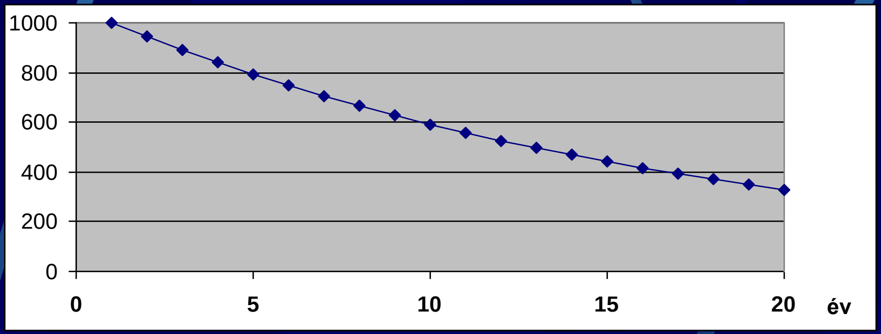
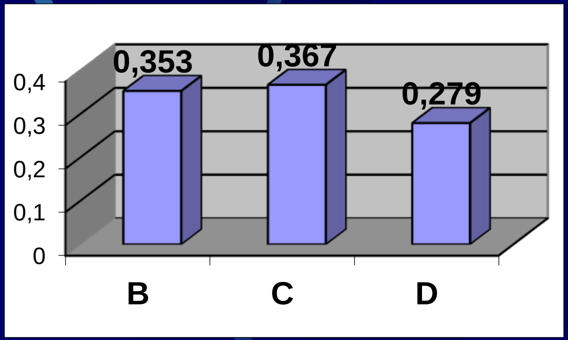
Cost-benefit analysis of alternatives, multi-criteria analysis of alternatives





Transport networks practice 1-2.
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Need for analysing network alternatives

- The aim of the comparative analysis of network development alternatives, as part of the network planning process, is to prepare a recommendation for decision.
- Comparison requires numerical indicators, characterising technical, economical, social and environmental effects.
- The essence of the analysis is the calculation, forecast and comparison of costs and benefits for several years.

Need for analysing network alternatives

- The aim of the analysis is to choose the most appropriate and efficient technical solution from technically, financially and legally feasible project alternatives for further preparation.
- There is a need for the accurate determination of expected achievements, according to the resulted indicators. When the analysis includes the determination of the aim, indicators describing that aim shall be established.

Need for analysing network alternatives

- In the analysis process financial, economical and other factors have an important role, because certain advantages can be described only using non-quantifiable factors. Determining the numerical value of these factors is possible by expert opinion or virtual valuation.
- In the analysis process outputs of the environmental effect analysis, and in case or roads, outputs of the safety audit shall be taken into account as well.

Methods for analysing network alternatives

- **In case of technically, financially and legally feasible project alternatives the analysis can be performed (according to the EU Guidelines) by:**
  - **cost-benefit analysis (CBA),**
  - **simplified cost-benefit analysis ,**
  - **multi-criteria assessment (MCA).**
- **The MCA may consider even non-quantifiable factors within the analysis process.**

Cost-benefit analysis

- The cost-benefit analysis (CBA) within the project preparation process is connected to technical and environmental planning tasks applying an integrated approach.
- Consequently, the cost-benefit analysis is usually performed within the preparation of a feasibility study.
- Different financial indicators are calculated in the cost-benefit analysis in order to help the comparison of project alternatives.

Cost-benefit analysis indicators

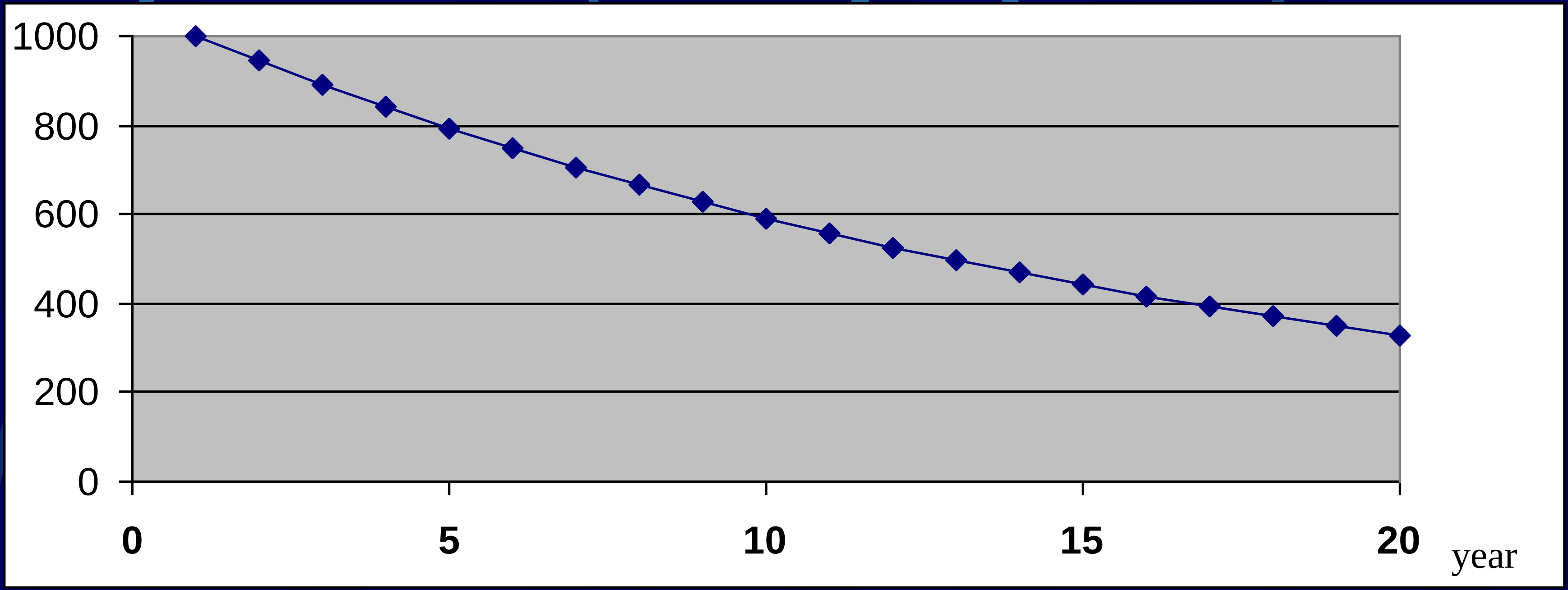
- **ENPV (economic net present value) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time, characterising the profitability of the project. ENPV is a key factor for decision, because only projects with positive ENPV are feasible.**
- **Calculation:**

$$ENPV = \sum_{t=0}^{n} \frac{X_t}{(1+i)^t}$$

- **where *X* is the cash flow for a given year (benefit - cost), *i* is the discount rate and *t* is the actual year**

Cost-benefit analysis indicators

Example for net present value applying 6% discount rate



WORKSHEET

Cost-benefit analysis indicators

- **ERR (economic internal rate of return) is the discount rate that makes the net present value (NPV) of a project zero.**
- **If ENPV = 0 then i = ERR**
- **BCR (benefit-cost ratio) is an indicator showing the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms. The requirement for the BCR indicator is to be greater than 1. The BCR is usually not enough, because it provides information only the proportion of benefits and costs without their absolute values.**

Cost-benefit analysis indicators

- According to the EU Guidelines, a project is feasible for financial support when the social utility can be proven by a cost-benefit analysis. Requirements for CBA indicators in case of a feasible project are:
  - ENPV shall be positive,
  - ERR shall be higher than the applied social discount rate,
  - BCR shall be above 1.

Cost-benefit analysis indicators

- A generalised cost-benefit indicator can be defined as the proportion of the positive results in natural dimensions and the project costs in monetary dimension. This is the specific cost to achieve a unit of positive effect. :

$$\frac{\text{results in natural dimension}}{\text{investment costs + operation costs}}$$

- This indicator can be calculated for:
  - the life time of the project, considering all effects and the NPV of costs,
  - a given year, calculating yearly effects and yearly costs.

Cost-benefit analysis indicators

- **In case of the simplified economic cost-benefit analysis the alternatives are compared by their effects and costs.**
- **This method can be applied when the effects of the alternatives vary significantly.**
- **The simplified benefit-cost indicator for the comparison:**

$$\frac{\text{summarised effects}}{\text{summarised surplus costs}}$$

- **This indicator shows for the alternatives the achievable effect by using a unit cost.**

Cost-benefit analysis indicators

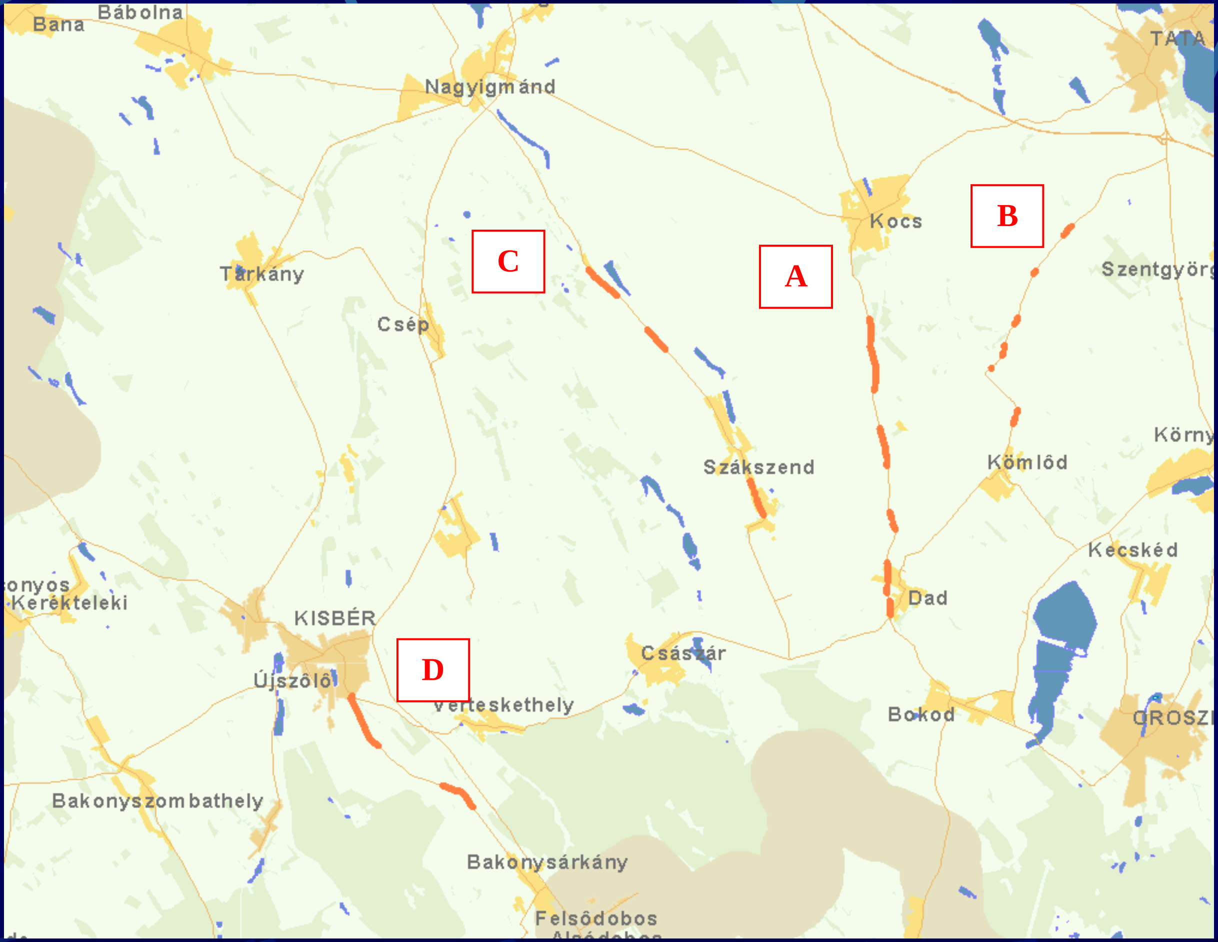
- **Steps of choosing the most efficient alternative at relative minimal risk, applying the simplified cost-benefit analysis:**
  - **estimation of investment and operation costs,**
  - **estimation of socio-economic and environmental effects,**
  - **comparison of alternatives based on benefit/cost indicators.**
- **Assessment of project alternatives always shall consider the „do nothing” case without the project as well.**

CBA example (Worksheet)

- In the example reconstruction of four low-volume traffic Hungarian secondary roads are compared. In the initial year of the analysis (2010) all these roads had been heavily deteriorated.
- Data source was the National Road Databank of the Hungarian Road Management Co.
- There was no public transport on the road „A”, therefore it has been left out.

CBA example (Worksheet)

Road sections in the example, indicating deteriorated parts



CBA example (Worksheet)

Factors and their values used in the example

Project alternative		B	C	D
Section length	m	10754	15618	7329
Deteriorated length	m	1066	2500	2524
Average daily traffic	pcu/d	429	360	369
Complex condition index		4.8	5.1	5.3
Inhabitants concerned	person	1225	1537	940

CBA example (Worksheet)

- Calculation of the cost-effectiveness indicator:

$$\frac{\text{condition improvement} * \text{traffic performance}}{\text{reconstruction cost}}$$

- Effect of condition improvement is decreasing the complex condition index by 2.0. Condition improvement for the total section is calculated as a weighed average by length of the indices of the better reconstructed part and the remaining part.
- Traffic performance is the section length multiplied by its average daily traffic (vehicle kms).

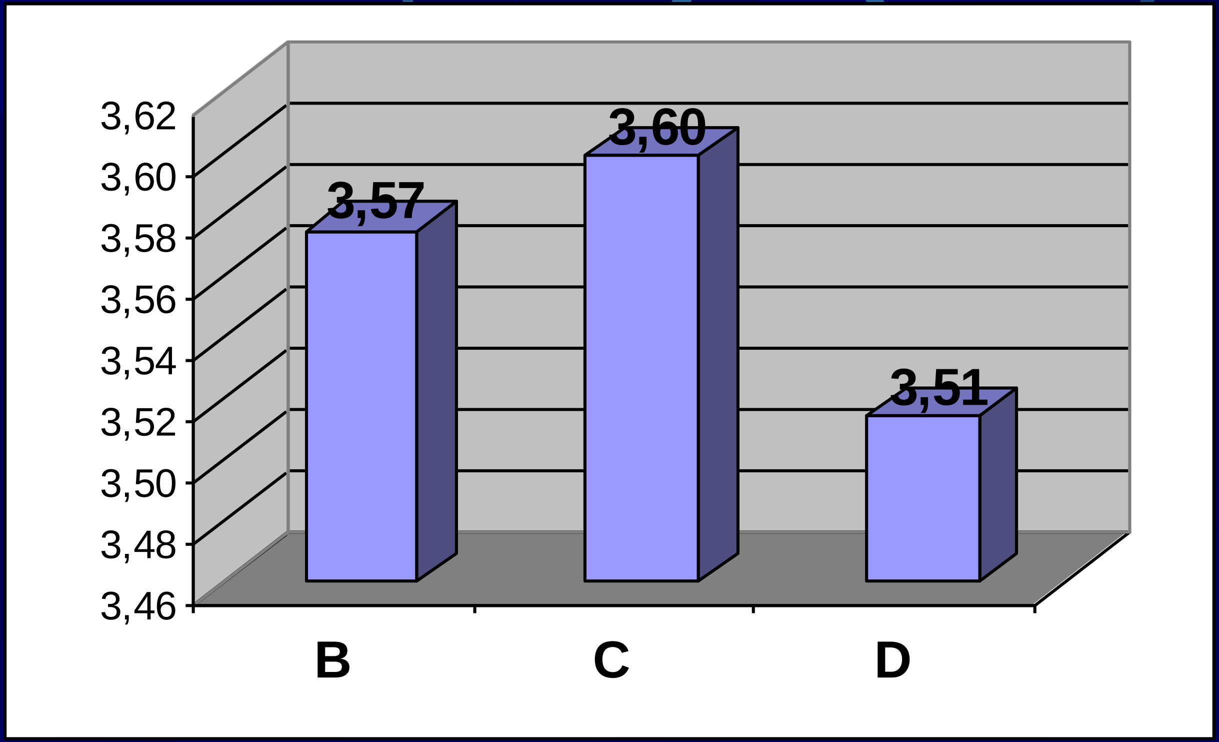
CBA example (Worksheet)

Calculation of the cost-effectiveness indicator:

	B	C	D
reconstruction cost mHUF	256	500	530
condition improvement (CI)	0.20	0.32	0.69
traffic performance (TP)	4613	5622	2704
CI * TP	915	1800	1863
cost-effectiveness indicator	**3.57**	**3.60**	**3.51**

CBA example (Worksheet)

Based on the comparison of the cost-effectiveness indicators, the priority ranking is: C, B, D



CBA example (Worksheet)

- Simplified economic cost-benefit analysis for the first 4 years with 6% discount rate:
- Cost: reconstruction cost, since operation costs in the first 4 years are negligible.
- Benefit: road user cost decrease, calculated as NPV.
- Road user cost decrease: multiplication of the condition improvement and the traffic performance and the specific road user cost (in this example 80 Ft / vehicle km).

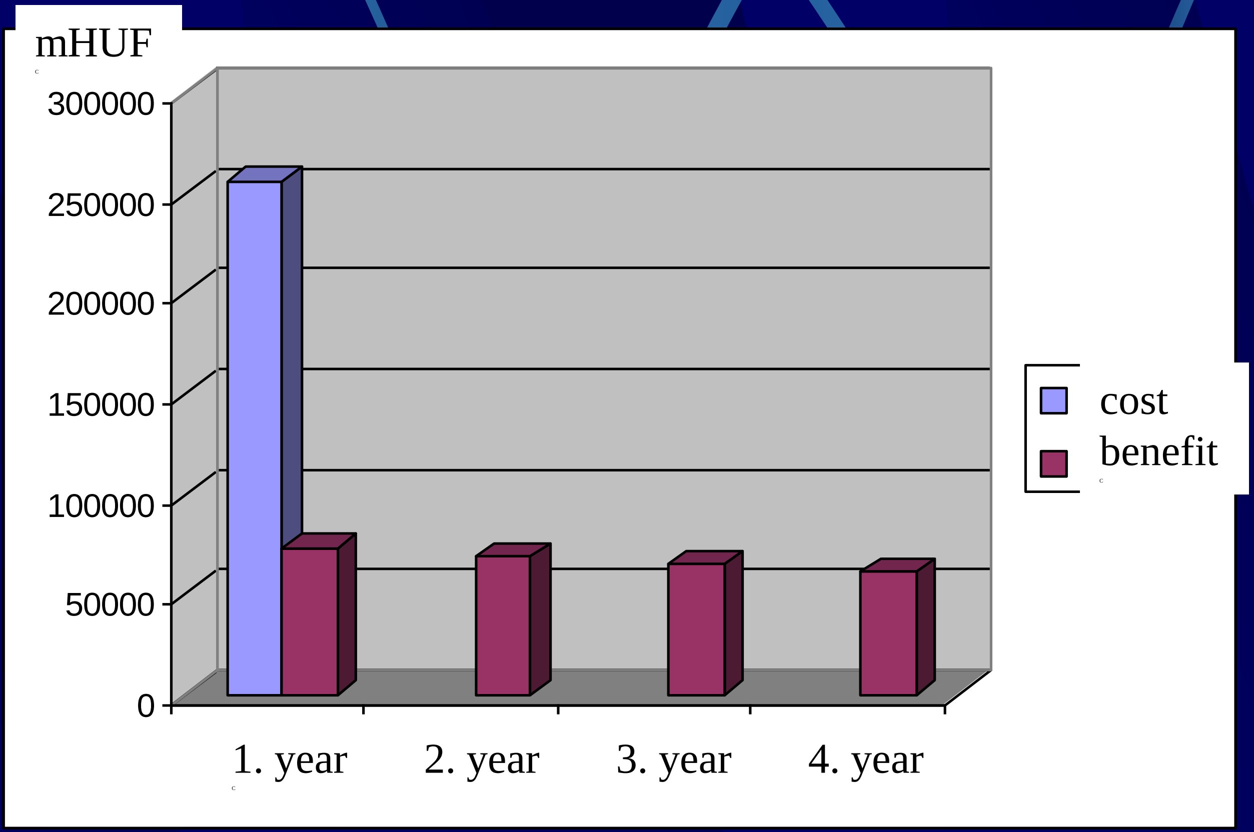
CBA example (Worksheet)

Calculation of economic indicators:

	B	C	D
reconstruction cost mHUF	255840	500000	530040
road user cost decrease mHUF	268755	528914	547341
1. year	73170	144000	149017
2. year	69029	135849	140582
3. year	65121	128159	132625
4. year	61435	120905	125118
net present value ENPV mHUF	**12915**	**28914**	**17301**
benefit-cost ratio BCR	**1.05**	**1.06**	**1.03**
internal rate of return ERR	**9.8%**	**10.3%**	**8.4%**

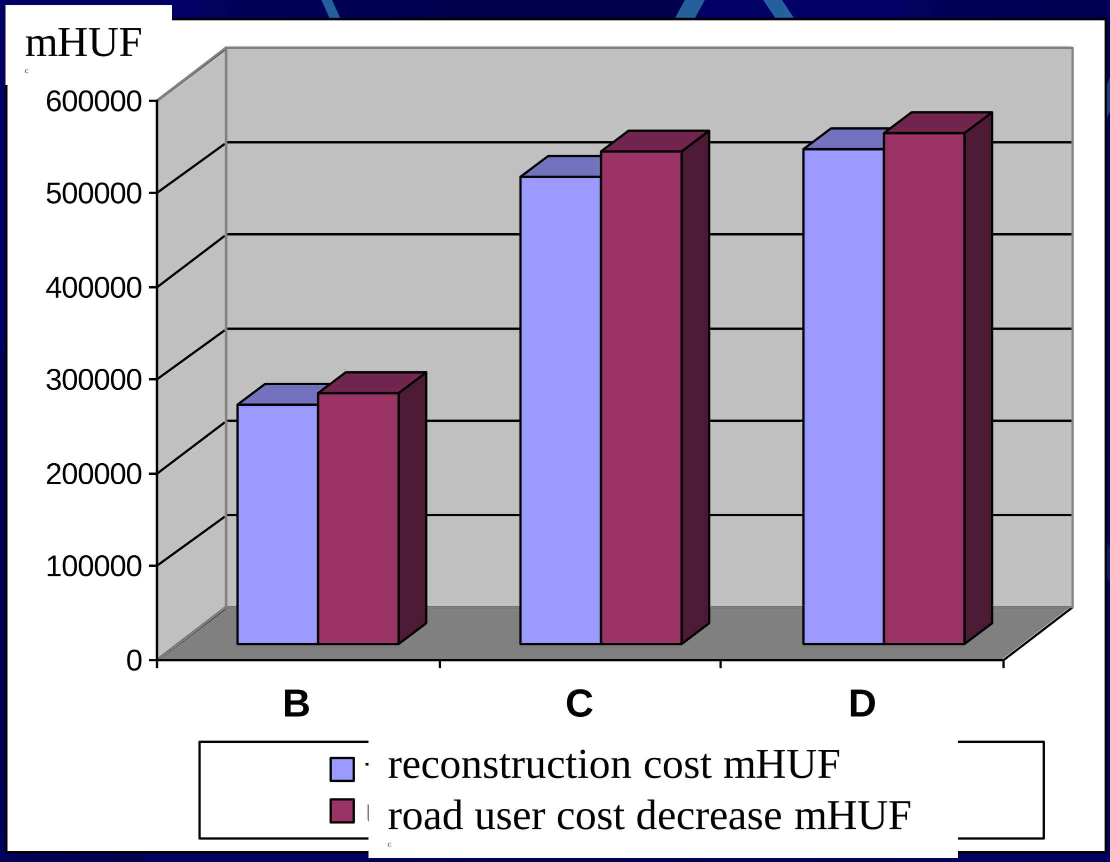
CBA example (Worksheet)

NPV of yearly costs and benefits for alternative B



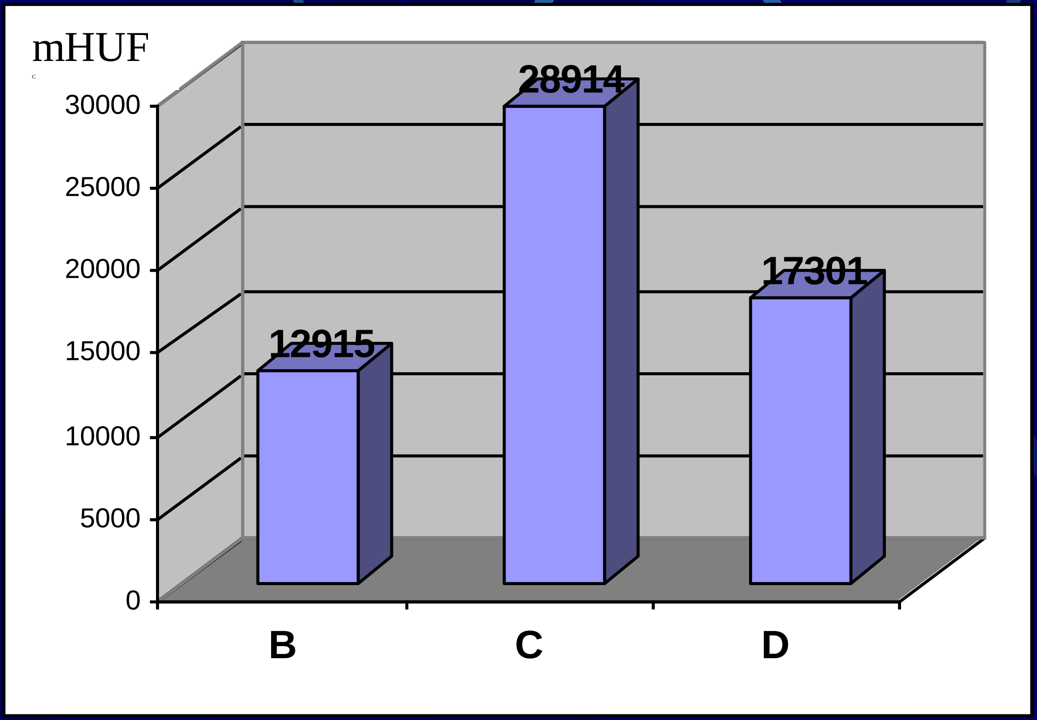
CBA example (Worksheet)

Comparison of costs and benefits



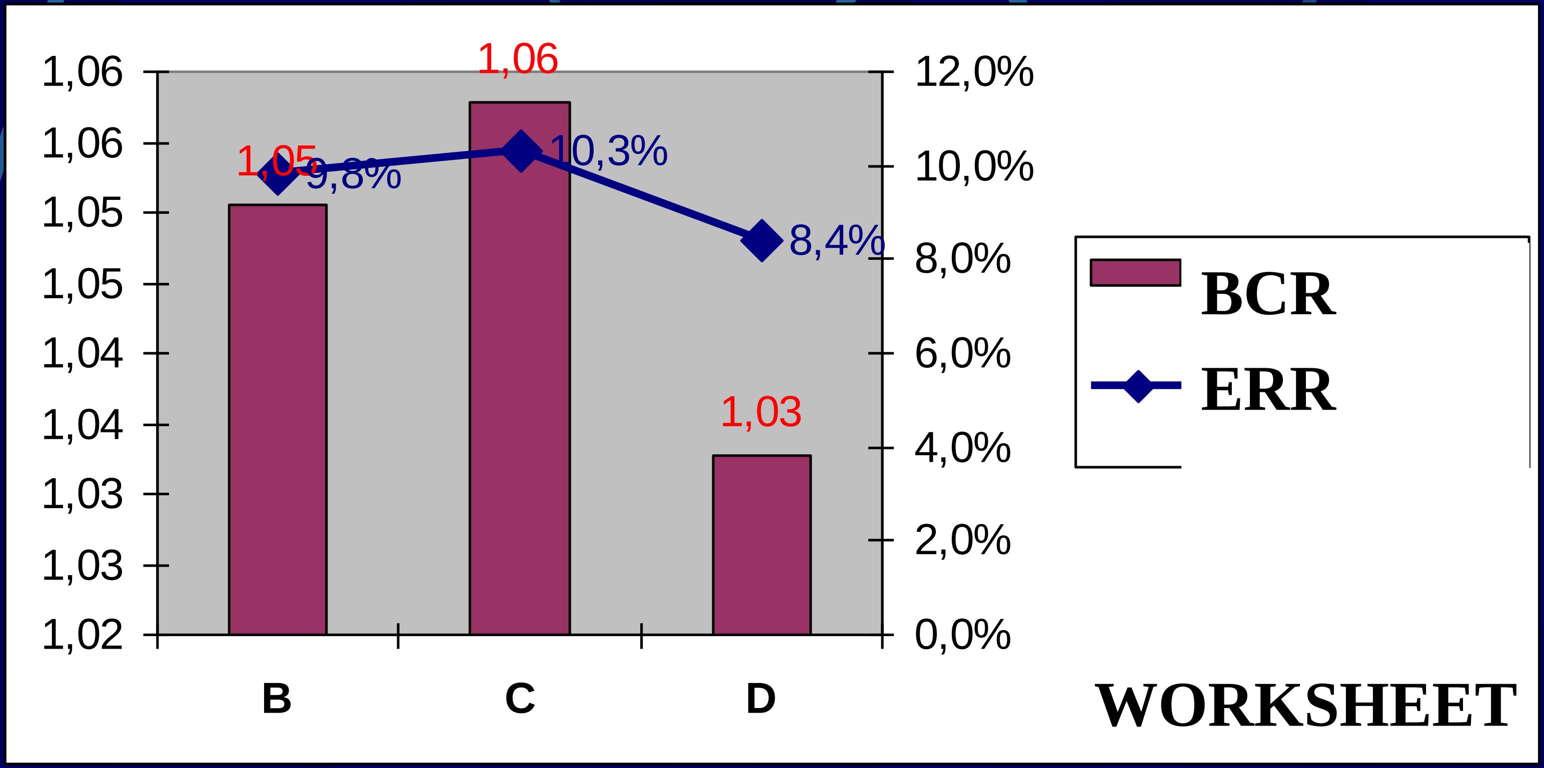
CBA example (Worksheet)

- Priority ranking based on the ENPV values of analysed alternatives (NPV of the difference of benefits and costs): C, D, B



CBA example (Worksheet)

- Priority ranking based on the BCR and ERR values: C, B, D



Multi-criteria analysis

- Multi-criteria analysis (MCA) is suitable for ranking and determining priorities.
- Its essence is the calculation of relative importance of assessment factors based on the preferences of the decision maker.
- MCA methods: decision tree, expert weighing, outranking, pairwise comparison, etc.
- An up-to-date analysis method is the Analytic Hierarchy Process, AHP (developed by Saaty).

Multi-criteria analysis

- **The Analytic Hierarchy Process is based on the analysis of hierarchic matrices containing relative importance values of assessment factors. Relative importance values are described on a scale from 1 to 9, usually applying only odd numbers (1, 3, 5, 7 and 9).**
- **Pairwise comparison of factors is performed by experts for all possible case.**
- **Results in case of n assessment factors are presented as a_{ij} elements in the $n \times n$ matrix.**
- **This method is widely used nowadays at various fields.**

$e_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n}$

Multi-criteria analysis

- After filling in the matrix, the next step is the calculation of an eigenvector (*e*) containing relative weights (w_i), characterising the importance of assessment factors. A good approximation is to calculate a geometric average instead.

$$e_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n}$$

$$w_i = \frac{e_i}{\sum_{1}^{n} e_i}$$

- The first level AHP matrix provides the relative importance of assessment factors but does not show the actual differences between the real assessment factors of different project alternatives.

Multi-criteria analysis

- Sometimes there is an inconsistency within the pairwise comparison, that can be measured by the consistency ratio (*CR*). This ratio is referred to the totally random comparison results and its value must remain below 0.1
- Second level AHP matrices indicate the differences of every assessment factor in case of the analysed project alternatives. A second level AHP matrix is prepared for every assessment factor, containing the weights of the project alternatives from the point of view of the given assessment factor (w_{vi}).

Multi-criteria analysis

- **Second level AHP matrices contain proportions of actual numerical values of assessment factors for each alternative ($v_{ij} = x_i / x_j$ for the x assessment factor). In case of non-quantifiable factors the proportion of expert values given as points or virtual values are put into the matrix, consequently $CR = 0$.**
- **Quantitative and qualitative differences between the assessed alternatives this way can be totally considered.**
- **In case of cost-like factors, it is advisable to use their reciprocal values, since less cost is usually indicates a better alternative.**

Multi-criteria analysis

- **The last step is the calculation of the general performance vector ($\underline{r}$) of the assessment weights (r_i) in order to establish the ranking order, applying known matrix operations.**

$$r_i = \sum_{1}^{n} w_{vi} w_i$$

- **This result matrix is the third level AHP matrix, suitable for both absolute and relative rankings.**

MCA example

- In the example for the AHP analysis there are four assessment factors:
  - reconstruction length (related to reconstruction cost), that is a cost-like variable, where the less value is the better,
  - average daily traffic,
  - complex condition index, calculated from unevenness, load bearing capacity and surface distress marks,
  - socio-economic part is taken into account in a simplified way, using the number of concerned inhabitants.

MCA example

Factors and their values used in the example

Project alternative		B	C	D
Deteriorated length	m	1066	2500	2524
Average daily traffic	pcu/d	429	360	369
Complex condition index		4.8	5.1	5.3
Inhabitants concerned	person	1225	1537	940

MCA example

Relative importance values of assessment factors:

- **reconstruction length is more important than traffic (3),**
- **condition index is more important than reconstruction length (3) and significantly more important than traffic (5),**
- **inhabitants concerned is the most important assessment factor, it is more important than condition index (3), significantly more important than reconstruction length (5) and extremely more important than traffic (7),**
- **at symmetrical matrix fields the reciprocal values (1/3, 1/5 and 1/7) are given.**

MCA example

Filling in the first level AHP matrix - reconstruction length

	reconstr. length	traffic	condition index	in-habitants
reconstr. length		3		
traffic				
condition index				
in-habitants				

MCA example

Relative importance values of assessment factors:

- **reconstruction length is more important than traffic (3),**
- **condition index is more important than reconstruction length (3) and significantly more important than traffic (5),**
- **inhabitants concerned is the most important assessment factor, it is more important than condition index (3), significantly more important than reconstruction length (5) and extremely more important than traffic (7),**
- **at symmetrical matrix fields the reciprocal values (1/3, 1/5 and 1/7) are given.**

MCA example

Filling in the first level AHP matrix - condition index

	reconstr. length	traffic	condition index	in-habitants
reconstr. length		3		
traffic				
condition index	3	5		
in-habitants				

MCA example

Relative importance values of assessment factors:

- **reconstruction length is more important than traffic (3),**
- **condition index is more important than reconstruction length (3) and significantly more important than traffic (5),**
- **inhabitants concerned is the most important assessment factor, it is more important than condition index (3), significantly more important than reconstruction length (5) and extremely more important than traffic (7),**
- **at symmetrical matrix fields the reciprocal values (1/3, 1/5 and 1/7) are given.**

MCA example

Filling in the first level AHP matrix - inhabitants

	reconstr. length	traffic	condition index	in-habitants
reconstr. length		3		
traffic				
condition index	3	5		
in-habitants	5	7	3	

MCA example

Relative importance values of assessment factors:

- **reconstruction length is more important than traffic (3),**
- **condition index is more important than reconstruction length (3) and significantly more important than traffic (5),**
- **inhabitants concerned is the most important assessment factor, it is more important than condition index (3), significantly more important than reconstruction length (5) and extremely more important than traffic (7),**
- **at symmetrical matrix fields the reciprocal values (1/3, 1/5 and 1/7) are given.**

MCA example

Filling in the first level AHP matrix - reciprocal values

	reconstr. length	traffic	condition index	in-habitants
reconstr. length		3	0.333	0.2
traffic	0.333		0.2	0.143
condition index	3	5		0.333
in-habitants	5	7	3	

MCA example

Filling in the first level AHP matrix – 1 for main diagonal

	reconstr. length	traffic	condition index	in-habitants
reconstr. length	1	3	0.333	0.2
traffic	0.333	1	0.2	0.143
condition index	3	5	1	0.333
in-habitants	5	7	3	1

MCA example

The first level AHP matrix with calculated weights

AHP	reconstr. length	traffic	condition index	in-habitants	geom. average	**weight**
reconstr. length	1	**3**	0.333	0.2	0.669	**0.118**
traffic	0.333	1	0.2	0.143	0.312	**0.055**
condition index	**3**	**5**	1	0.333	1.495	**0.263**
inhabitants	**5**	**7**	**3**	1	3.201	**0.564**

MCA example

- **Importance order of assessment factors based on weights: inhabitants concerned, condition index, reconstruction length and traffic.**
- **The most important factor is the number of inhabitants concerned, that is a social factor, providing slightly more than half (0.564) of the summarised weight values.**
- **The value of the *CR* consistency ratio is 0.043 remaining below the critical limit (0.1).**

MCA example

The second level AHP matrices

reconstr. length	B	C	D	geom. average	**weight**
B	1	2.345	2.368	1.771	**0.541**
C	0.426	1	1.010	0.755	**0.231**
D	0.422	0.990	1	0.748	**0.228**

traffic	B	C	D	geom. average	**weight**
B	1	1.192	1.163	1.115	**0.370**
C	0.839	1	0.976	0.935	**0.311**
D	0.860	1.025	1	0.959	**0.319**

MCA example

The second level AHP matrices

condition index	B	C	D	geom. average	**weight**
B	1	0.929	0.899	0.942	**0.314**
C	1.077	1	0.969	1.014	**0.338**
D	1.112	1.032	1	1.047	**0.349**

inhabitants	B	C	D	geom. average	**weight**
B	1	0.797	1.303	1.013	**0.331**
C	1.255	1	1.635	1.271	**0.415**
D	0.767	0.612	1	0.777	**0.254**

MCA example

- Second level AHP matrices contain proportions of actual numerical values of four assessment factors for each alternative as well as weights of alternatives from the point of view of the given assessment factor.
- In the third level AHP matrix, each alternative has got a row, showing weights of alternatives by assessment factors, calculated in the second level AHP matrices.
- The lowest row contains the relative importance weights of assessment factors, calculated in the first level AHP matrix.
- Right columns contain assessed weights and ranking.

MCA example

The third level AHP matrix with ranking

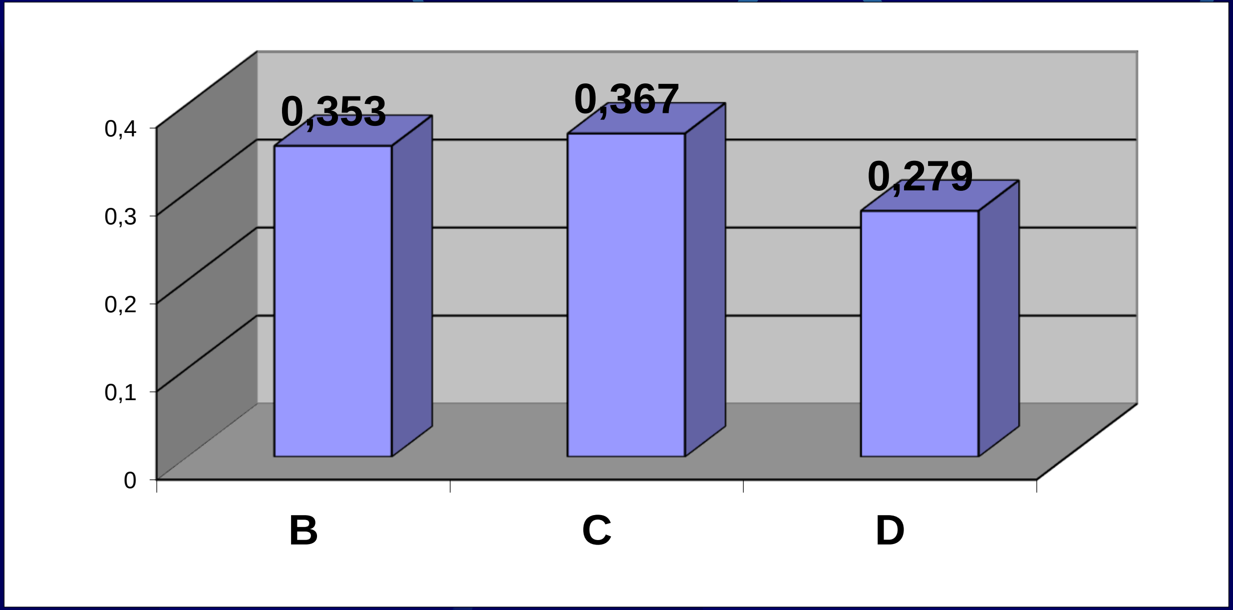
Result	reconstr. length	traffic	condition index	in-habitants	assessed weight	ranking
B	0.541	0.370	0.314	0.331	**0.353**	**II**
C	0.231	0.311	0.338	0.415	**0.367**	**I**
D	0.228	0.319	0.349	0.254	**0.279**	**III**
weight	**0.118**	**0.055**	**0.263**	**0.564**	1.000	

MCA example

- **Based on th calculated assessed weights and ranking, Project „C" has become the most favourable reconstruction alternative, however, there is only a slight difference related to the second best alternative (Project „B") within assessment weights.**
- **The first place of Project „C" is partially explained by the higher number of inhabitants concerned, highlighting the effect of non-technical factors within the multi-criteria analysis process.**
- **There is some agreement and a slight disagreement between the results of the MCA and the CBA.**

MCA example

Chart of AHP assessed weights



- **Based on the MCA analysis, the ranking of project alternatives is: C, B, D**

Summary

Finally, the resulted rankings of different analysis methods can be confronted, providing a complex decision preparation.

	B	C	D
cost-effectiveness indicator	2	1	3
net present value ENPV mHUF	3	1	2
benefit-cost ratio BCR	2	1	3
internal rate of return ERR	2	1	3
multi-criteria assessment weight	2	1	3
RECOMMENDED RANKING	**2**	**1**	**3**

Summary

- **Realistic comparison of project alternatives requires quantifiable indicators, characterising the technical, the economical, the social and the environmental effects.**
- **Cost-benefit analysis evaluates cost-effectiveness of project alternatives, calculating net present values of social benefits and costs.**
- **Cost-benefit analysis is applied for comparison and validation of financial support.**

Summary

- Multi-criteria analysis is suitable for ranking and determining priorities.
- Its essence is the calculation of relative importance of assessment factors based on the preferences of the decision maker.
- In the analysed example the ranking of alternatives (C, B, D) has become the same in almost all applied methods.

Thank you for your attention!

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