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COMPUTER AIDED APPRAISAL OF ALTERNATIVE BYPASS DURING TUNNEL CLOSURE

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Abstract: *Effective traffic solutions by tunnels are always of the public interest. They are expected to improve the functioning of transportation infrastructure. There are often inconsistent views of the economic facet of the matter and disunite opinions on appraisal and realization. By solving of a specific problem the paper presents a rigorous approach to economic analysis within comparing and research of traffic solution realized today mostly in computer aided fashion. The problem is what is better during closure of one tunnel tube: to use bypass via existing motorway or to build up and to use a flexible lane in reverse direction within second tunnel tube left in operation. The results of presented research gives more general applicable conclusions.*

Key words: *tunnel closure, bypass, benefit-cost analysis, present value, sensitivity analysis, break-even analysis.*

1 INTRODUCTION

Utilize of computers at appraisal and searching for solutions is accompanied mostly by building up respective model and consequently by making a computer system according to requirements [1], [2]. In the case there is presented system for appraisal of bypass alternatives during closure of one tunnel tube. The transport solution rests in either to use an existing motorway outside of tunnel or to use one traffic lane in free second tube of the tunnel by equipping it and to switch it for reverse direction. Respective model is expected to accept and to regard all the key parameters describing transport situation in given stretch as well as the most relevant economic factors as are required investments, requirements on facilities and operation, expected revenues from toll, all that in terms of time value of money. Particularly necessary is to take into consideration the specification of capital costs and possible increasing costs and tolls over a given time horizon. To take two views of economic evaluation is also important, either from private business viewpoint, without taking into

account externalities, or from public sector viewpoint, including different benefits or losses, usually hardly to quantify in monetary units.

2 EVALUATION SYSTEM

2.1 INPUT AND OUTPUT DATA

The data represent inputs available for user in order to set up a model situation according to particular traffic case. The outputs are the results of research and evaluation for appraisal. They are suitably arranged [3], [4] and divided into three categories, as blocks of data, named: *space coherences, time coherences and evaluation*.

2.1.1 SPACE COHERENCES

In this block of data (fig. 1), where white cells feature entry items and filled cells are computed ones, there are defined:

The types and numbers of entering vehicles into given motorway stretch. The system enables to divide vehicles into 5 categories. It is up to user to name and to classify them following research intentions.

The toll tariff rates for each defined category of vehicles, separately for use of given motorway and for tunnel. The tariffs are defined per 1km.

A ratio value in the variable named *EntriesMix* that specifies how many vehicles take decision to use motorway and how many to use tunnel. Such defined variable enables to investigate different cases of mix vehicles traffic via given road stretch. Within research of comparing so-called pure, mutually exclusive alternatives, i.e. bypass by motorway versus passage via tunnel, the value is set on 1.

The distance, the speed, the waste of time and the accident data needed for respective computations, separately for: bypass, using 2^{nd} lane being set in reverse direction, normal passage during current operation of tunnel and for vehicles in 1^{st} lane during closure when traffic is digested there. The waste of time takes into consideration an increase of time being spent in given road stretch compared to the current operation with respective valuation. Regarding accidents, analogically, it is taken into consideration presumed increase numbers of accidents due to extended distance, more complicated and digested traffic following from estimations of numbers accidents per km and day in given road stretch with respective valuation. These possibilities enable to include into investigation also externalities and to pursue research within benefit-cost analysis as well, mostly demanded at public project assessment.

The numbers vehicles driving in from the reverse side during closure using already only 1^{st} lane available. There can be different number of vehicles driving contrarily within given road stretch.

The computed overall numbers of vehicles in direction of bypass.

The computed average values of toll paid per vehicle and km, separately for motorway and for tunnel.

The computed values of waste of time, separately at using bypass, 2nd lane and 1st lane, during closure.

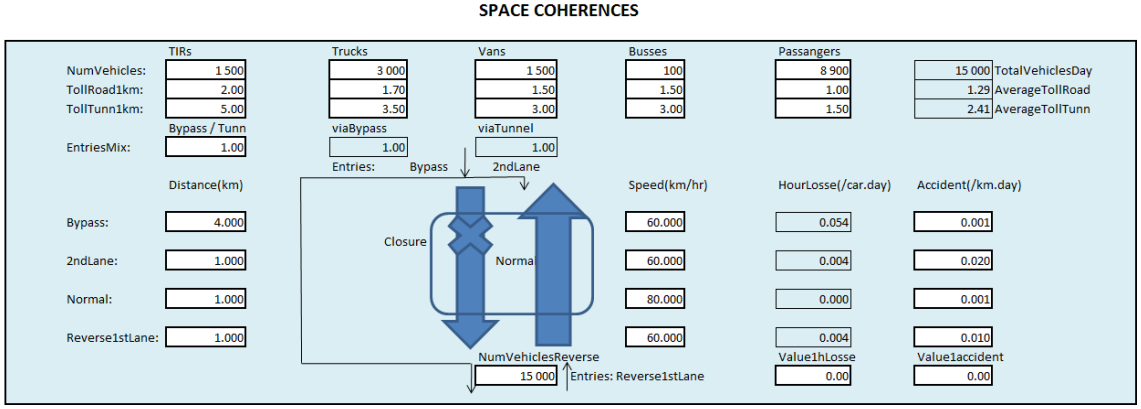


Fig. 1 *Exhibit of the data block SPACE COHERENCES in modeled case*

2.1.2 TIME COHERENCES

In this block of data (fig. 2) it is suitable to define 2 blocks, separately for case of the bypass via motorway and for case using 2nd lane of tunnel tube in operation during the closure time. With regard to technical and economic realization they represent two different data models. Their benefit and cost realization is needed to apprehend in time differentiation, i.e. in terms of the time value of money, so that the particular blocks are displayed in a depictive form [5] of cash flow diagram, i.e. by course of positive and negative money flows over time axis in chosen half year steps.

In the block *BYPASS* there are then defined the following input and output data:

- the numbers of days for tunnel tube closure within a half year,
- the overall time horizon for research given by number of half years,
- the computed expected revenue from toll per a half year for using motorway,
- the costs for setting up and equipping bypass, the current costs for its maintenance per 1 day and the costs for its cancel in the end of closure,
- the computed total costs for maintenance of bypass,
- the computed opportunity costs being set by value in variable of *LostReven(0to1)*, representing a lost revenue ratio from toll compared to normal operation in tunnel,
- the computed losses represented by values of waste of time and by values of increased number of accidents due to bypass driving with longer distance and more complicated traffic.

In the block *2ndLANE* there are defined the following input and output data:

- the computed expected revenue from toll per a half year for use of tunnel,
- the revenue from liquidation of equipment and furnishes to build up the flexible 2nd lane, in the end of life expectation of tunnel, in this case 60 half years, i.e. 30 years,
- the investments needed to build up and to equip the flexible 2nd lane of tunnel tube, separately for 30 years life expectation investment and 7 years life expectation ones with respective costs for their maintenance per a half year. All that provided that the investment with 7 years life cycle must be assigned for each 7 year period with possibilities of trade-in if certain salvage values arise,

- the costs occurred by operative equipping such a flexible switchable lane (fixed part and variable part per 1km), next by its current maintenance (fixed part per 1 day and variable part per 1km) and costs for cancel of such equipment after ending of closure (fixed part and variable part per 1km). According to circumstances, in certain cases, it is not necessary to utilize all that possibilities,
-the computed losses representing values of waste of time and values of the increased numbers of accidents due to getting traffic more digested in tunnel during the closure.

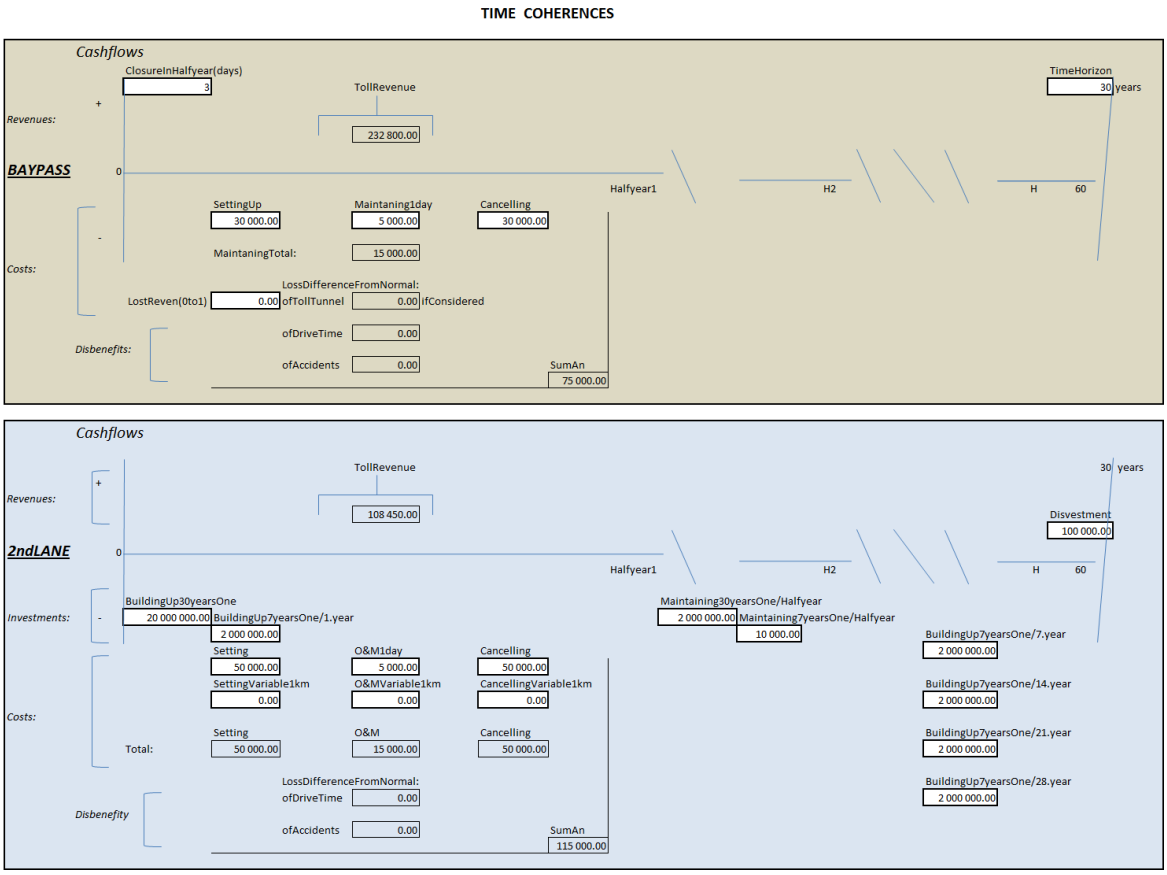


Fig. 2 *Exhibit of the data block TIME COHERENCES in modeled case*

2.1.3 APPRAISAL

It is the 3rd data block with name of *EVALUATION* (fig. 3) in that there are entered values of financial parameters and displayed results. They are as follows:

- the interest rate per annual (*i* %), i.e. financial costs of proceeds accrued to set up and to operate the alternative *bypass* and separately for setting up and operating the alternative *2ndlane*,
- the expected increase (*g* %) of toll charges yearly and separately increase of costs yearly, that is possible but not necessary to use in research,
- the computed present value *PWBypass* in EUR for cash flow of the alternative *bypass* in given case,
- the computed present value *PW2ndlane* in EUR for cash flow of the alternative *2ndlane* in given case,

- the evaluation (*Bypass vs. 2ndLane*) with designation of the alternative resulting as economically better one,
- the computed present value *SumPWMix* in EUR for the variant of mixture, i.e. if driving of vehicles is set by ratio value in parameter *EntriesMix*, given in the block of space coherence. In such case there defined part of vehicles use bypass and the rest 2nd lane. It enables to evaluate various cases of traffics via given road stretch, simultaneously taking into research different economic cases of investing and operating of motorway and tunnel. In such a way a sophistic entering values of data enables to carry out also overall appraisal of transport solutions, e.g. within assessment of case: road versus tunnel construction at given specific conditions of a region.

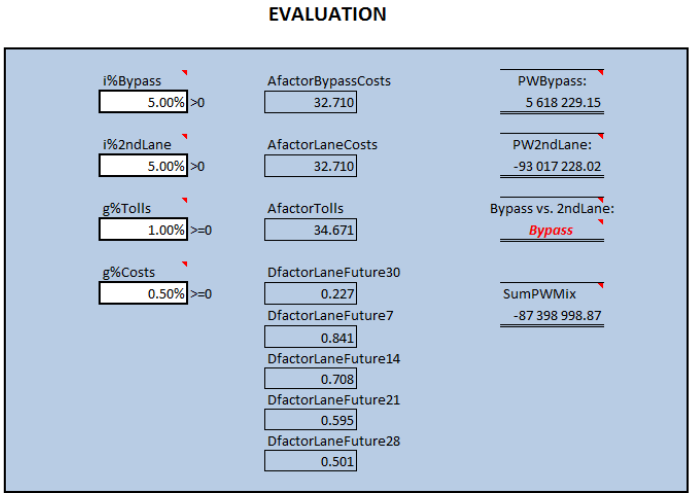


Fig. 3 *Exhibit of the data block EVALUATION in modeled case*

2.2 ANALYSES

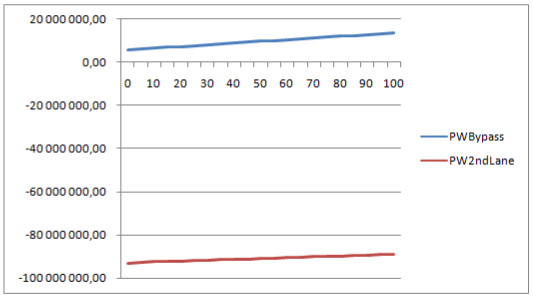
The system enables also next possibilities of research as are sensitivity analysis, break-even analysis, what-if analysis, scenario analysis as well as to search for a concrete solution. Regard to the extent of the paper there are presented only sensitivity analysis and break-even analysis (fig. 4) in a given investigated case.

The sensitivity analysis allows to observe in table or in graph sensitivity of investigated indicator, in this case, present value, on change of key parameter values, e.g. number of vehicles, toll charges, number of closure days or length of bypass, usually in percentage deviation from a basic initial case as the most expected one.

The break-even analysis enables, in this case, at comparing two pure, mutually exclusive, alternatives: bypass versus 2nd lane, at certain relevant range of key parameters values defined on *x* axis (e.g. number of vehicles, toll charges, number of closure days, length of bypass, required investments) to observe whether there is intersection between course of present value of the first and the second alternative. If so, it would mean that solution (what alternative is better off) depends on value of the respective parameter on *x* axis, e.g. on level of toll charges or investments. Then, before a such value on *x* axis it would be better the first solution and behind it the second one.

B) Break-even:

TollGrowth%	PWBypass	PW2ndLane
0	5 618 229.15	-93 017 228.02
5	6 021 804.53	-92 502 118.41
10	6 425 379.92	-92 314 112.60
15	6 828 955.30	-92 126 106.80
20	7 232 530.69	-91 938 101.00
25	7 636 106.08	-91 750 095.20
30	8 039 681.46	-91 562 089.40
35	8 443 256.85	-91 374 083.60
40	8 846 832.23	-91 186 077.79
45	9 250 407.62	-90 998 071.99
50	9 653 983.00	-90 810 066.19
55	10 057 558.39	-90 622 060.39
60	10 461 133.78	-90 434 054.59
65	10 864 709.16	-90 246 048.79
70	11 268 284.55	-90 058 042.99
75	11 671 859.93	-89 870 037.18
80	12 075 435.32	-89 682 031.38
85	12 479 010.70	-89 494 025.58
90	12 882 586.09	-89 306 019.78
95	13 286 161.48	-89 118 013.98
100	13 689 736.86	-88 930 008.18



A) Sensitivity:

PW2ndLane	%	NumbVehicles	TollRevenues	DaysClosure	Distance2ndLane
	-50	-94 897 286.03	-94 897 286.03	-94 651 958.17	-93 017 228.02
	-40	-94 521 274.43	-94 521 274.43	-94 325 012.14	-93 017 228.02
	-30	-94 145 262.82	-94 145 262.82	-93 998 066.11	-93 017 228.02
	-20	-93 769 251.22	-93 769 251.22	-93 671 120.08	-93 017 228.02
	-10	-93 393 239.62	-93 393 239.62	-93 344 174.05	-93 017 228.02
Base case	0	-93 017 228.02	-93 017 228.02	-93 017 228.02	-93 017 228.02
	10	-92 641 216.41	-92 641 216.41	-92 690 281.98	-93 017 228.02
	20	-92 265 204.81	-92 265 204.81	-92 363 335.95	-93 017 228.02
	30	-91 889 193.21	-91 889 193.21	-92 036 389.92	-93 017 228.02
	40	-91 513 181.60	-91 513 181.60	-91 709 443.89	-93 017 228.02
	50	-91 137 170.00	-91 137 170.00	-91 382 497.86	-93 017 228.02

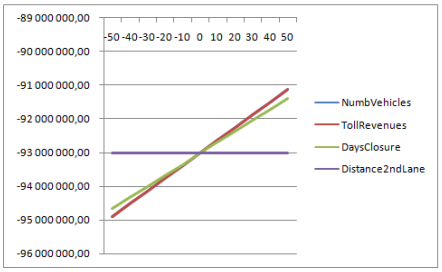


Fig. 4 *Exhibit of sensitivity analysis for the alternative of 2nd lane and break-even analysis for the toll growth in modeled case*

3 EXAMPLE OF APPLICATION

3.1 ASSIGNMENT

For illustration there was chosen an exhibit (fig. 1 to fig. 4) of economic comparing two possibilities of traffic solution during a tunnel tube closure, using estimated values of a modeled road stretch [6]. The first alternative consists in application of bypass, i.e. via existing motorway, which is simple and brings up number of advantages. At this traffic solution, there is no need an extraordinary investment. The respective flow of vehicles is diverted and in no way it interferes operation and closure of tunnel tubes. It means prolonging rout and time for vehicles driving across given locality and decrease of the revenue from tunnel toll.

In the second alternative, there is supposed to equip the 2nd lane of the tunnel tube left in operation in order to be flexible (switchable in both directions) and its resetting at every closure before and after that. This option, clearly, brings up some disadvantages. Particularly, there are needed additional investments to secure the flexibility of 2nd lane, next it brings about more digested traffic in both directions within free tunnel tube and also increased requirements on operation costs, control of traffic and safety management. On the other side, it is possible to suppose a increase of toll revenue due to usage of tunnel and decreasing waste of time for users. Task is to evaluate and to compare the two alternatives of traffic solution during closure of one tunnel tube. Each of them has different course of supposed costs and revenues within chosen time horizon which is 30 years.

In the presented study it is supposed overall passage of 15ths vehicles daily in both direction with a computed toll on average per vehicle and per 1km, which is 1.29 EUR for use of motorway and 2.41 EUR for use of tunnel, all that resulting from given numbers and toll rates according to particular categories of vehicles.

The bypass via motorway represents in given case distance of 4 km with average speed of 60 km/hour, with increase of waste of time by 0.054 hour/vehicle per day and with expected accident events of 0.001 accident/km per day. The using the 2nd lane of tunnel tube in operation, the distance amounts to 1 km, average speed 60 km/hour, increase of waste of time 0.004 hour/vehicle per day and expected accident events 0.020 accident/km per day. The normal operation of tunnel represents distance of 1 km, average speed 80 km/hour and accident events 0.001 accident/km per day. The digested traffic in the 1st lane during the closure represents average speed of 60 km/hour, increase of waste of time 0.004hour/vehicle per day and accident events 0.010 accident/km per day. For this lane, it is supposed the distance in km and number of vehicles driving in to be same as at current operation. The valuation of waste of time and accident (set 0 values) were eventually excluded from the research for simplification and relatively small relevance and impact on results.

The number of closure days and the overall time horizon were set on 3 days and 60 half years. i.e. 30 years respectively. The revenue of toll in case of bypass amounts to 232 800 EUR per half year. The costs for bypass installation are estimated to 30 000 EUR, the costs for its maintenance per day 5000 EUR and for cancel of bypass 30 000 EUR. In the given case, it is not taken into consideration the costs representing the losses of tunnel tolls as well as the costs owing to waste of time and increasing of accidents, for their omissible impact.

In the case of using 2nd lane, the revenue of toll amounts to 108 450 EUR per half year and there is supposed also revenue 100 000 EUR from salvage value of the built-in equipment in the end of tunnel life expectation, i.e. after 30 years. The allocations of particular investments according to their time cycles are for the 30 years investments 20 millions EUR, for the 7 years ones 2 millions EUR, and their maintenance costs per half year are 2 millions EUR and 10 000 EUR respectively. The fixed costs to switch the flexible lane to reverse direction are estimated to be 50 000 EUR, the costs for its maintenance and operation per 1 day are supposed to be 5 000 EUR and for cancel such lane 50 000 EUR. The variable costs per 1km as for its equipping, operation and maintenance and also at its canceling are not taken into consideration. Neither in this case are there regarded the costs owing to waste of time and increase of accidents, for their omissible impact.

3.2 RESULTS

As read in the block *EVALUATION* (fig. 3), annual interest rate of funding for the both options, i.e. the bypass via motorway and the use of 2nd lane, is the same 5 %. It is supposed annual increase of revenue from toll by 1% and increase of costs yearly by 0.5 %. Additionally, there are displayed also some computed financial factors as the annuity factors, discount factors to look after computing process. The parameter *Bypass vs. 2ndLane* in given case as the better alternative indicates *Bypass*, hence, the using motorway, since the present value in *PWBypass* gives expressly high positive value of 5 618 229.15 EUR, while the alternative of 2nd lane is at given conditions deeply lost with the present value in *PW2ndLane* resulting -93 017 228.02 EUR. The value in *SumPWMix* is in this research irrelevant, since it has evaluated and compared individually only pure, i.e. mutually exclusive alternatives, not mix cases of vehicle traffic, i.e. certain part via motorway and left part via tunnel.

4. CONCLUSIONS

The results provided by given research imply as unambiguously better solution to use the bypass via existing motorway. The sensitivity analysis as well as the break-even analysis additionally point out that in given case it is impossible to expect the positive values of net present value in the alternative of *2nd lane* even though there would be favorable trends such factors as are increasing toll or increasing numbers of paying vehicles. A next research with aim to enforce the usage of 2nd lane could be interesting, e.g. by cutting relatively high investments needed for this alternative realization, proposing different construction and technical solution, simultaneously with increasing of the tolls and getting worse traffic conditions on the bypass road. Justification of such considerations, nevertheless, must stem always from concrete conditions of transport situation and from overall review of the problem.

References

[1] Power, D.J., Shardea, R., 2007: Model-driven decision support systems: Concepts and research directions.Decision Support Systems. ELSEVIER B.V. 43 (2007) 1044-1061.
[2] Lawrence, J.A., Pasternack, B.A.,2002: Applied Management Science, 2nd edition. Wiley Publishing.
[3] Walkenbach, J., 2010: Excel 2010 Bible. Wiley Publishing, Inc., NJ.
[4] Wells, E., Harsharger, S., 1997: Microsoft Excel 97 Developers Handbook. Microsoft Press.
[5] Guimaraes, T., Igbaria, M., Lu, M., 1992: The Determinants of DSS Success: An Integrated Model. Decision Sciences 23, No. 2, 1992, 409-430.
[6] Cvoliga, M., 2013: Strategy, process preparation and construction of tunnels in Slovak Republic, FBERG, University of Technology, Košice.

Review: *Reviewer name*