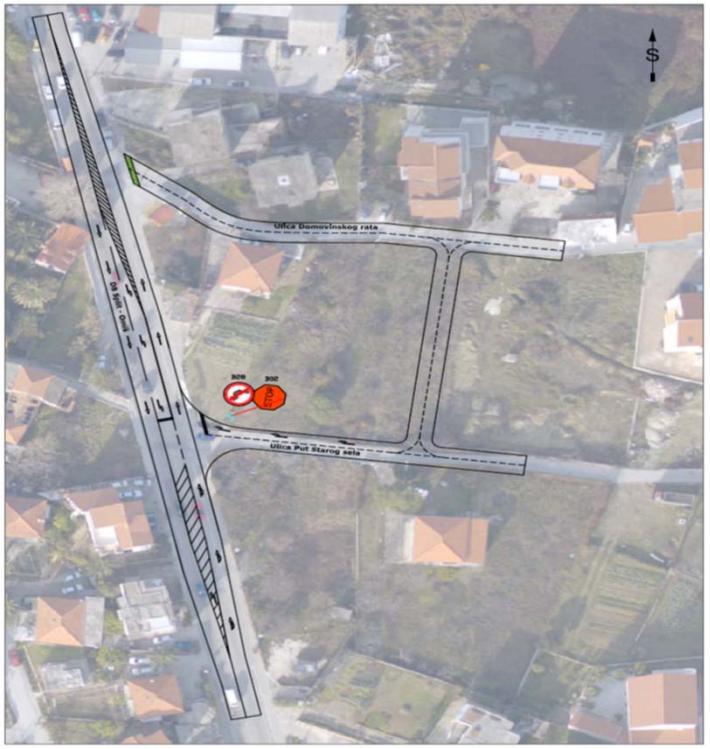




AHP MODEL - ALTERNATIVES

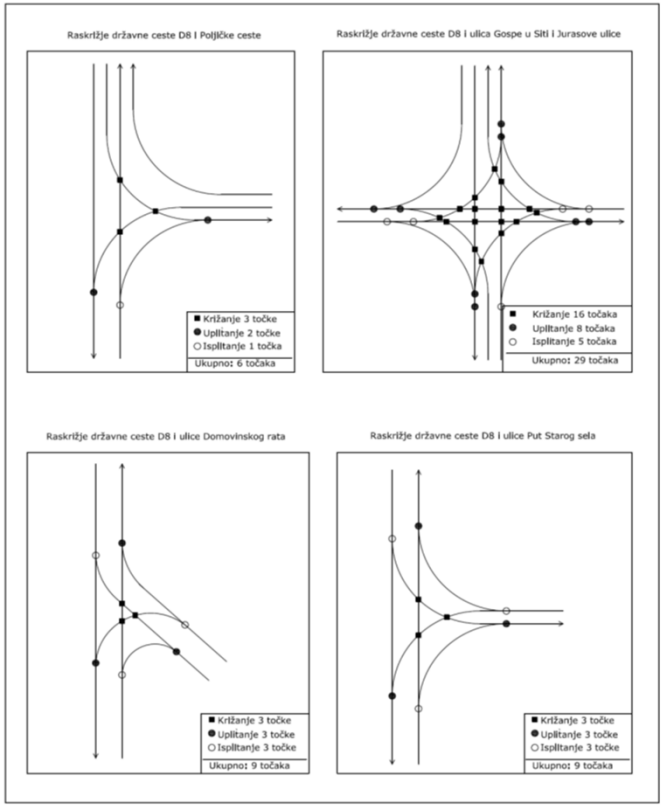
The second alternative (Variant 2) involved converting intersection 1 into a roundabout and closing intersection 2. In this alternative, intersection 1 would feature on its southeastern side three new approaches from Gospe od Siti street, D8-Omiš and Jurasova street. Intersection 3 would also be closed, and Domovinskog rata street would be connected via by-pass with Put Staroga sela street. Finally, an extra lane for left turns would be added to intersection 4.



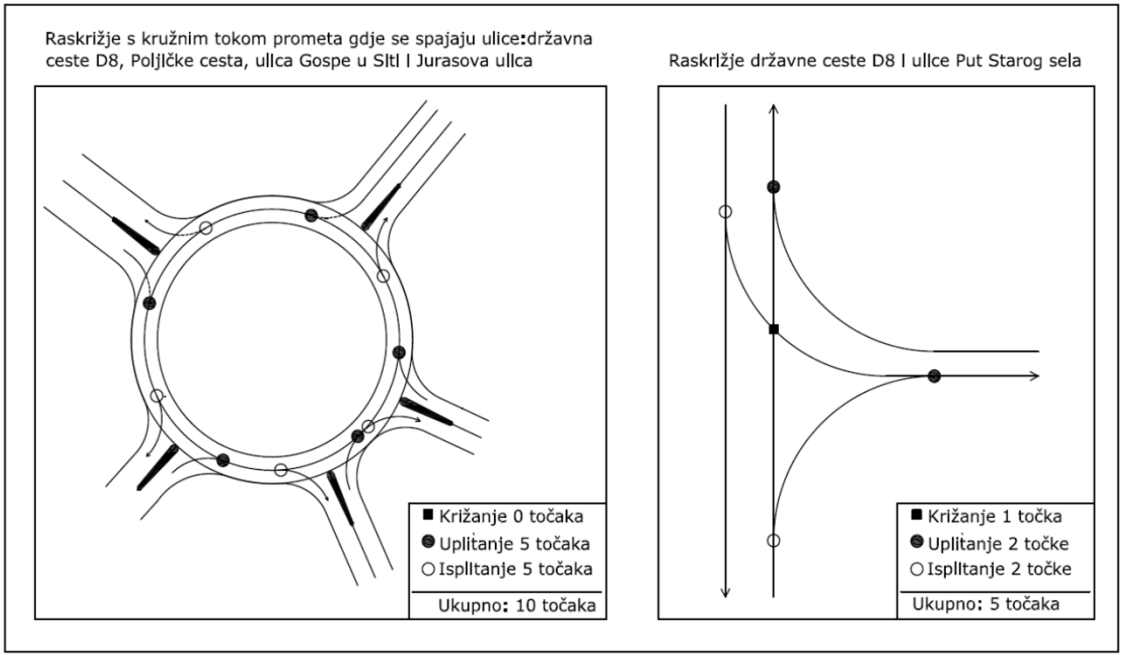


AHP MODEL – comparison alternatives according to conflict points

V1

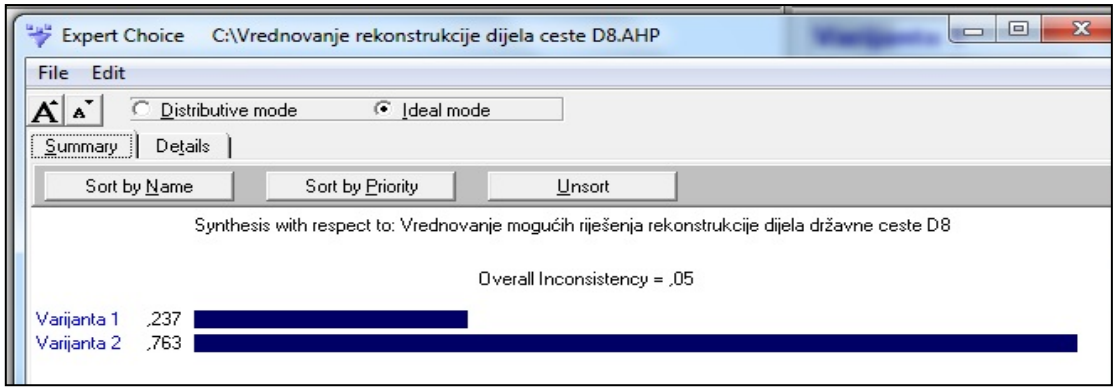


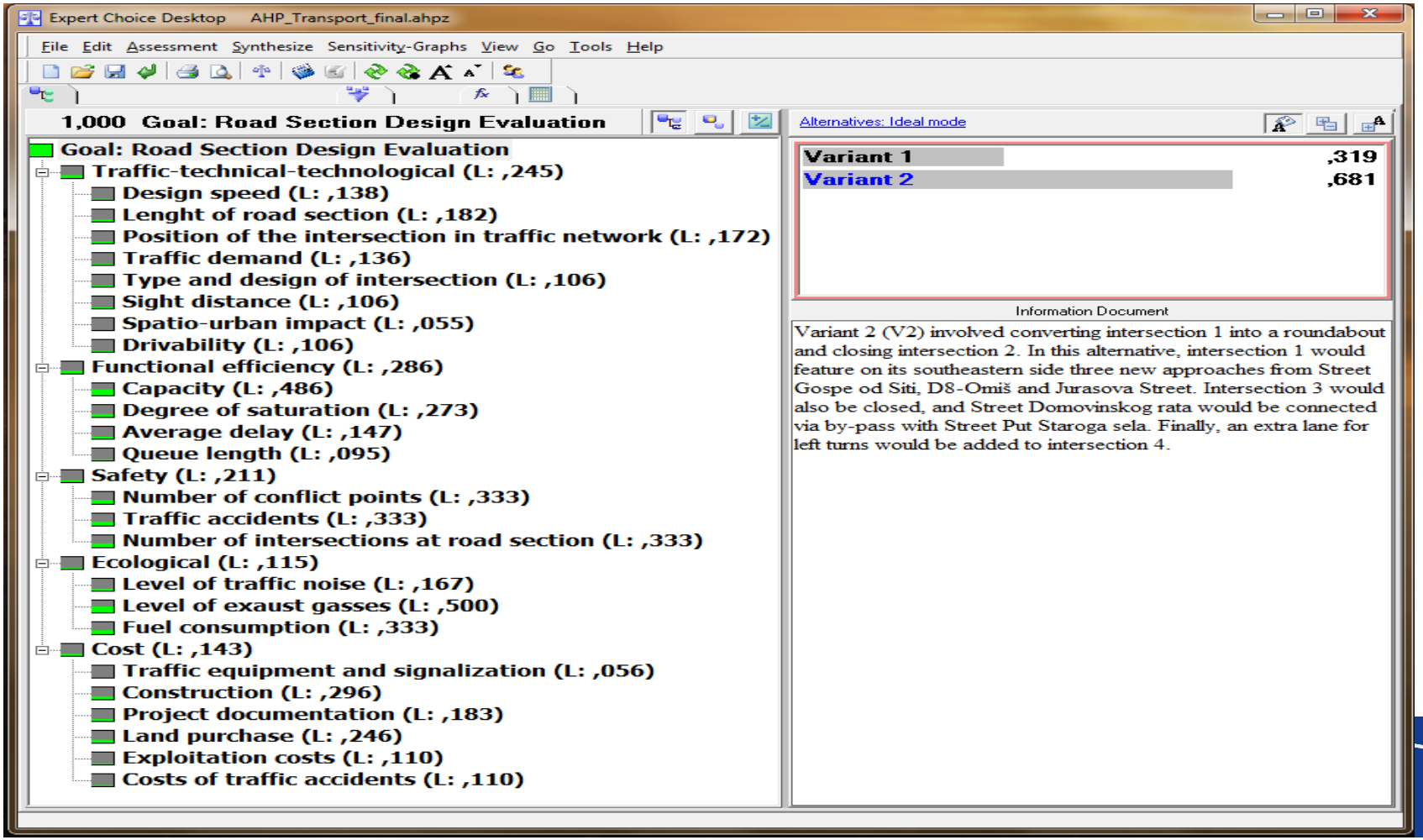
V2



Alternatives	Number of conflict points	Rank	Saaty scale	
			V 1	V 3
V1	53	2	1	1/7
V2	15	1	7	1

AHP MODEL - results





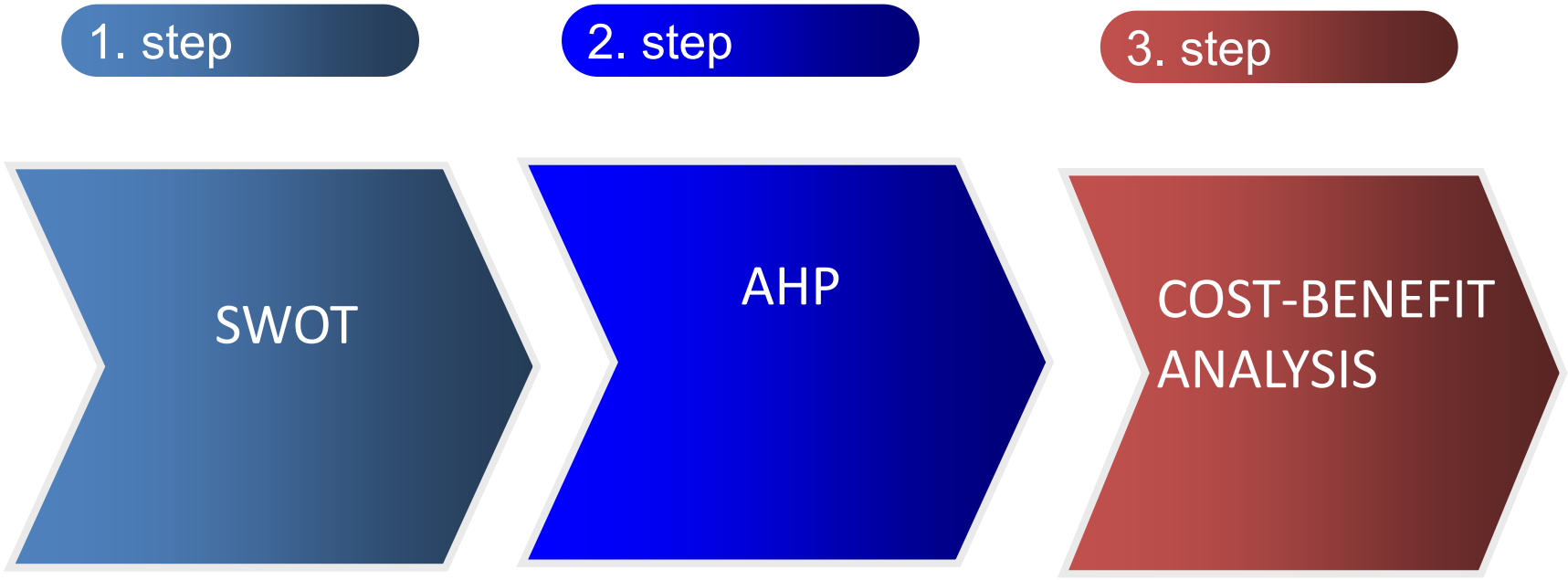
Application of the selected methods

Goal:

Selection of the reconstruction design on the railway line

Osijek – Strizivojna/Vrpolje

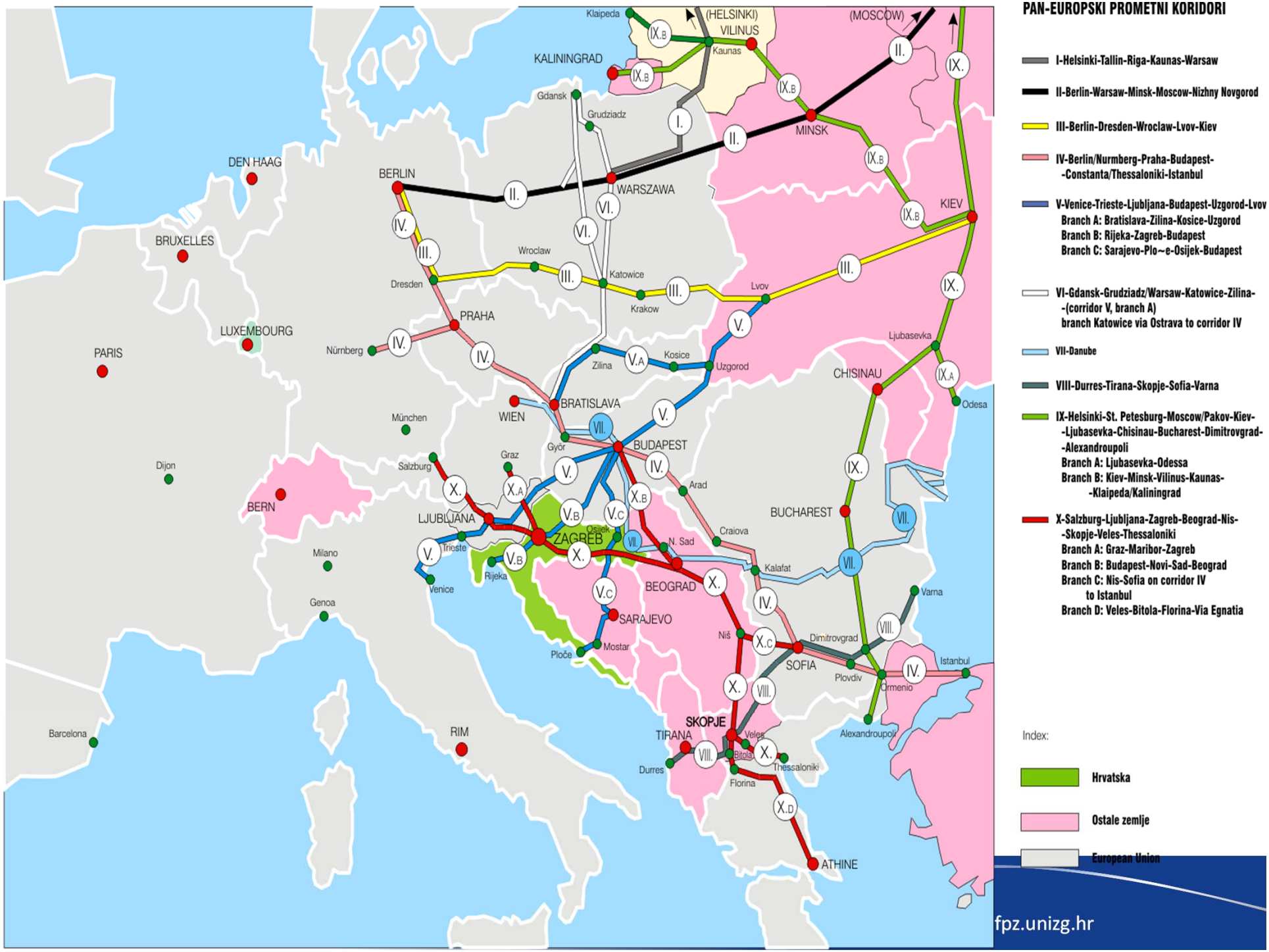
Applying a methods



Relevant parameters for applying methods

BASIC PARAMETERS	SWOT ANALYSIS	MULTI-CRITERIA ANALYSIS	COST-BENEFIT ANALYSIS

• **Analysis of the existing technical-technological condition of the railway line**
  • location and significance of the railway line Osijek – Strizivojna/Vrpolje
  • technological-technical characteristics of the line section
  • traffic technology
  • scope and tendency of transport
• **Variant technical-technological solutions**
• **Basic characteristics of the future condition of the railway line**
	• Strengths
	• Weaknesses
	• Opportunities
	• Threats
		• Defining of the function of objective
		• Definition of alternatives
		• Criteria selection
		• Subcriteria selection
		• Defining the criteria weights
		• Defining of hierarchical structure
		• Analytical hierarchical process
			• **Traffic forecast**
			• **Economic aspect of the project**
			• **Project costs** (reconstruction investments, costs of disturbing traffic on the existing line, increase of investment due to electrification of the line (Variant 3))
			• **Project benefits** (savings in: costs of investment and current maintenance, costs of travel time of passengers and goods, difference in transport price between road and railway, reduction of external traffic costs, effects due to speed increase, remaining value)
			• **Scheduling plan**
			• **Analysis of sensitivity**


PAN-EUROPSKI PROMETNI KORIDORI
I-Helsinki-Tallin-Riga-Kaunas-Warsaw
II-Berlin-Warsaw-Minsk-Moscow-Nizhny Novgorod
III-Berlin-Dresden-Wroclaw-Lvov-Kiev
IV-Berlin/Nurmberg-Praha-Budapest-
-Constanta/Thessaloniki-Istanbul
V-Venice-Trieste-Ljubljana-Budapest-Uzgorod-Lvov
Branch A: Bratislava-Zilina-Kosice-Uzgorod
Branch B: Rijeka-Zagreb-Budapest
Branch C: Sarajevo-Plo~e-Osijek-Budapest
VI-Gdansk-Grudziadz/Warsaw-Katowice-Zilina-
-(corridor V, branch A)
branch Katowice via Ostrava to corridor IV
VII-Danube
VIII-Durres-Tirana-Skopje-Sofia-Varna
IX-Helsinki-St. Petesburg-Moscow/Pakov-Kiev-
-Ljubasevka-Chisinau-Bucharest-Dimitrovgrad-
-Alexandroupoli
Branch A: Ljubasevka-Odessa
Branch B: Kiev-Minsk-Vilinus-Kaunas-
-Klaipeda/Kaliningrad
X-Salzburg-Ljubljana-Zagreb-Beograd-Nis-
-Skopje-Veles-Thessaloniki
Branch A: Graz-Maribor-Zagreb
Branch B: Budapest-Novi-Sad-Beograd
Branch C: Nis-Sofia on corridor IV
to Istanbul
Branch D: Veles-Bitola-Florina-Via Egnatia
Index:
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Ostale zemlje
European Union
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(MOSCOW)
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Gdansk
Grudziadz
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DEN HAAG
BERLIN
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BRUXELLES
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Dresden
Lvov
Krakow
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LUXEMBOURG
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Kosice
Uzgorod
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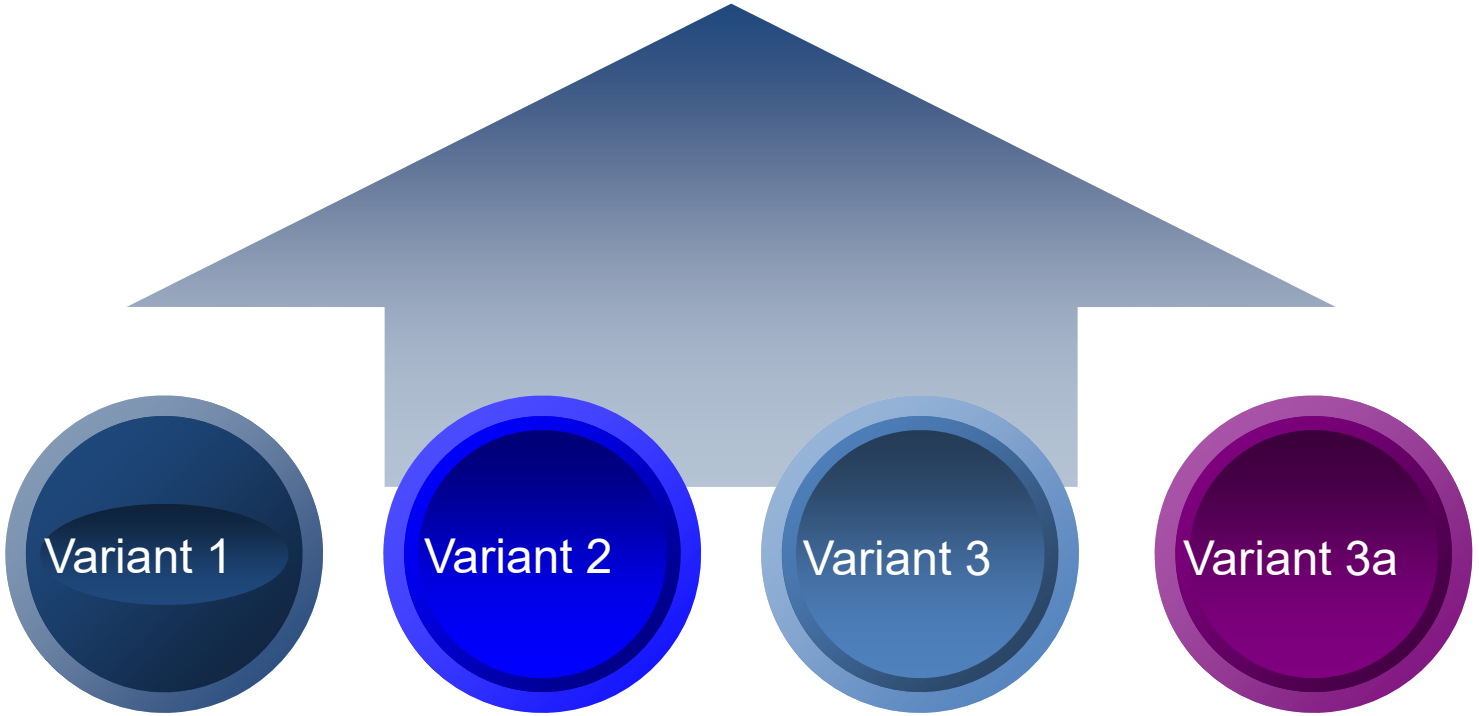
Đakovo
Markušica-Antin
Stari Mikanovci
Ivankovo
Vinkovci
Budrovci
Strizivojna
-Vrpolje
Perkovci
Koparica-Beravci
Sikirevci
Darda
Osijek
Čepin
Cs. OLT 1
Brijest
Antunovac
Ernestinovo
Laslovo-Korod
Novi Dalj
Borovo
Gabos
Ostrovo
Mirkovci
Rokovci
Privlaka
Cerna
Otok
Središte

Analysis of current situation

Technological and technical characteristics	Technology of traffic
- exploitation length is 48.33 km, - the line is single-track and it is not electrified, - there is no automatic block instrument, - only a small section of the line can accommodate axle loads of 225kN and 80kN/m and a speed of 80 and 100km/h, - on the most part the axle load of 180kN and 64kN/m and the speed of 50km/h are permitted, - maximal line gradient is 8‰ in both directions, - the valid railway line resistance is 9daN/t. There are 37 crossings on the section, - low speeds are the result of poor condition of the substructure of the track and permanent way, obsolete system of railway station protection, curve radii and at-grade crossings.	- the traffic operates on a single track, - traffic is regulated during the running time between two stations, - the traction is organised by diesel-engine trains for passenger traffic and diesel locomotives for a couple of high-speed trains for passenger transport, and for cargo trains, - masses of trains are predetermined to tilting elements of the railway line and traction forces of the locomotives, and a number of other restrictions (train braking, the lengths of railway station tracks, length of the platforms, etc.), - masses of passenger trains range from 84 tonnes in local traffic to 300 tonnes in international traffic, - the planned masses of cargo trains are around 1400 tonnes.

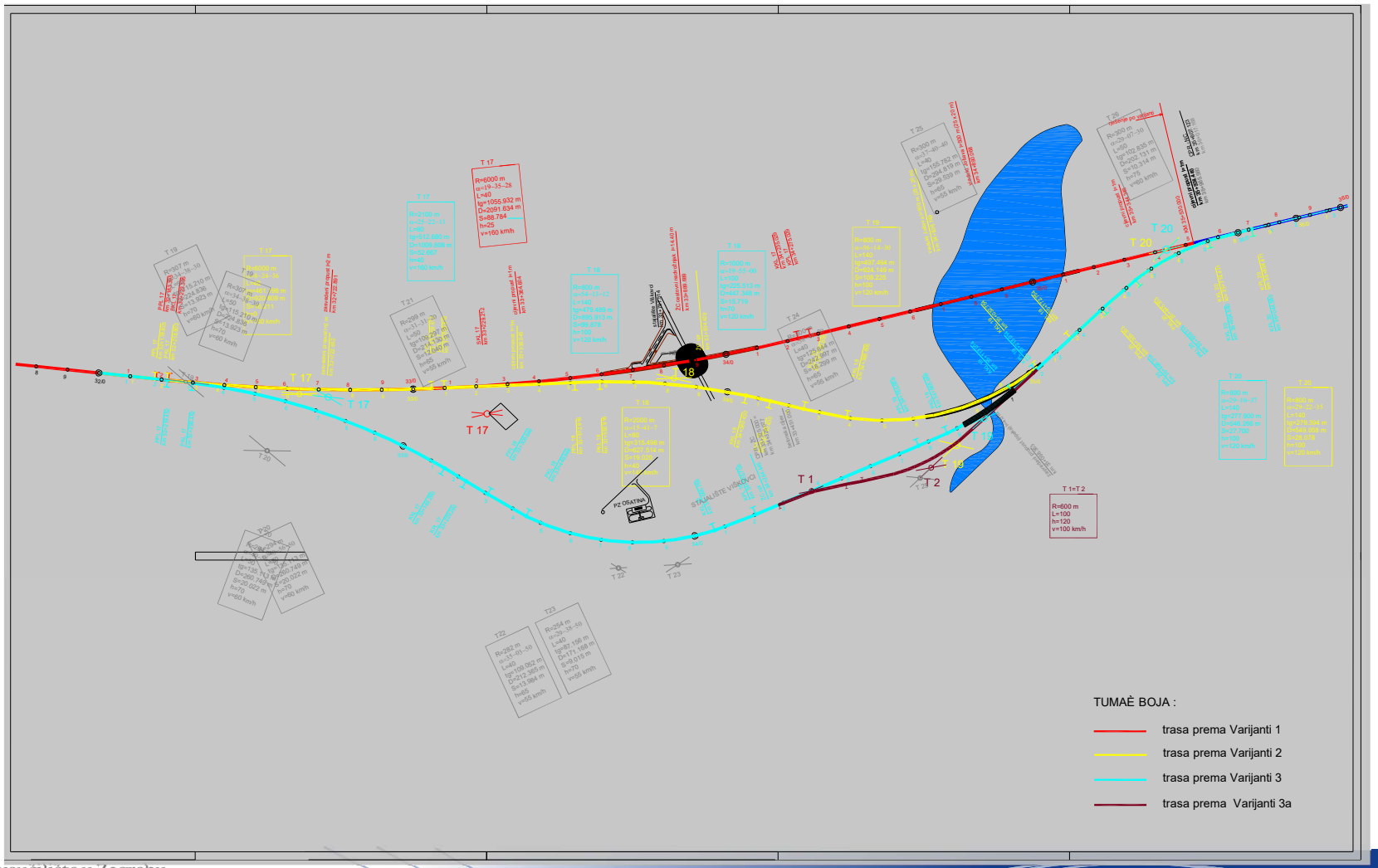
Variants of new techno-technological solutions (project of reconstruction) on a railway segment Osijek – Strizivojna/Vrpolje



Variants

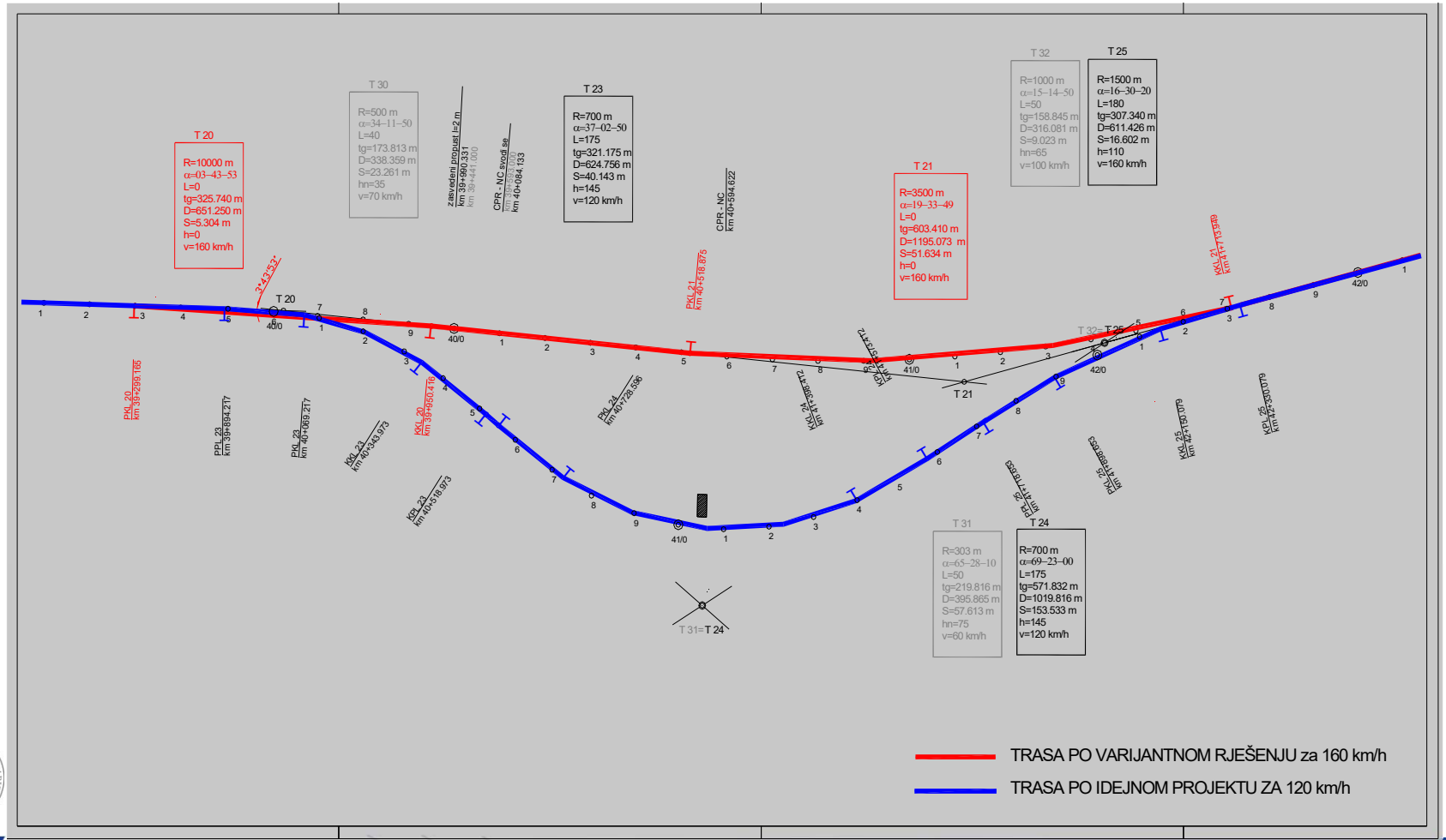
Variant	Characteristics
Variant 1, for the region of Viškovci according to Preliminary solution, speeds of 160km/h	The preliminary variant solution of deviating the route according to Variant 1 starts at km 26+770 after the crossing point Semeljci, and ends at km 35+530 before the railway station Đakovo. The route can accommodate speeds of 160km/h. A new station Viškovci is planned on the route along the facility of the road overpass. The railway station would have a platform in the length of , shelter of , parking lot for passenger cars, and a ramp for disabled persons. The deviation track level is much more favourable than the track level of the existing railway line. The gradients are much milder, and the elevating and lowering of the track level on the length of two kilometres is avoided. Besides, the track level is elevated on the lowest part by ca. 3m and lowered at the highest section by about 5.5m which will bring substantial savings in exploitation and comfortable ride. Viaduct Jošava starts at km 34+715,075 and ends at km 35+215,075. The viaduct axis is at km 34 +965,075. The viaduct consists of 25 span structures in the length of 20m each, i.e. total length of .
Variant 2, for the region of Viškovci according to Preliminary solution, speeds of 120km/h	The preliminary variant solution of deviating the route according to Variant 2 starts at km 33+000, from the crossing point Semeljci it is the same as in Variant 1, and ends at km 35+600 before the railway station of Đakovo. The route can accommodate the speed of 120km/h. The intention of this variant is to try to avoid the viaduct across the Jošava lake which is 500m long according to Variant 1. By constructing the longitudinal profile it has been determined that according to this variant a viaduct of the same length as according to Variant 1 ( ) is also required, and the route elements are less favourable.
Variant 3, for the region of Viškovci according to Preliminary solution, speeds of 120km/h	Variant 3 was developed as an attempt to come as close as possible to the existing railway line in order to avoid big works, and especially to shorten the length of the bridge spanning the Jošava lake. For the mentioned reasons the new route has significantly poorer altitude and layout elements than Variants 1 and 2. The route is designed for the speed of 120km/h. The drawback of this variant is that it passes through the place of Kuševac, and there the crossing with the county road needs to be grade separated. The existing water duct across Jošava, with the opening of 4m, is in extremely poor condition, and it has been also concluded that it is necessary to construct a new bridge about 15m away from the existing water duct. By realising the longitudinal profile, it has been determined that this variant also requires a viaduct in the length of 200m. An additional drawback of this variant is that the embankments before and after the viaducts would be in the Jošava lake with high uncertainty in constructing the embankment on such a terrain, i.e. with the need of comprehensive reconstruction or lengthening of the viaducts. Besides, the works would greatly disturb the traffic on the existing railway line, and increase the construction costs, which is also a significant drawback of this variant.
Variant 3a, for the region of Viškovci according to Preliminary solution, speeds of 100km/h	This variant represents a sub-variant of Variant 3 on the section from the crossing to the existing water duct Jošava. This variant intends to completely avoid the construction of a new bridge, and to remain on the existing line route. This can be achieved, but with the route elements that allow speeds of 100km/h. This variant requires the construction of a new bridge on the Jošava and at the place of the existing one with an opening stipulated by “Vodoprivreda”. All the mentioned variants differ most in the regions of Viškovci and Meteor.

Viškovci


TUMAČ BOJA :
trasa prema Varijanti 1
trasa prema Varijanti 2
trasa prema Varijanti 3
trasa prema Varijanti 3a

Viškovci

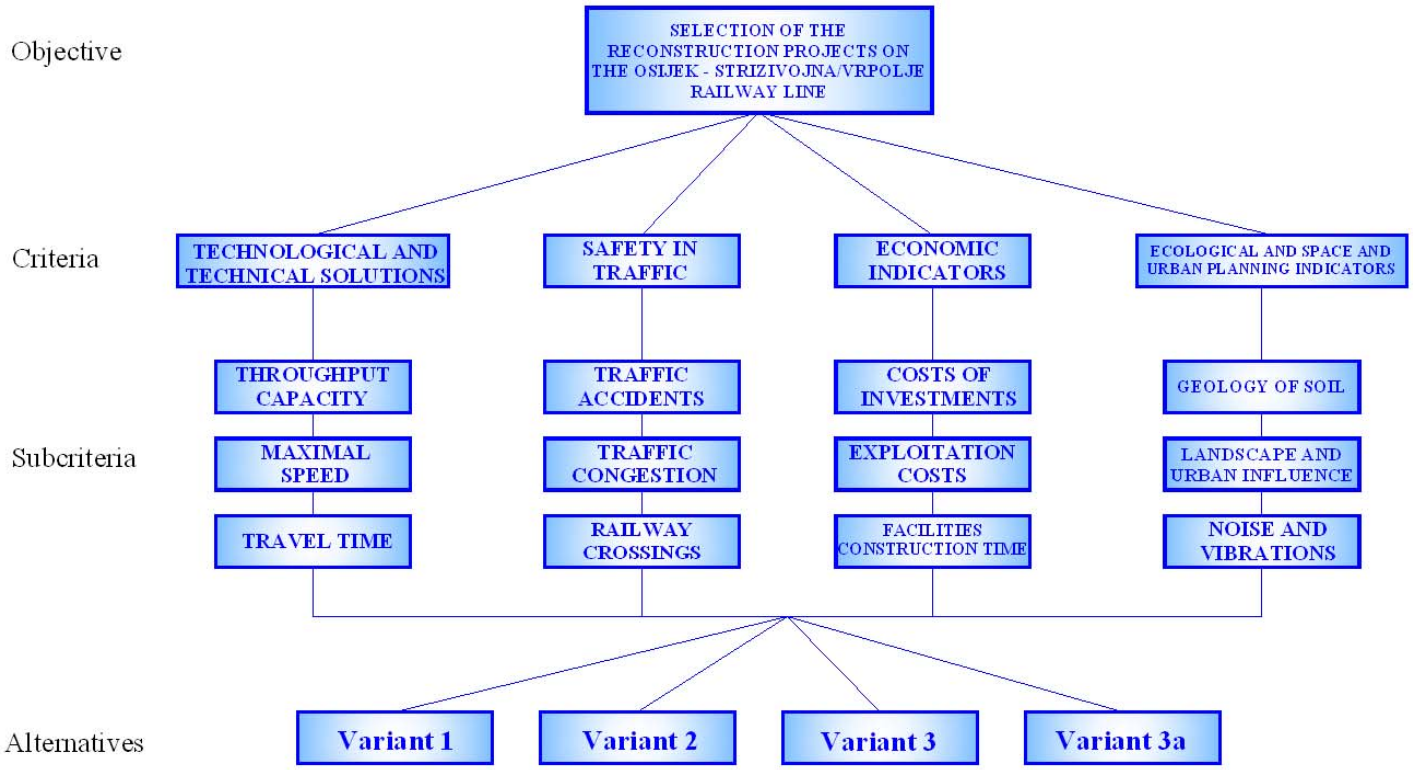
Meteor


T 20
R=10000 m
α=03–43–53
L=0
tg=325.740 m
D=651.250 m
S=5.304 m
h=0
v=160 km/h
T 30
R=500 m
α=34–11–50
L=40
tg=173.813 m
D=338.359 m
S=23.261 m
hn=35
v=70 km/h
T 23
R=700 m
α=37–02–50
L=175
tg=321.175 m
D=624.756 m
S=40.143 m
h=145
v=120 km/h
T 21
R=3500 m
α=19–33–49
L=0
tg=603.410 m
D=1195.073 m
S=51.634 m
h=0
v=160 km/h
T 32
R=1000 m
α=15–14–50
L=50
tg=158.845 m
D=316.081 m
S=9.023 m
hn=65
v=100 km/h
T 25
R=1500 m
α=16–30–20
L=180
tg=307.340 m
D=611.426 m
S=16.602 m
h=110
v=160 km/h
T 31
R=303 m
α=65–28–10
L=50
tg=219.816 m
D=395.865 m
S=57.613 m
hn=75
v=60 km/h
T 24
R=700 m
α=69–23–00
L=175
tg=571.832 m
D=1019.816 m
S=153.533 m
h=145
v=120 km/h
T 31=T 24
TRASA PO VARIJANTNOM RJEŠENJU za 160 km/h
TRASA PO IDEJNOM PROJEKTU ZA 120 km/h

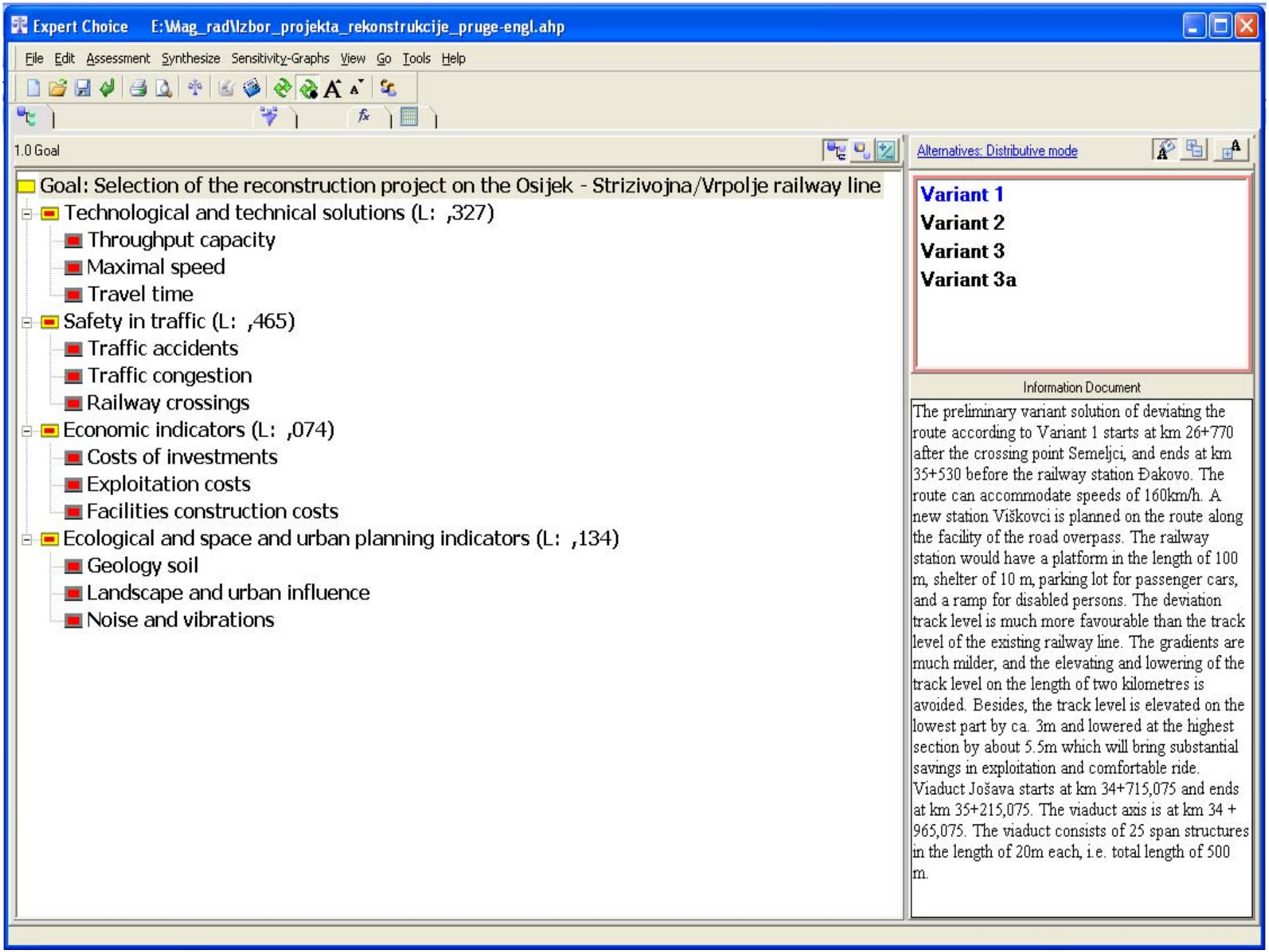
SWOT MATRIX

Variant	Strategy		Conclusion
	S – O	W – T	
Variant 1	- allows maximal speeds of 160km/h, - provides best exploitation conditions because the track level and track geometry are much more favourable not only in relation to the existing line but also in relation to other variants - at Viškovci there is no level crossing, thus increasing safety.	- necessary construction of viaduct Jošava, in the length of 500m, - increased investments due to the viaduct construction.	this variant needs to be analysed in more detail
Variant 2		- allows maximal permitted speeds of , - regarding exploitation parameters – track level and track geometry it is worse than Variant 1, - acc. to this variant, a viaduct is required almost the same length as according to Variant 1 (500m).	this variant needs to be left out of further analysis
Variant 3	- according to exploitation parameters (track level and track geometry) it is better than Variant 2, - regarding investments it is less than in Variant 1	- allows maximal permitted speeds of , - regarding exploitation parameters (track level and track geometry) it is worse than Variant 1, - it requires viaduct of the length of about 200m, - significant restoration of swamp land in front and behind the viaduct.	this variant needs to be analysed in more detail
Variant 3a	- regarding investments it is of lower order compared to Variant 3.	- allows maximal permitted speeds of , - regarding exploitation parameters (track geometry) it is worse than Variant 3.	this variant needs to be left out of further analysis

MCDM
- AHP METHOD -



Hierarchy structure of AHP model


Expert Choice E:\Mag_rad\Izbor_projekta_rekonstrukcije_pruge-engl.ahp
File Edit Assessment Synthesize Sensitivity-Graphs View Go Tools Help
1.0 Goal
Goal: Selection of the reconstruction project on the Osijek - Strizivojna/Vrpolje railway line
Technological and technical solutions (L: ,327)
Throughput capacity
Maximal speed
Travel time
Safety in traffic (L: ,465)
Traffic accidents
Traffic congestion
Railway crossings
Economic indicators (L: ,074)
Costs of investments
Exploitation costs
Facilities construction costs
Ecological and space and urban planning indicators (L: ,134)
Geology soil
Landscape and urban influence
Noise and vibrations
Alternatives: Distributive mode
Variant 1
Variant 2
Variant 3
Variant 3a
Information Document
The preliminary variant solution of deviating the route according to Variant 1 starts at km 26+770 after the crossing point Semeljci, and ends at km 35+530 before the railway station Đakovo. The route can accommodate speeds of 160km/h. A new station Viškovci is planned on the route along the facility of the road overpass. The railway station would have a platform in the length of 100 m, shelter of 10 m, parking lot for passenger cars, and a ramp for disabled persons. The deviation track level is much more favourable than the track level of the existing railway line. The gradients are much milder, and the elevating and lowering of the track level on the length of two kilometres is avoided. Besides, the track level is elevated on the lowest part by ca. 3m and lowered at the highest section by about 5.5m which will bring substantial savings in exploitation and comfortable ride. Viaduct Jošava starts at km 34+715,075 and ends at km 35+215,075. The viaduct axis is at km 34 + 965,075. The viaduct consists of 25 span structures in the length of 20m each, i.e. total length of 500 m.

RESULTS OF SWOT ANALYSIS

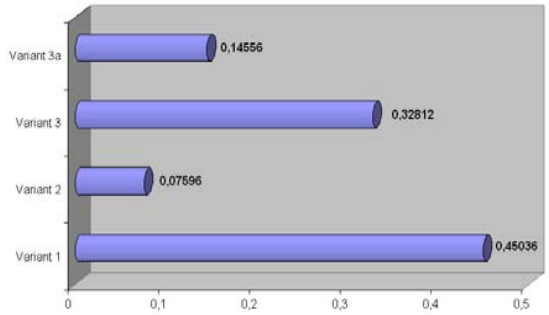
Variant 1

Variant	Strategy	
	S – O	**W – T**
Variant 1	- allows maximal speeds of 160km/h, - provides best exploitation conditions because the track level and track geometry are much more favourable not only in relation to the existing line but also in relation to other variants - at Viškovci there is no level crossing, thus increasing safety.	- necessary construction of viaduct Jošava, in the length of 500m, - increased investments due to the viaduct construction.

Results of AHP method

SELECTION OF THE RECONSTRUCTION PROJECTS ON THE OSIJEK - STRIZIVOJNA/VRPOLJE RAILWAY LINE
1,0

TECHNOLOGICAL AND TECHNICAL SOLUTIONS 0,28110		SAFETY IN TRAFFIC 0,51316		ECONOMIC INDICATORS 0,08493		ECOLOGICAL AND SPACE AND URBAN PLANNING INDICATORS 0,12081	
Variant 1	0,50808	Variant 1	0,46665	Variant 1	0,19673	Variant 1	0,42518
Variant 2	0,06162	Variant 2	0,07953	Variant 2	0,08569	Variant 2	0,08732
Variant 3	0,33339	Variant 3	0,31458	Variant 3	0,31906	Variant 3	0,37973
Variant 3a	0,09691	Variant 3a	0,13924	Variant 3a	0,39853	Variant 3a	0,10776



Results of cost-benefit analysis

Variant / Indicator	Variant 1	Variant 3
Economic rate of return	14,34 %	13,86 %
Economic relative net present value	+0,6284	+0,5693
Payback period	11 years	12 years

QUIZ - AHP

DANKE!

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