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APPLICATION OF TRAFFIC SIMULATION IN THE DESIGN OF INTERSECTION SYSTEMS CONCERNING TRAFFIC AND ENVIRONMENT

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Abstract

Application of traffic simulation in traffic engineering belongs to the handling of the capacity problems and the special traffic flowing questions for a long. The following article partly demonstrates a traditional capacity proceeding regarding new or new-type road network items in Hungary and partly gives an account of the applicabilities of the simulation for modelling the environment effects of road traffic.

Keywords: simulation, roundabout, overtaking lane, environment effects.

Introduction

Intersections are the most sensitive points of road networks, being their layout essential for transmissible traffic volume from multiple directions, for service level and safety. Technical discussion of intersections is almost as old as motorisation itself and it is a central field of traffic engineering activity.

The task's dimensions may be well characterised by the fact that even Hungary's road network with its low or medium density has more than a hundred thousand intersections together with those belonging to the local governments, and about forty thousand are in the national highway network. Approximately five thousand intersections have connecting components all belonging to the state highway network. The major part of our intersections is the level intersection equipped by traffic signs [1].

Two main reasonable demands can be set towards intersections: partly, their capacity should desirably exceed the typical traffic demands, at the same time more and more corresponding to the HCM A-F criteria [3]; partly, they have to be safe. Intersection safety is a complex idea, considering important to be easy to recognize, oversee, understand and traverse. Safety obviously cannot be set apart from capacity, as impatience due to long waiting may cause accidents, and, on the other hand, e.g. insufficient viability may reduce traffic volume able to pass.

Simulation with accelerated playing is an effective method for gaining complete knowledge on the intersection processes, repeating innumerably and in various forms every day. Today's computer science and moreover the hardware basis has reached the level permitting an in-depth analysis on vehicle level after a few seconds of run of a whole day's intersection traffic process when it is correctly generated.

Essentials of Intersection Traffic Simulation

The basis of intersection traffic simulation is a multiple random number generation. Series' independence is ensured by the fact that a random number generated last by the preceding process serves as stating elements for the next generation.

The aim of the simulation is to produce a vehicle flow where the volume, composition, and the leading vehicle of the platoon can arbitrarily be given. In the traffic generated vehicles are accelerating, slowing, attempting to keep themselves to the given speed limit, overtaking, sensing upward and downward slopes. The technique of movement is based on dividing the road into field parts (vehicle units), and after calculating their changing occupation modifying it. Decision on occupation depends on the new vehicle positions. Three kinds of vehicles take part in the process: passenger cars, and light and heavy trucks.

The method's advantage is that headways in the simulated traffic may either be of a so-called traditional, i.e. Poisson distribution or of a negative exponential one fitting better to the actual measurement. (It should be mentioned here that Werner Brilon uses Poisson distribution in the new German Intersection Design Regulation.) [2], [5].

The method is general in the sense that it can analyse practically all types of intersections:

- connection, group of connections,
- crossing,
- expanded crossing,
- roundabouts.

Two- and four-lane cross-sections can be studied in the main direction of the intersections or in one direction in the case of roundabout.

General intersection geometry data:

- length and type of climbing lanes,
- radii of curbs,
- mode of regulation (yield sign, STOP),
- lane helping joining in beside the main direction, facilitating access,
- dimension of expansion,

- existence of an auxiliary lane (expanded intersection),
- radius of two-lane roundabout,
- number of lanes joining to the roundabout,

General traffic data:

- traffic distribution among straight and turning movements,
- traffic composition (passenger car %, light and heavy trucks %),
- percentage of vehicles moving in platoons,
- length of the platoons,
- platoon leading vehicle type percentage,
- average speed of vehicles approaching the intersection from secondary directions,
- average speed in the main direction.

Headway distribution function is a basic data of the simulation (given as an arbitrary function or on the base of measurement).

Headway limits may be given as individual values to each movement type or as a variable in the function of speed. The simulation analysis program can run on IBM PC AT 486-586, with operating system MS/PC DOS 2.0 or higher. The result is a continuous simulation running in actual time co-ordinates or considerably faster ones depending on computer type, and can be stopped in any moment. Data obtained during the simulation or at stopping:

- denomination of traffic lanes,
- maximum length of the necessary storage lanes,
- entering and leaving traffic volume for each lane,
- average, minimum, and maximum waiting time,
- average speed of individual movements in the intersections for each lane,
- minimum, maximum and average value of the so-called travel in system time, meaning time spent on the whole simulated section (in most cases 500–500 m straight section plus intersection area).

As seen, the calculation result is not exact in a traditional sense, giving no capacity or service level. The intersection's suitability can be determined by comparing the travel time of a low volume testing traffic and that of the studied one.

Suitability of the Simulation for Determination of the Capacity of Level Intersection

In the case of a 'traditional' intersection with yield regulation the following transmissible traffics can be obtained by simulation for two-two lane roads and for those with the same cross sections but with roundabout junction.

Table 1

File name	Traffic of main direction [pcph]	Traffic of secondary direction [pcph]	Maximum stop time [s]	Average travel time max. [s]	Service level
C11	400	200	69	204	A
C12	400	300	43	206	A
C13	500	200	63	202	A
C14	500	300	90	213	B
C15	500	400	98	216	B
C16	600	200	111	241	C
C17	600	300	116	238	C
C18	600	400	106	257	D
C19	600	500	111	267	D
C20	700	200	101	252	D
C21	700	300	141	294	E
C22	700	400	140	304	F
C23	700	500	153	358	F
C24	700	600	133	449	F
C25	400	100	42	199	A
C26	800	100	185	310	F
C27	800	200	177	341	F
C28	800	300	223	405	F

Table 1 shows transmissible traffics from the individual directions of a crossing.

Information to the *Table*:

average travel time maximum [s]: maximum time necessary to pass through the total simulation section (intersection area + 2×500 m);

Level of service: defined with A – F, the meaning of the individual levels:

A: $(t) + 10$ s,
B: between $(t) + 10$ s and $(t) + 40$ s,
C: between $(t) + 40$ s and $(t) + 60$ s,
D: between $(t) + 60$ s and $(t) + 80$ s,
E: between $(t) + 80$ s and $(t) + 100$ s,
F: $> (t) + 100$ s,
(t): travel time of a minimum volume free traffic.

- headways are of Poisson distribution,
- vehicles: passenger cars,
- traffic distribution: main direction - 70% straight, 20% to the left, 10% to the right; secondary direction - 80% straight, 10% to the left, 10% to the right.

Table 2 also shows transmissible traffic of an average crossing with the difference that headway distribution corresponds to the actual traffic studies, and 30% heavy vehicles take part in the traffic both in main and the secondary directions.

Table 2

Main direction traffic [V/h]	Subordinate direction traffic [V/h]	Maximum stop time [s]	Average travel time max. [s]	Service level
400	250	119	207	A
400	150	56	207	A
400	300	87	208	A
500	150	57	201	A
500	300	88	219	B
500	400	86	238	B
700	150	126	237	B
700	300	227	293	E
700	400	169	356	F
700	500	137	312	F

Results of roundabout simulation are seen in *Table 3*, also with heavy vehicle traffic of 30%, and headway distribution according to actual measurements.

Results published in the *Tables* are for illustration only. However, numerous average values, resulting of simulation tests indicate that a level *traditional intersection* has an average transmissible *entering traffic* of *2000 pcph*, that of a roundabout with similar cross-section is *2500 pcph* [4], [6], [7].

Suitability of Simulation for Environmental Analysis

The appropriate selection and control of intersections in urban built-up areas of high pedestrian and bicycle traffic is a very important question today because of Hungary's poor quality vehicle fleet and consequently high air pollution. The simulation method can very well estimate pollution due to a given intersection's traffic flow, only requiring specific emission values corresponding to a vehicle's momentary speed. *Table 4* helps to compare a roundabout traffic and a crossing with 'STOP' control regarding emission for a few typical air polluting materials. It is well seen that the continuous roundabout traffic means less impact to the more favourable environment.

Simulation made by traffic light control with the same traffic yields worsening results (*Table 5*).

Table 3

Main direction traffic		Subordinate direction traffic		Maximum stop time	Average travel time max	Level of service
[V/h]	[pcph]	[V/h]	[pcph]	[s]	[s]	
350	434	150	186	25	215	A
350	434	300	372	25	226	B
450	558	150	186	45	216	A
400	496	300	372	33	221	A
600	744	150	186	43	230	B
550	682	300	372	42	238	B
550	682	350	434	71	261	C
600	744	250	310	62	281	D
600	744	400	496	89	309	E
600	744	450	558	82	570	F
650	808	350	434	121	619	F

Suitability of Simulation for the Qualification of Special Intersection Systems

The using of overtaking lanes begun first in countries having low density highway and town system, and thus great distances between the settlements. The two-lane main road is here expanded in 4-5 km distances into four-lane sections of about 1 km length, where passenger cars may perform overtaking manoeuvres without obstacles and thus the forming of platoons occurring more and more often with the increase of traffic may be reduced. This method provides roads of good service level and satisfactory capacity for the most important traffic directions, being able to satisfy traffic demands for a longer period with lower costs, and thus further four-lane expansions of the remaining sections can be built later.

Due to the circumstances and to the above detailed advantages the overtaking lanes are widely applied in the different parts of the world. Canada, Australia, numerous African countries, in Europe France, Germany, Finland are the most important application sites, with good starting experiences.

Simulation comparative tests of overtaking lanes have been performed for geometrical versions shown in *Fig. 1*.

Simulation results are shown in *Tables 6* and *7*. It can be seen that both the entering traffic volume of a direction and the average travel time are more favourable at the overtaking lane version.

Table 4

Control of the intersection	Number of lanes main-secondary direction	Entering traffic [pcph] main-secondary direction	NO_x kg/h	Pb g/h	CO kg/h
	2-2	333-167	1.02	2.18	8.61
	2-2	417-167	1.25	2.58	10.21
	2-2	500-167	1.47	2.88	11.56
	2-2	500-250	1.58	3.48	13.64
Roundabout fourlegs	4-2	500-83	1.24	2.73	10.71
	4-2	500-167	1.47	3.17	12.45
	4-2	500-250	1.74	3.49	13.88
	4-2	584-83	1.49	3.16	12.42
	4-2	584-167	1.61	3.74	14.51
	4-2	584-250	1.87	4.28	16.61
	4-2	666-83	1.73	3.81	14.90
	4-2	666-167	1.86	4.43	17.04
	2-2	333-167	1.12	2.00	8.16
	2-2	417-167	1.25	2.58	10.23
	2-2	500-167	1.39	3.18	12.33
	2-2	500-250	2.40	6.97	25.48
Crossing with 'STOP' regulation	4-2	500-83	1.15	2.23	8.98
	4-2	500-167	1.33	2.91	11.41
	4-2	500-250	1.74	3.84	14.92
	4-2	584-83	1.33	2.56	10.32
	4-2	584-167	1.60	3.56	13.84
	4-2	584-250	2.41	5.96	22.51
	4-2	666-83	1.44	2.93	11.71
	4-2	666-167	2.48	6.02	22.84

The higher speed of the overtaking lane versions can be seen graphically in *Fig. 2*, being in harmony with the *Tables 6* and *7*.

Summary

The above examples demonstrate that simulation is a very effective method for performing a large number of tests within a short time when real-time observations would last too long. If the model is based on correct traffic measurements, the results will provide a precise model. Two traffic engineering tools proved to be effective: both rotary intersections and overtaking lane highway sections have larger capacity, higher service level, and

Table 5

Control of intersection	Number of lanes Main direction - subordinate direction	Entering traffic [pcph] Main direction - subordinate direction	Pb g/h
	2-2	333-167	2.6
	2-2	417-167	3.1
	2-2	500-167	3.5
	2-2	500-250	4.2
Crossing with traffic light	4-2	500-83	2.8
	4-2	500-167	3.4
	4-2	500-250	4.0
	4-2	584-83	3.2
	4-2	584-167	3.8
	4-2	584-250	4.5

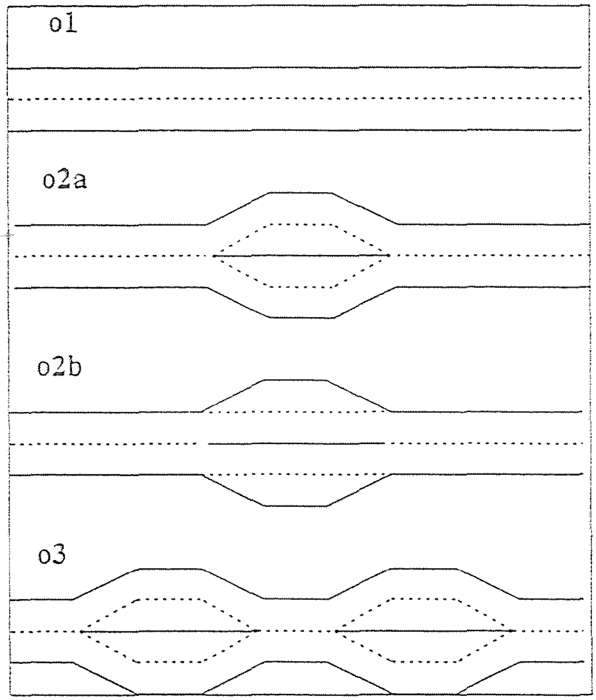

Fig. 1. Geometrical versions of simulation runs

Table 6
03 version of Figure 1 /20%, heavy truck

Traffic	Mark	V average [km/h]	Passing traffic [pcph]	Entering V/h	travel time [s]
100	a	79.5	10	86	679.0
200	c	74.1	9	204	738.1
300	e	71.8	13	308	765.0
400	g	69.5	20	403	731.7
500	i	65.2	66	489	761.9
600	k	63.3	57	587	775.1
700	m	63.9	86	678	761.7
800	o	61.1	93	795	790.6
900	q	60.5	196	866	788.2
1000	s	60.2	225	982	779.0
1100	u	59.0	341	1063	813.9
1200	w	59.4	350	1149	808.2
1300	y	58.3	424	1198	816.9
1400	'@'	55.7	562	1329	832.5

Table 7
03 version of *Fig. 1* /20%, heavy truck

Traffic	Mark	V average [km/h]	Passing traffic [pcph]	Entering V/h	travel time [s]
100	a	84.4	1	113	663.0
200	c	79.9	3	212	594.2
300	e	76.7	7	309	615.9
400	g	74.0	12	400	711.0
500	i	73.8	21	512	599.6
600	k	72.1	39	624	647.9
700	m	71.7	50	742	564.0
800	o	72.1	43	862	559.2
900	q	70.4	95	922	572.01
1000	s	70.3	62	1039	559.5
1100	u	68.1	143	1151	567.2
1200	w	67.8	118	1222	581.2
1300	y	66.3	181	1345	577.8
1400	'@'	65.0	224	1412	617.7

lower impact on the environment than the traditional versions; their wide-range application would undoubtedly be reasonable.

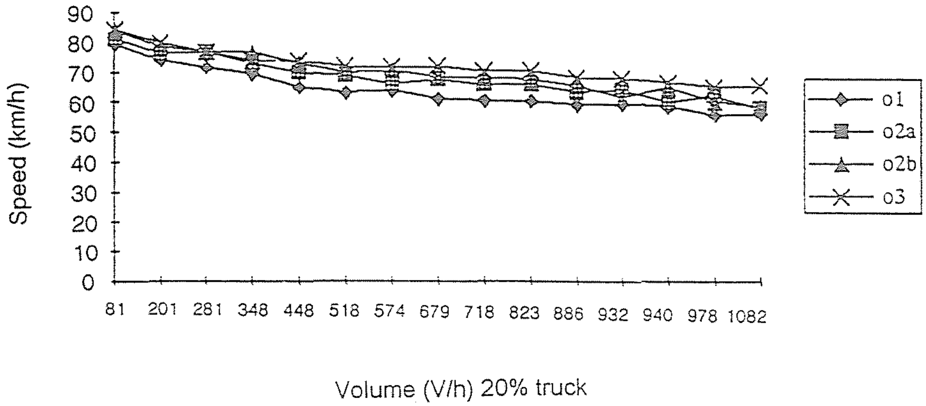

Fig. 2. Speed comparison for the individual versions (truck 20%)

References

1. BOTMA, H. – FI, I.: Traffic Operation on 2-Lane Roads in Hungary and the Netherlands. Highway Capacity and Level of Service. Brannolte (ed), 1991. Balkema, Rotterdam, ISBN 9054100117.
2. BRILON, W.: Leistungsfähigkeit von Kreisverkehrsplätzen. Siebentes Deidesheimer Seminar 21/21 April, 1989.
3. Highway Capacity Manual. Washington, DC, 1985.
4. Investigations for the Determination of Intersections' Capacity in the Outskirts. (in Hungarian) TUB Department of Road Engineering, Scientific Publications, 1986.
5. BRILON, W. – GROSSMANN, M.: The New German Guideline for Capacity of Unsignalised Intersections. Intersections without Traffic Signals II. Springer-Verlag, 1991.
6. BÉNYEI, A. – FI, I.– CSORJA, ZS. – CSANÁDI, J.: Roundabouts on Roads in the Outskirts. (in Hungarian) Innotech Science Park of the Technical University of Budapest, 1990.
7. FI, I.: Simulation of Road Section and Intersection Traffic Capacity Analysis, *News Letter*, TUB 1991. 2.