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Road and Rail Infrastructure III

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IDENTIFICATION OF AT-GRADE INTERSECTIONS CHARACTERISTICS FOR DEFINING BASIC INPUTS INTO MCA METHODOLOGY

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Abstract

The article deals with the determination of basic traffic engineering and measurable urban planning criteria needed for a complex assessment of intersections. The current assessment method of intersections in accordance with applicable regulations is virtually bound on suitable capacities but each intersection may also be described by means of a set of clearly expressed values; based on these values, its suitability for given conditions and thus also the utility value of a proposed design solution may be determined by means of the Multi-Criteria Assessment (MCA) application. The basic criteria defining each at-grade intersection were the mean delay time, the safety index, environmental impacts (particularly CO_2, NO_X and PM), noise impacts on the surroundings, construction and operating costs. In this context, it is obvious that it is also necessary to define the input parameters of a respective intersection on the basis of which the above values of the criteria will be defined. The article primarily describes the dependences between the above criteria and input traffic volumes for basic shapes of intersections. In the first phase, basic layout types of intersections were modelled in the form of a set of basic shapes of intersections – in the future, we plan to extend this set by multi-lane intersections and intersections with separate turn lanes. The distribution of traffic volumes into individual branches was carried out for several basic combinations. The dependences are elaborated in a clear graphical and tabular form allowing the designer or investor to make a preliminary assessment of different design options of an intersection, particularly in the initial phases of design. It is also possible to use the dependences as an alternative to computerised assessment in accordance with applicable regulations.

Keywords: *multi-criteria assessment, intersection, intersection capacity, environmental impacts, noise impacts*

1 Introduction

The performance and quality of the road network is primarily affected by its design elements. In urban areas the apparently critical limiting element are intersections. In this context, an adequate design of intersections determines all traffic engineering characteristics of the network. The design of intersections is obviously regulated by a set of technical criteria that must be observed in the design. At the same time, virtually each developed country has its own applicable set of technical and legislative regulations that describe and, to some extent, limit the design process. The article describes the method of obtaining rough input data for all relevant characteristics affecting the design of an intersection. The final values may subsequently serve as the basic input for the multi-criteria analysis of the respective design solution or for the recalculation and subsequent operational and economic assessment according to a relevant methodology in force (HDM-4).

2 Methodology of defining inputs for MCA

2.1 Existing assessment procedures of intersections

Comparing the design and assessment methods used e.g. in Europe, it comes out at a closer look that while the technical and design parameters of projects differ only marginally, the assessment of traffic engineering data is performed using a relatively large scale of methods that are not always ideal. The majority of such assessments do not take into account running costs, or potential environmental and noise emissions which, however, have a relatively large impact on the surroundings, especially in high-density developments. The current design practice is such that an intersection is evaluated in traffic engineering terms by its capacity (LOS), while the priority in terms of investment are construction costs.
The assessment in terms of capacity based on applicable regulations is relatively simple. A major problem, however, is that according to conducted surveys the results reached during this assessment quite often differ from reality. Moreover, different methodologies which do not provide comparable results when compared against each other frequently apply in different European countries. Therefore, due to very similar drivers' behaviour across Europe, it is clear that the applied methodologies often work under ideal conditions that, however, rarely occur in practice.
Safety of intersections is also practically not assessed numerically or analytically based on predictive models. The absolute majority of safety audits and assessments are related to the existing situation, i.e. the moment when the respective intersection has already been assessed. In conjunction with the fact that for a valid safety assessment, the respective intersection must be in operation for min. 10 years (some sources even say 20-25 years), it is clear that the current situation is not ideal.
Construction costs are of interest particularly to the investor. In terms of the operational and economic assessment, however, it is evident that construction costs account for only a relatively small proportion of the total funds spent on the intersection. Thus, neglecting running costs of a designed solution is a fatal mistake in the long-term perspective.

2.2 Traffic engineering and economic criteria

In the context of traffic engineering criteria, it must be emphasised that these criteria lend themselves to unambiguous quantification and comparison. Also, there are numerous other factors playing some role in the design that may affect the result, such as the existing configuration, coordination with other intersections, etc. The following basic criteria were identified:
· intersection capacity (mean delay time);
· intersection safety (safety index);
· vehicle emissions (emissions of CO_2, NO_x, PM);
· noise emissions (average equivalent noise level L_{dvn});
· construction costs (€);
· running costs (€/hour).

The Aimsun micro simulation software was used to identify the traffic engineering characteristics and emissions for individual types of intersections. An integral part of the project was also the software calibration to the conditions valid in the Czech Republic and the subsequent verification of the calibration. The safety of an intersection was identified on the basis of exact research conducted in the conditions of the Czech Republic, while construction and running costs were identified using applicable methodologies in force in the Czech Republic (URS data base, HDM-4).

2.3 Assessed shapes of intersections and distribution of traffic volumes

The basic types of intersections were identified in accordance with the Czech norms, which define the following shapes to be potentially used for newly built and reconstructed intersections (Fig. 1):
- crossroad (4-leg intersection) with/without TL;
- T – intersection (3-leg intersection) with/without TL;
- single – lane roundabout;
- multi – lane roundabout (different types of turbo – roundabout).

Only basic types of intersections were modelled in the first step. The set of intersections will be further extended and the most frequent configurations situated in the road network will be modelled. The next step was the determination of approach traffic volumes and their distribution. It is, however, impossible to consider any arbitrary approach traffic volumes in individual branches as the number of permutations would be too high. For this reason, basic configurations of the traffic volume distribution into intersection branches were selected (Fig. 2) plus two basic compositions of traffic volumes according to the numbers of heavy vehicles in the main-minor road distribution (4%-4% / 15%-8%). The basic types of distribution are:
- 1:1:1:1 (intersection movements in the ratio 1:2:1);
- 1:2:1:2 (intersection movements in the ratio 1:2:1);
- 1:3:1:3 (intersection movements in the ratio 1:2:1);
- 2:3:1:4 (intersection movements in the ratio 2:3:1);
- 1:2:2:1 (intersection movements see Fig. 2).

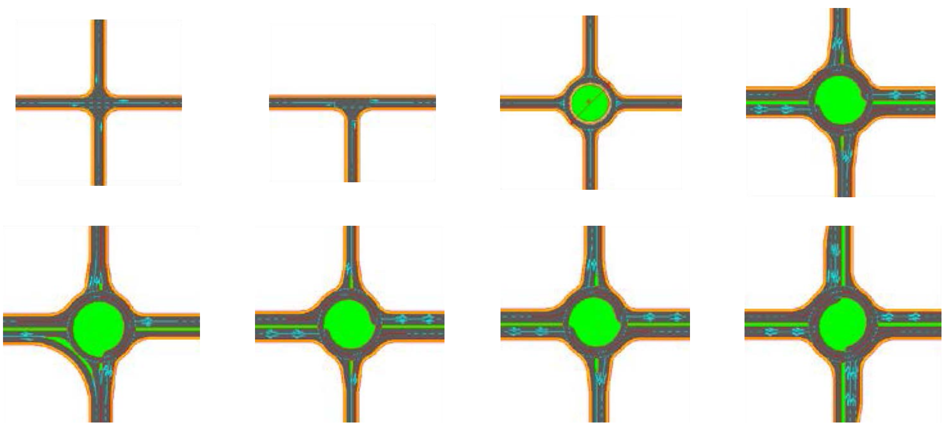

Figure 1 Basic set of intersection types

Traffic volumes will be defined by both the total traffic volume that an intersection should transfer in peak hour and by the traffic volume distribution. The range of traffic volumes selected was 1000 – 3200 veh/h in steps of 200 veh/h.

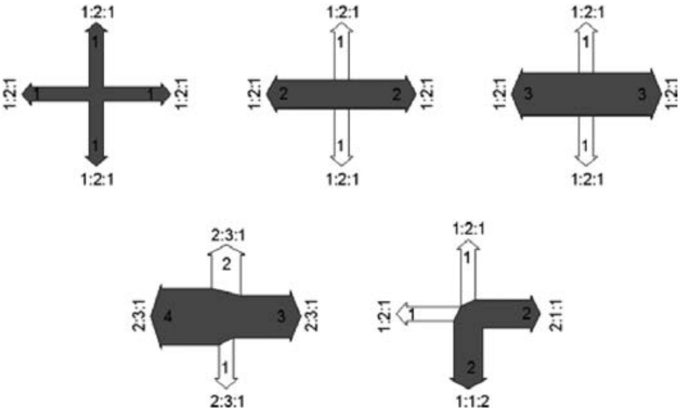

Figure 2 Traffic volume distribution

3 Identification of input data for MCA in practice

3.1 Identification of traffic engineering data by means of micro simulations

All traffic engineering values for the above shapes of intersections and expected distributions of traffic volumes were identified by means of micro simulations. For the purposes of this article, a model output for a single-lane roundabout with a diameter of 40 meters related to total traffic volumes will be presented. The estimated configuration of the traffic volume distribution into intersection branches is in the ratio 1:3:1:3 (intersection movements in the ratio 1:2:1) with 15%/8% of heavy vehicles. The values obtained from the micro simulation model are displayed in Table 1.

Table 1 Micro simulation results for a single-lane roundabout

Volumes [veh/h]	Avg. delay [sec]	CO_2 [kg]	NO_X [kg]	PM_{10} [kg]	$PM_{2,5}$ [kg]	L_{dvn} [dB]
1000	16.4	199.9	0.76	0.049	0.030	61.39
1200	19.1	239.0	0.90	0.059	0.035	62.06
1400	22.2	277.8	1.04	0.068	0.041	62.69
1600	26.7	318.5	1.20	0.078	0.047	63.28
1800	35.0	359.1	1.34	0.088	0.053	63.79
2000	45.9	399.7	1.50	0.098	0.059	64.33
2200	69.5	441.9	1.65	0.108	0.065	64.86
2400	447.0	508.5	1.92	0.123	0.074	65.65

It is evident from the results that the relevant interval of the solution is in the range of 1000 – 2200 veh/h. Values below 1000 veh/h need not be addressed in practice as the growth in delay times at uncontrolled intersections at such low traffic volumes is linear, while at higher traffic volumes (2400 veh/h and above) the busiest approaches already get congested, which leads to an unacceptable rise in average delay times. For better clarity, the growth in the given parameters may also be displayed visually by graphs in Fig. 3 and Fig. 4.
The above table and enclosed graphs clearly show the growth pattern of individual criteria with respect to input traffic volumes. In the case of average delay, the growth in the delay time for traffic volumes between 200-1600 veh/h is practically linear, while from ca 1600 veh/h the growth in average delay starts to be more rapid.

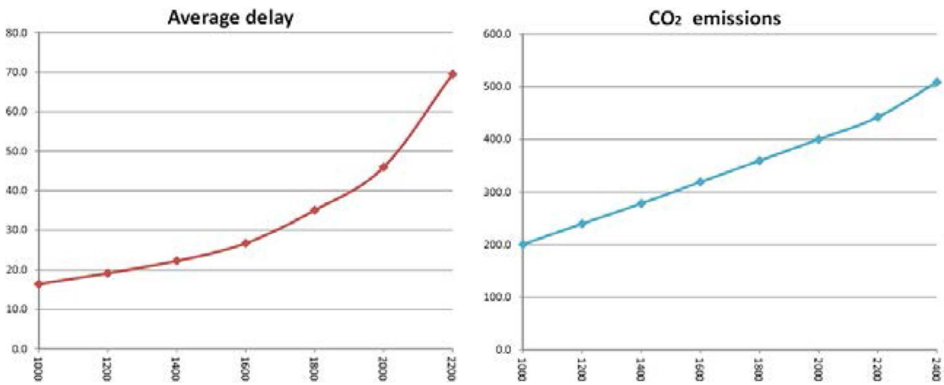

Figure 3 Graphs of average delay (and CO_2 emissions) related to volumes

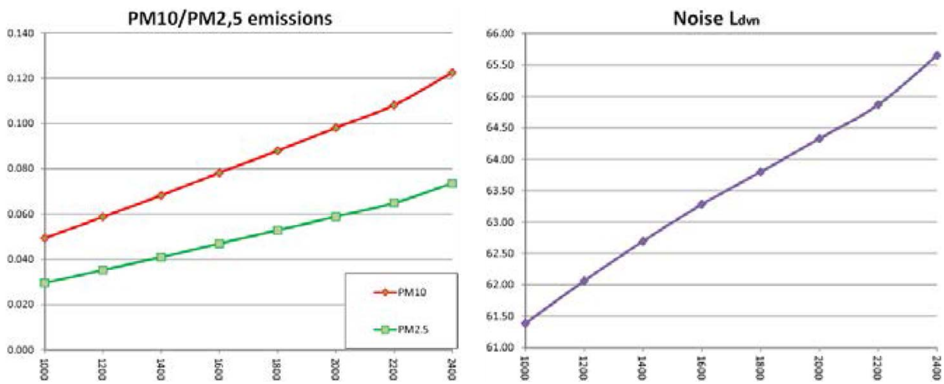

Figure 4 Graphs of PM (and noise emissions) related to volumes

The growth of emissions of individual exhaust gases and noise emissions is linear, as expected, but once the limit capacity of an intersection is exceeded, there is also a steeper rise of individual criteria. In fact, however, this is a limit case as the intersection should be designed so that a similar situation does not occur there.

3.2 Safety index identification

The safety of individual design solutions cannot be practically identified using micro simulation models. Although there are procedures based on traffic models and taking over data from them (e.g. SSAM), these are predictive models that have not been realistically verified in practice and their results are, therefore, not applicable in European conditions. Safety was identified on the basis of exact research conducted in the Czech Republic defining the safety of an intersection by means of a so-called safety index (I_S). The safety index is based on two principal parameters that must be expressed mathematically:

- accident index (I_A) – based on accident statistics from individual already constructed intersections;
- design safety index (I_C) – this index is based on basic design and traffic engineering principles. Each intersection has a certain type of collision points and collision flows where collision movements occur – if the risk rates of such movements may be identified and the relationship between the number of collision points and actual accidents derived, the respective safety index may subsequently be determined.

The considered ratio of both partial indices is 65:35 (1).

$$I_S = 0.65 * I_A + 0.35 * I_C \tag{1}$$

The results for individual types of intersections are displayed in Table 2. We must, however, emphasise that these are initially determined indices, and both the range of their values and the values themselves will be further modified as research continues.

Table 2 Safety index based on at-grade intersection type

Intersection type	Statistics [RN]	I^A [pts]	Conflict points	I_c [pts]	I_s [pts]
T-intersection	0.8	7.5	8	8.0	7.7
Crossroad	1.2	1.0	24	1.0	1.0
T-intersection+TL	0.7	10.0	3	10.0	10.0
Crossroad+TL	1.2	8.0	8	3.4	6.4
RA – 1/1	0.7	10.0	4	9.8	9.9
RA – 2/2	1.2	3.0	16	2.0	2.7
TRA – turbo/egg	1.0	5.0	12	5.4	5.1

3.3 Construction and running costs

Construction costs were determined based on the applicable budget methodology using the URS price system. The final price for the intersection without adjacent sidewalks, considered as newly built, is € 207,895. The price includes only construction works, excluding the costs of traffic engineering measures, relocations of existing networks, etc. Running costs were determined following practical instructions for the assessment of the cost-effectiveness of projects (Czech Road and Motorway Directorate). Running costs and their growth are evident from Fig. 5. Once the intersection capacity is exceeded, there is a noticeable increase in delay times and thus a steep rise in running costs.

Volumes veh/h	PN €/h
1000	1334
1200	1616
1400	1904
1600	2232
1800	2594
2000	3003
2200	3580
2400	7304

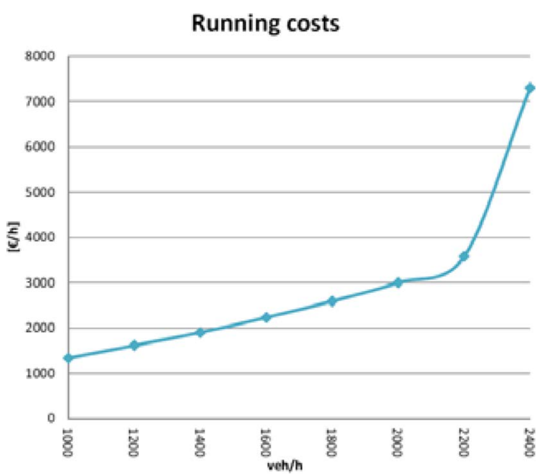

Figure 5 Running costs and their growth

4 Future applications of results

All the above outputs offer relatively interesting application possibilities. Intersections are described using a complex set of data taking into account and quantifying the properties of an intersection in order to assess the designed or existing solution. The basic application domain, therefore, is the application of the results in the subsequent MCA-based assessment of intersections with clearly declared weights of individual criteria. Another option is a purely economic comparison – practically all the above criteria may be expressed in financial terms. Last but not least, the results may be used in design and traffic engineering practice for the purpose of rough estimates of the characteristics and impacts of a proposed solution. Thus, the data offer a relatively wide scope of applications, although with respect to input data, their indicative nature must be taken into account. The identified values will never replace a complex micro simulation model, which, however, is only used in the subsequent phases of project documentation.

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