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Science in Traffic
Preliminary Communication
U. D. C. 656.021.2:625.739:519.24
Accepted: Nov. 5, 1998
Approved: Dec. 23,1998

ANALYSIS OF VEHICLE ARRIVALS AT A SELECTED INTERSECTION IN THE CITY OF ZAGREB

SUMMARY

The paper analyses the statistics of vehicle arrival at a selected intersection in the city of Zagreb. The intersection has all the elements of movement: going straight, left turns and right turns. The statistic analysis in this work is based on the measurements carried out by means of a device for gathering information on traffic, HI-STAR Model NC-90A.

We have shown that four days (Monday - Thursday) have the same statistical regularity. Two intervals have been isolated in which normal distribution can be accepted: one from 6 a.m. to 12 noon and another from 1 p.m. to 4 a.m. The period from 6 a.m. to 12 noon has Gauss distribution with the expected peak traffic density at $\mu = 9.9$ o'clock (i.e. at six minutes to ten o'clock) and standard deviation $\sigma = 3.1$. The periods from 1 p.m. to 4 a.m. have Gauss distribution with the expected peak traffic density at $\mu = 15.6$ o'clock (i.e. at twenty-four minutes to six p.m.) and standard deviation $\sigma = 4.2$. The results can be used for traffic regulation at that intersection i.e. for the traffic signal control of the intersection.

1. INTRODUCTION

Over the recent decades, mathematical methods and procedures have occupied a special place in planning and organisation of urban traffic. Statistics, as a scientific discipline plays an important role in traffic. Special attention is paid to gathering data and there are devices that gather the necessary data automatically, as well as software packages that provide instantaneously the basic statistics of the gathered data. In order to reach certain regularities, a more complex statistical apparatus and the intuition of the researcher are needed.

Today, due to a huge number of vehicles in urban centres, traffic often gets congested, especially during rush-hours when the number of vehicles may increase several times compared to some calmer parts of the day. Although the increase in traffic density may be predicted based on experience, it depends first of all on the urban centre: whether the centre of the town or the suburbs are considered, whether the main or secondary roads are considered, whether these refer to routes towards major facilities such as hospitals, shopping centres, production organisations, schools, faculties, etc. This paper deals with the analysis of traffic density at an intersection involving traffic towards a hospital, an area including business and office centres, and a link with the centre of the town and the business administrative centres. The observed intersection itself is a specific point in traffic. The data of vehicle arrivals at several intersections in the city centre of Zagreb have been analysed and it has been concluded that every intersection needs to be analysed separately due to its specific features.

One of the reasons for analysing the vehicle arrival at a certain intersection is the optimisation of the traffic signal operation at the intersection. The aim is to avoid unnecessary waiting in case of few vehicles from a certain direction. The vehicles are counted according to a certain classification and the data are then statistically processed, so as to increase the throughput capacity of a certain intersection.

In order to use the quantitative methods for traffic control in urban centres, it is necessary to gather first a sufficient amount of quality data.

2. GATHERING DATA AND THE CLASSIFICATION

The statistical analysis carried out in this paper is based on the measurements obtained by a device for gathering traffic data, HI-STAR Model NC-90A. The device is installed on the surface (road) and records and stores data on vehicles passing over it.

The device can measure:

- vehicle length

Vehicles are categorised in groups:

1. vehicle length up to 4.6 m
2. vehicle length from 4.6 to 5.2 m

3. vehicle length from 5.2 to 7.3 m
4. vehicle length from 7.3 to 9.1 m
5. vehicle length from 9.1 do 11.3 m
6. vehicle length from 11.3 do 12.5 m
7. vehicle length from 12.5 do 18.6 m
8. vehicle length from 18.6 do 30.2 m
9. vehicle length over 30.2 m

- vehicle speed (expressed in km/h)
- inter vehicle distance

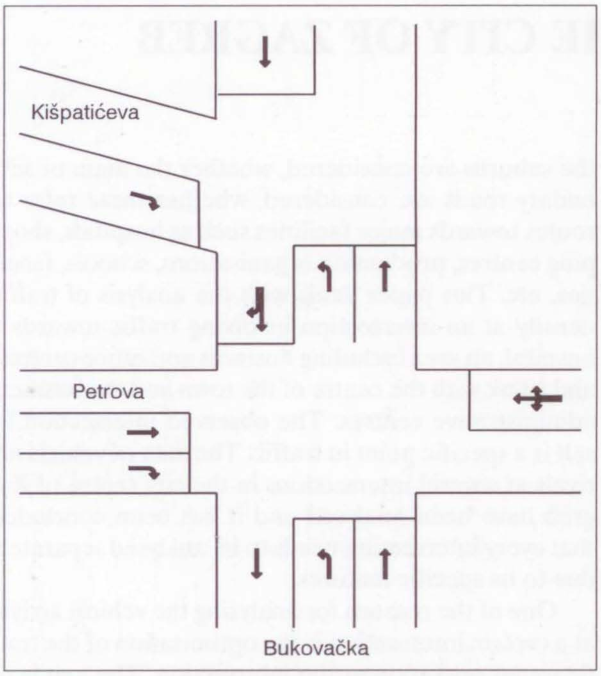

Figure 1 - Intersection of Petrova and Bukovačka Streets

- temperature of the surface (°C), information whether the road is wet or dry...

Based on the gathered data which are recorded every hour, the device can make a simple statistical analysis of the measured direction, such as:

- total and average number of vehicles per hour
- total number of vehicles during the day
- average time of vehicle arrival at the intersection (in seconds)
- surface temperature range

etc.

Measurements carried out in this paper have been done at the intersection of the Petrova and Bukovačka Street in the period from 20th to 27th October 1996 (for a week).

The basic statistical analysis has shown that a total of 43,222 vehicles passed through the given location during measurements, at an average speed of 30.44 km/h. The average vehicle arrival time to the intersection was 6.75 seconds, and the road surface temperature varied from 4 to 20°C.

3. STATISTICAL ANALYSIS

The data on vehicle count classified according to their length d are presented in Figure 2.

Segments of Figure 2 are given in Figures 2a to 2h.

Figure 3 shows the results obtained on Monday, October 21, 1996, and similar data would be obtained for the rest of the week-days, as can be seen in Figure 2. It is obvious that the number of vehicles of over 4.6 m in length is negligible, i.e. it does not cause any significant change in the traffic density. Therefore, only

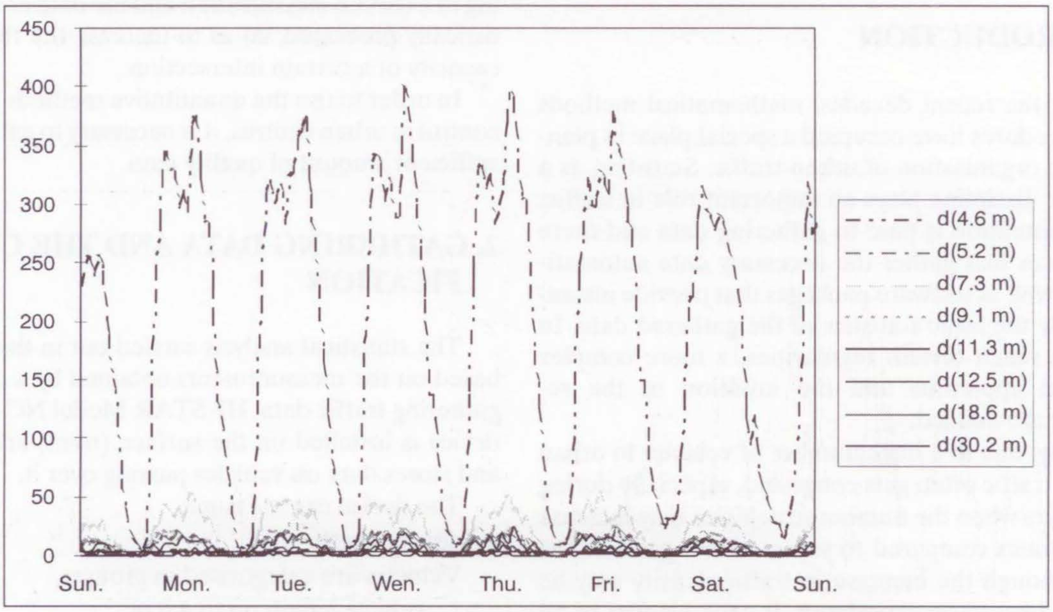

Figure 2 - Vehicle arrival to the intersection on the days of measurements, classified according to the vehicle length

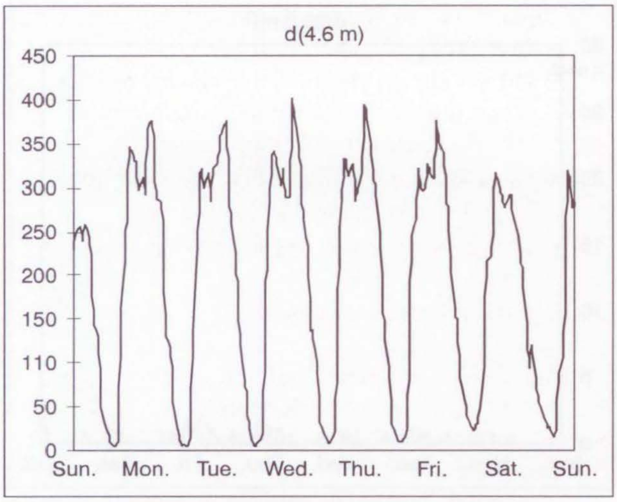

Figure 2a - Vehicles up to 4.6 m

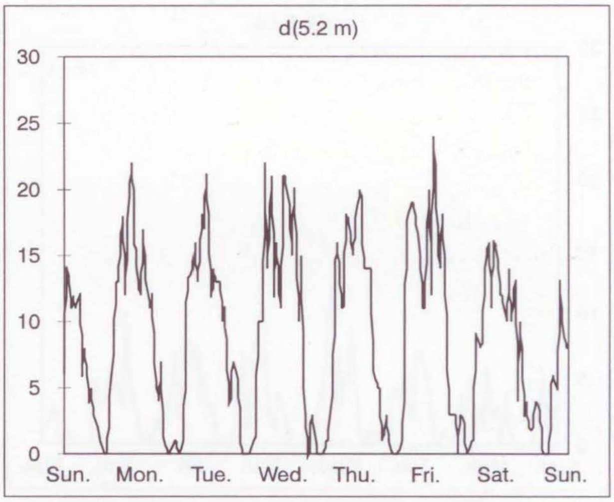

Figure 2b - Vehicle length - 4.6 to 5.2 m

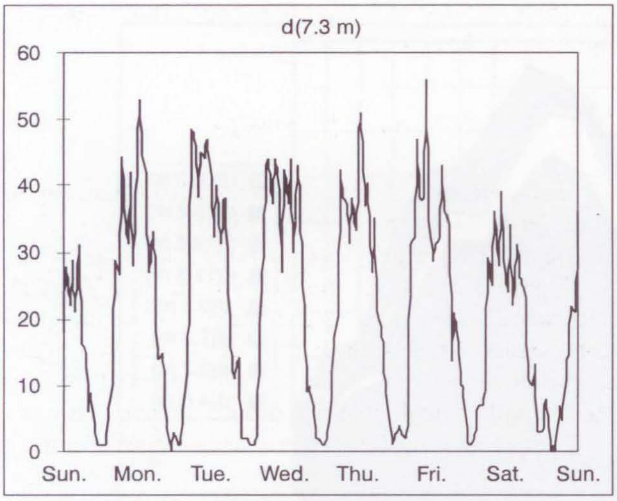

Figure 2c - Vehicle length - 5.2 to 7.3 m

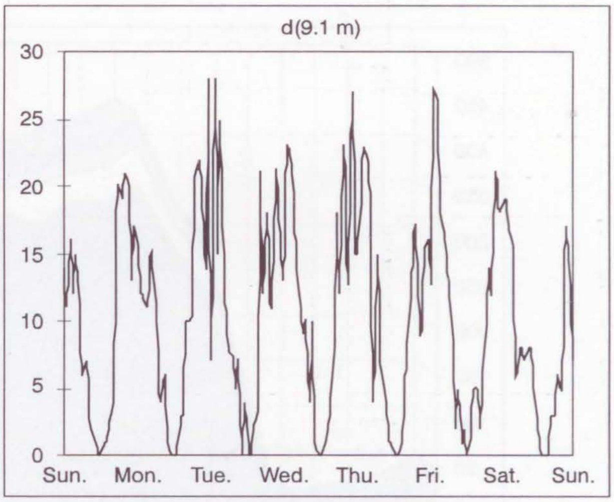

Figure 2d - Vehicle length - 7.3 to 9.1 m

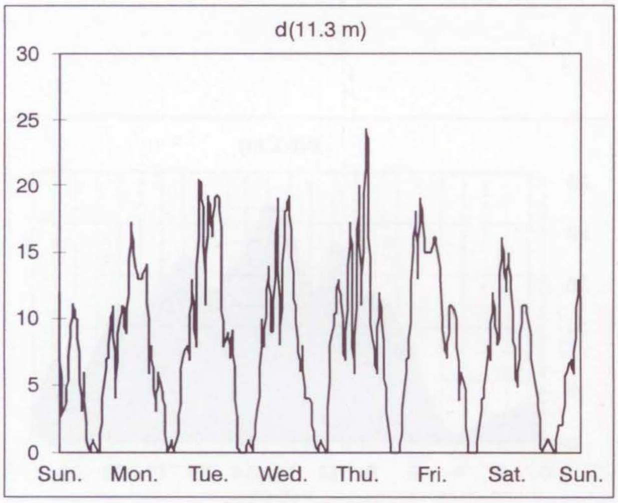

Figure 2e - Vehicle length - 9.1 to 11.3 m

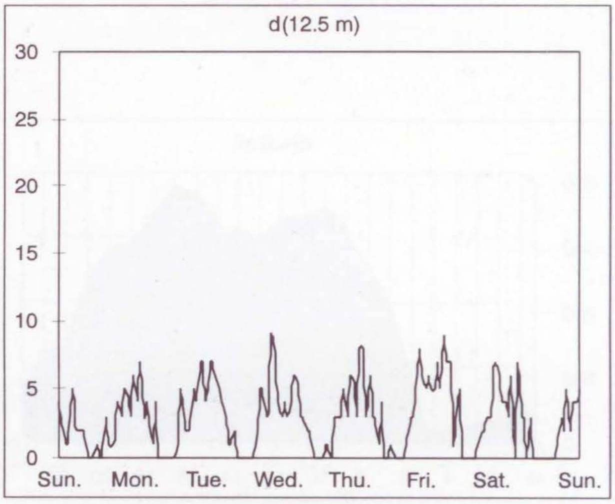

Figure 2f - Vehicle length - 11.3 to 12.5 m

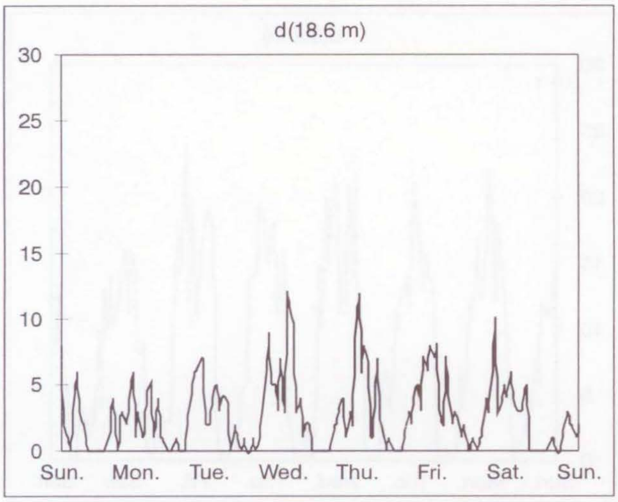

Figure 2g - Vehicle length - 12.5 to 18.6 m

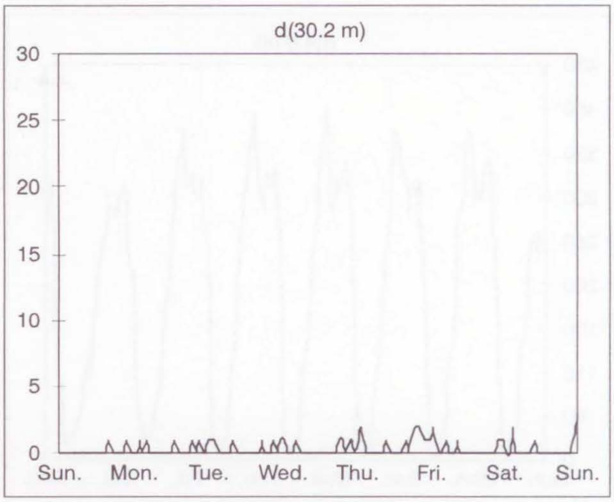

Figure 2h - Vehicle length over 18.6 m

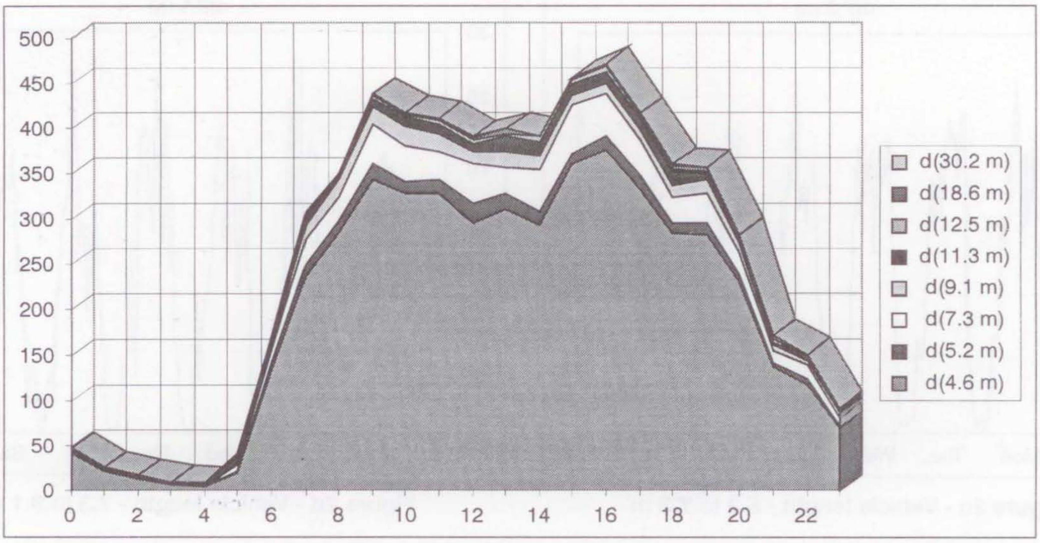

Figure 3 - Number of vehicles arriving at the intersection (data for October 21, 1996), Every layer presents a vehicle category depending on the vehicle length

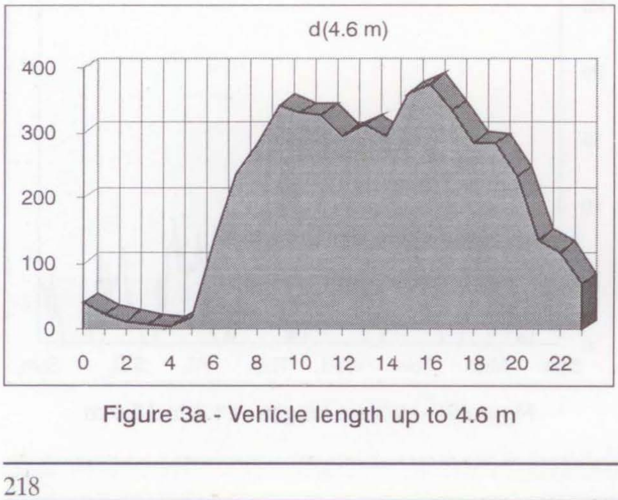

Figure 3a - Vehicle length up to 4.6 m

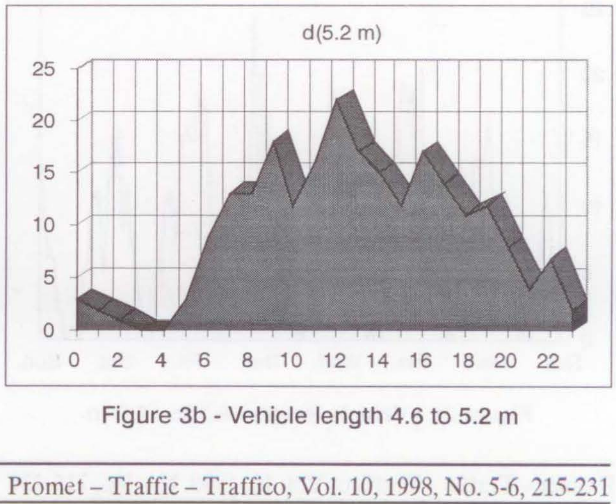

Figure 3b - Vehicle length 4.6 to 5.2 m

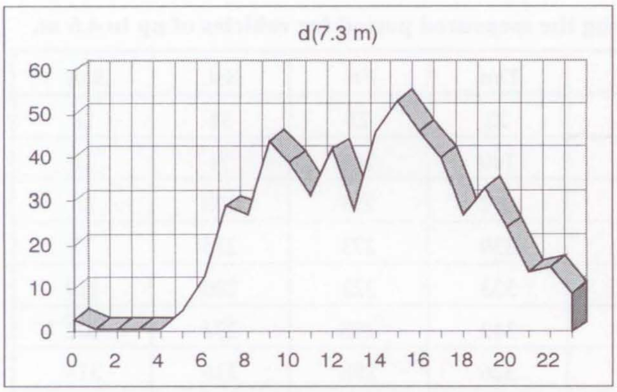

Figure 3c - Vehicle length 5.2 to 7.3 m

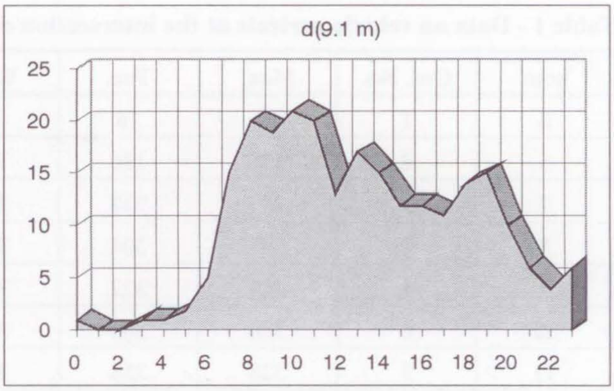

Figure 3d - Vehicle length 7.3 to 9.1 m

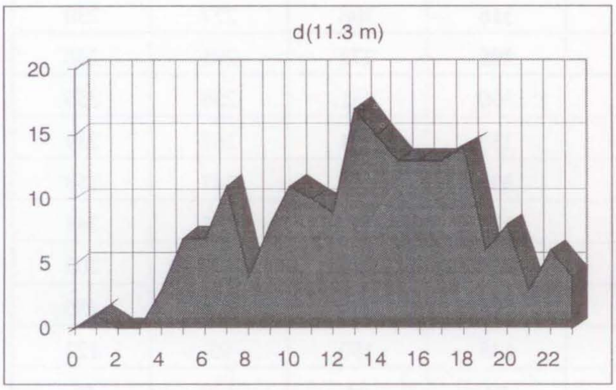

Figure 3e - Vehicle length 9.1 to 11.3 m

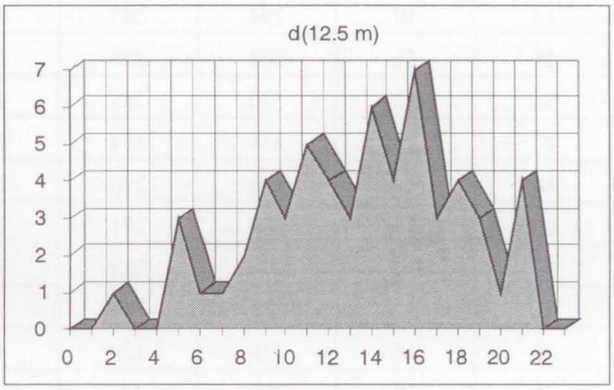

Figure 3f - Vehicle length 11.3 to 12.5 m

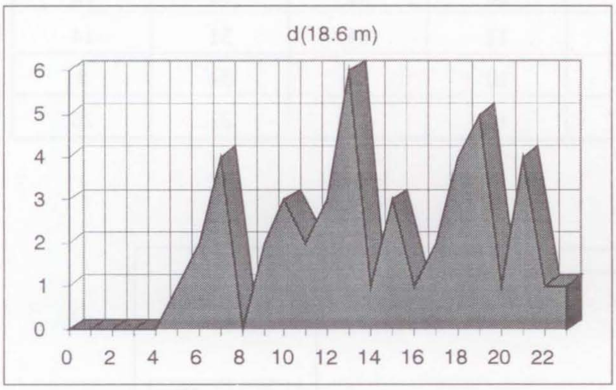

Figure 3g - Vehicle length 12.5 to 18.6 m

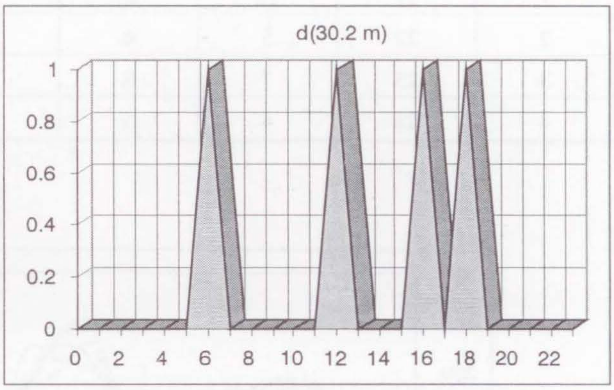

Figure 3h - Vehicle length over 18.6 m

the vehicles shorter than 4.6 m can be considered as the density indicators. The paper will further deal only with this vehicle category. The data graphically presented in Figure 2, referring to the vehicle category of up to 4.6 m (passenger cars) are presented in Table 1. These data will be processed numerically.

Using statistical analysis we will try to determine the behaviour. Starting from the assumption that the obtained curves have a certain similarity to the Gauss' distribution, the upper curve is logically divided into 7 separate ones, according to the days. In dividing the curve we shall not consider a strict classification per days, i.e. it will not be the data for the interval from 0 to 23 (time including the data of one day) that will be taken into consideration, but instead, the data from 5 a.m. (of the designated day) to 4 a.m. (of the following day) will be considered. The reason for this is obvious. When looking at the graph or the input data according to which this is precisely the time of traffic calm, i.e. this is where the graph in Figure 2 shows the minimums.

The measurement starts and ends on Sunday, at 2 p.m. and by joining the ends and beginnings, the graph will result in an interval corresponding to Sunday.

Table 1 - Data on vehicle arrivals at the intersection during the measured period for vehicles of up to 4.6 m.

hour	Ord. No.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.	Sun.
5	1	20	16	19	22	25	31	28
6	2	135	136	160	140	144	71	15
7	3	237	232	225	232	235	128	38
8	4	285	304	336	330	273	215	77
9	5	344	322	342	333	323	220	119
10	6	330	300	335	312	298	274	202
11	7	328	318	302	326	298	316	318
12	8	297	283	323	284	328	294	276
13	9	312	323	289	298	319	291	284
14	10	294	327	289	316	308	277	230
15	11	361	356	399	395	378	291	248
16	12	376	361	382	390	351	286	256
17	13	334	374	347	338	334	267	239
18	14	286	290	300	306	288	247	258
19	15	284	271	265	304	275	225	243
20	16	232	212	218	232	220	200	202
21	17	137	177	137	174	150	129	150
22	18	118	120	138	138	150	93	122
23	19	70	81	87	83	94	120	65
0	20	42	57	43	39	60	70	41
1	21	12	25	28	26	45	58	22
2	22	5	6	15	11	34	51	14
3	23	7	8	8	10	23	34	8
4	24	4	5	9	11	10	31	26

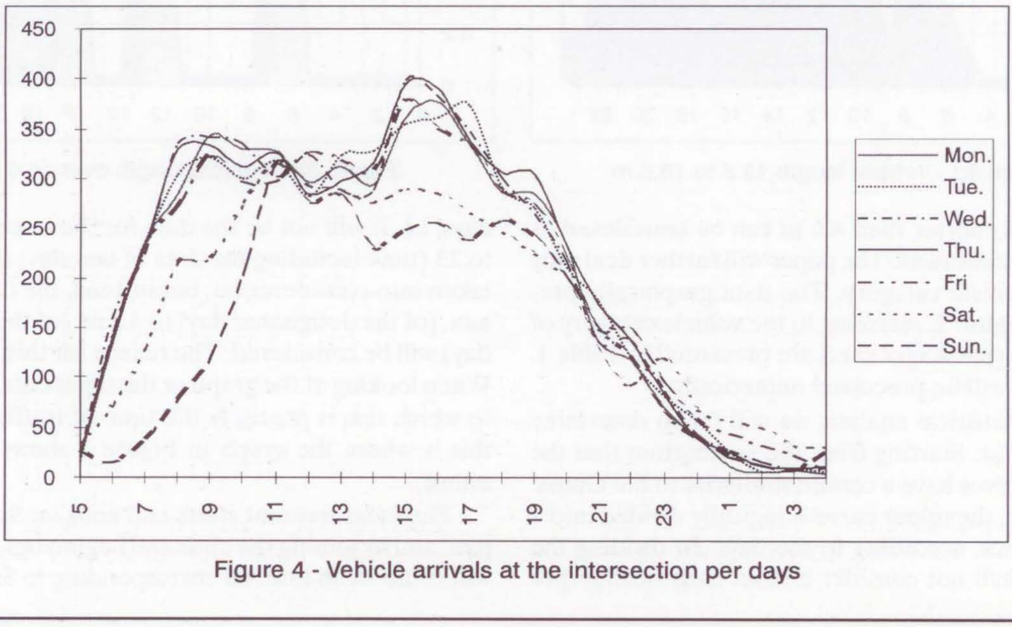

Figure 4 - Vehicle arrivals at the intersection per days

If the graphs indicating the vehicle arrivals at the intersection per week-days are overlapped (Figure 4), it can be noticed that the behaviour during the day is quite regular. Somewhat greater deviations may be noticed at the end of the week, on Saturday and Sunday.

In order to analyse the extent to which it may be claimed that the behaviour of vehicle arrival at the intersection depending on the time in the day is equal, χ^2 -test will be used.

The starting assumption is that the frequencies pattern does not deviate much from their average. Therefore, instead of using theoretical frequencies in the standard χ^2-test, the average of frequencies of the currently considered days will be introduced.

The hypothesis about equal distributions will be tested for each day separately, having the data for 24 hours, which means that the degrees of freedom is 24 - 1 = 23, with significance level of 5%. Apart from these characteristics, the limit is 35.17 (Supplement), which means that if the value χ^2 is assigned greater than that number, the hypothesis is rejected, otherwise it can be accepted.

Value χ^2 is calculated in the following way:

$$\chi^2 = \sum_{i=0}^{23} \frac{(f_i - fp_i)^2}{fp_i}$$

where:

i – is the ordinal number of the hour

f_i – vehicle count measured at the i-th hour (of a particular day)

fp_i – average number of vehicles at the i-th hour.

Let us consider first the results obtained for the whole week (Table 2). The values of fp are calculated as the average of all the seven days. As seen in the Table, all the values χ^2 are greater than the limit, and the hypothesis about the uniform vehicle arrival to the intersection during all the days in the week has to be re-

Table 2 - χ^2-test for testing equal distributions of frequencies during all the seven days.

hour	fp	χ^2(Mon)	χ^2(Tue)	χ^2(Wed)	χ^2(Thu)	χ^2(Fri)	χ^2(Sat)	χ^2(Sun)
5	23	0.391304	2.130435	0.695652	0.043478	0.173913	2.782609	1.086957
6	114.4286	3.698234	4.066524	18.14892	5.714464	7.642055	16.48225	86.39486
7	189.5714	11.86608	9.496071	6.621165	9.496071	10.88642	19.99795	121.1886
8	260	2.403846	7.446154	22.21538	18.84615	0.65	7.788462	128.8038
9	286.1429	11.69852	4.493331	10.90372	7.673062	4.74745	15.28914	97.63212
10	293	4.672355	0.167235	6.020478	1.232082	0.085324	1.232082	28.2628
11	315.1429	0.524543	0.025903	0.548116	0.374045	0.932522	0.002331	0.025903
12	297.8571	0.002467	0.741076	2.122371	0.644673	3.050428	0.049949	1.603905
13	302.2857	0.312179	1.419457	0.583918	0.060762	0.924183	0.421348	1.10613
14	291.5714	0.020228	4.304893	0.022678	2.046686	0.925667	0.728214	13.0021
15	346.8571	0.576665	0.240998	7.838609	6.682102	2.796187	8.995116	28.1751
16	343.1429	3.146188	0.929285	4.400143	6.398477	0.17991	9.51588	22.13037
17	319	0.705329	9.482759	2.45768	1.131661	0.705329	8.476489	20.0627
18	282.1429	0.052731	0.218807	1.130199	2.017288	0.121591	4.377288	2.065895
19	266.7143	1.120285	0.068865	0.011018	5.212411	0.257403	6.524141	2.108501
20	216.5714	1.099133	0.096495	0.009423	1.099133	0.054278	1.267998	0.9804
21	150.5714	1.223231	4.638791	1.223231	3.645432	0.002169	3.090404	0.002169
22	125.5714	0.456525	0.247196	1.230132	1.230132	4.752316	8.448562	0.101576
23	85.71429	2.880952	0.259286	0.019286	0.085952	0.800952	13.71429	5.005952
0	50.28571	1.36526	0.89651	1.055601	2.532873	1.876623	7.728896	1.714692
1	30.85714	11.52381	1.111772	0.26455	0.76455	6.482143	23.87566	2.542328
2	19.42857	10.71534	9.281513	1.009454	3.656513	10.92857	51.30357	1.516807
3	14	3.5	2.571429	2.571429	1.142857	5.785714	28.57143	2.571429
4	13.71429	6.880952	5.537202	1.620536	0.537202	1.005952	21.7872	11.00595
χ^2		80.83616	69.87199	92.72369	82.26806	65.76711	262.4513	579.0911

Table 3 - χ^2-test for testing equal distributions of frequencies during the five work-days.

hour	fp	χ^2(Mon)	χ^2(Tue)	χ^2(Wed)	χ^2(Thu)	χ^2(Fri)
5	20.4	0.007843	0.94902	0.096078	0.12549	1.037255
6	143	0.447552	0.342657	2.020979	0.062937	0.006993
7	232.2	0.099225	0.000172	0.223256	0.000172	0.033764
8	305.6	1.388613	0.008377	3.024084	1.948168	3.477618
9	332.8	0.376923	0.350481	0.254327	0.00012	0.288582
10	315	0.714286	0.714286	1.269841	0.028571	0.91746
11	314.4	0.588295	0.041221	0.489059	0.42799	0.855471
12	303	0.118812	1.320132	1.320132	1.191419	2.062706
13	308.2	0.046853	0.710707	1.196106	0.337573	0.378456
14	306.8	0.534029	1.329987	1.032725	0.27588	0.004694
15	377.8	0.747062	1.257914	1.189624	0.78306	0.000106
16	372	0.043011	0.325269	0.268817	0.870968	1.185484
17	345.4	0.376259	2.368153	0.007412	0.158541	0.376259
18	294	0.217687	0.054422	0.122449	0.489796	0.122449
19	279.8	0.063045	0.276769	0.782845	2.093066	0.082345
20	222.8	0.379892	0.523519	0.103411	0.379892	0.035189
21	155	2.090323	3.122581	2.090323	2.329032	0.16129
22	132.8	1.649398	1.233735	0.203614	0.203614	2.227711
23	83	2.036145	0.048193	0.192771	0	1.457831
0	48.2	0.79751	1.606639	0.560996	1.756017	2.888797
1	27.2	8.494118	0.177941	0.023529	0.052941	11.64853
2	14.2	5.960563	4.735211	0.04507	0.721127	27.60845
3	11.2	1.575	0.914286	0.914286	0.128571	12.43214
4	7.8	1.851282	1.005128	0.184615	1.312821	0.620513
χ^2		30.60372	23.4168	17.61635	15.67777	69.91009

jected. The greatest deviation is for the values obtained for Saturday and Sunday, which could already have been expected judging from the graphs.

If only the data obtained for the work-days (Monday - Friday) are considered, the results are obtained which are presented in Table 3. The values fp are now average frequencies of the observed five days.

Table 3 shows that the hypothesis of equal traffic density has to be rejected for Friday, whereas it can be accepted for other days. Here, the average frequency of five days has been taken as the theoretical frequency, so that another test will be made in order to compare only the first four days in the week (Table 4).

Results in Table 4 show that the hypothesis of uniform traffic density during the four "real" work-days can be accepted. The week-end has to be analysed separately, since it brings certain specific traffic flows. Friday is often said to be the beginning of the week-end, which is reflected in the traffic as well (often due to leaving work earlier, departures from the city in the afternoon hours...). On Saturday and Sunday there is usually "calming down" in traffic, i.e. the traffic density in the city is reduced.

4. DISTRIBUTION OF VEHICLE ARRIVALS FROM MONDAY TO THURSDAY

We will focus our attention now to the first four work-days to try to determine what type of movement is involved. After having determined that the deviation of frequencies from their average is small, only the average will be considered (fp from Table 4) which is presented in Figure 5.

Let us take a look at the graph. There is a continuous increase in the traffic density from the early morn-

Table 4 - χ^2-test for testing equal distributions of frequencies during the first four work-days.

hour	fp	χ^2(Mon)	χ^2(Tue)	χ^2(Wed)	χ^2(Thu)
5	19.25	0.029221	0.548701	0.003247	0.392857
6	142.75	0.420753	0.319177	2.084501	0.052977
7	231.5	0.13067	0.00108	0.182505	0.00108
8	313.75	2.634462	0.302988	1.577888	0.841633
9	335.25	0.228374	0.523676	0.135906	0.015101
10	319.25	0.361981	1.160728	0.777016	0.164644
11	318.5	0.283359	0.000785	0.854788	0.176609
12	296.75	0.000211	0.63711	2.32203	0.54781
13	305.5	0.138298	1.002455	0.891162	0.184124
14	306.5	0.509788	1.371126	0.999184	0.294454
15	377.75	0.74272	1.252316	1.1954	0.787723
16	377.25	0.004142	0.699967	0.059808	0.430915
17	348.25	0.583094	1.903984	0.004487	0.301687
18	295.5	0.305415	0.102369	0.068528	0.373096
19	281	0.032028	0.355872	0.911032	1.882562
20	223.5	0.323266	0.591723	0.135347	0.323266
21	156.25	2.3716	2.7556	2.3716	2.0164
22	128.5	0.857977	0.562257	0.702335	0.702335
23	80.25	1.30919	0.007009	0.567757	0.094237
0	45.25	0.233425	3.051105	0.111878	0.86326
1	22.75	5.07967	0.222527	1.211538	0.464286
2	9.25	1.952703	1.141892	3.574324	0.331081
3	8.25	0.189394	0.007576	0.007576	0.371212
4	7.25	1.456897	0.698276	0.422414	1.939655
χ^2		20.17864	19.2203	21.17225	13.553

ing hours till noon, with the peak density around 10 o'clock. Then follows a slight decrease in the number of vehicles and the next rush-hour is then between 3 p.m. and 4 p.m. Towards the end of the day, the number of vehicles at the intersection is decreasing almost continuously.

The sections of the obtained curve can be compared to the Gauss' curve i.e. to its sections. A some-

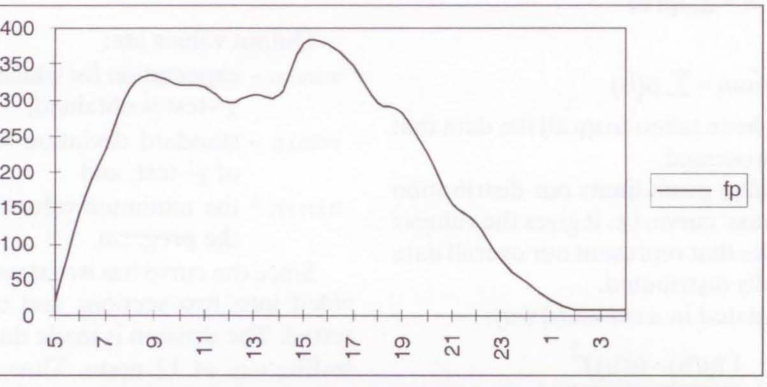

Figure 5 - Average frequencies of vehicle arrival at the intersection during the first four days (Monday - Thursday)

what modified χ^2-test is performed again, to show that the traffic density at the considered intersection is normally distributed per sections. The comparison with a section of the Gauss' curve will be made in such a way that the calculated theoretical probabilities are multiplied by factor $C = \Sigma fp/\Sigma p$, which would correspond to the number of total data if we had a complete Gauss' curve. By such multiplication, the total number of data matches the sum obtained in empirical frequencies.

Two intervals have been isolated and they can show the normal distribution of data: 6 a.m. - 12 noon and 1 p.m. to 4 a.m.

The following symbols are used in tables:

fp – average frequency;

p – theoretical probability of vehicle arrival to the intersection calculated for every hour of the given interval with the selected expectation and standard deviation

ft – theoretical frequency, and

χ^2 – (chi-square), the deviation measure from the normal distribution.

The values in the table are calculated in the following way out of the known data (hour, i.e. its ordinal number b giving us a continuous series of the basic argument and the empirical average frequencies):

p(b) = NORMALDIS(b. μ. σ. *false*).

where NORMALDIS function of the computer program Excel which gives the value of probability of argument b in normal distribution with expectation μ and standard deviation σ. The fourth argument (*false*) is the value of the logical variable which determines the sense of the function NORMALDIS as a probability function. With the other option of this value (*true*), the value of the distribution function of the normal distribution would be obtained with appropriate other parameters.

$$ft(b) = \frac{p(b) * N}{psum}$$

where

$$N = \sum fp(b)$$

and

$$psum = \sum p(b)$$

where the sums have been taken from all the data that are currently being processed.

Dividing by the value psum limits our distribution to a section of the Gauss' curve, i.e. it gives the values f theoretical frequencies that represent our overall data (per sections) normally distributed.

Finally, χ^2 is calculated in a standard way:

$$\chi^2 = \sum \frac{(fp(b) - ft(b))^2}{ft(b)}$$

and the table is checked (supplement) to see whether to reject or accept the hypothesis that our curve is normally distributed per sections.

The values of expectation and standard deviations could not be determined by standard numerical methods since the involved data do not cover the whole area of the Gauss' curve. Therefore, they were determined in such a way that the minimum value χ^2 was sought for the possible range of values for the expectation and standard deviation. The increment in the change of studied values both for μ and for σ was 0.1.

The program used for this calculation has been written using the software package Mathematica.

Input data are the following:

`sat1` – the starting hour of the currently observed interval and

`fp` – list of average frequency values for the considered interval

Program:

```
himin = 500;
n = Length[fp];
b = Table[i. {i. n}];
ukupno = Apply[Plus. fp];
For[mi = 1. mi <= n. mi = mi + 0.1.
  For[sd = 1. sd <= n. sd = sd + 0.1.
    pfun[x_] := PDF[NormalDistribu-
tion[mi. sd]. x];
    p = Map[pfun. b]; psum := Apply[Plus.
p];
    ftfun[x_] := x*ukupno/psum;
    ft = Map[ftfun. p];
    For[hisum = 0; i = 1. i <= n. i++.
    hi = (fp[[i]] - ft[[i]])^2/ft[[i]];
hisum += hi];
    If[hisum himin.
    himin = hisum; mimin = mi; sdmin =
sd]]];
    mimin = mimin + sat1 - 1;
Print[{mimin. sdmin. himin}]
```

Output values are:

`mimin` – expectation for which the minimum value of χ^2-test is obtained;

`sdmin` – standard deviation for the minimum value of χ^2-test, and

`himin` – the minimum value of χ^2-testa obtained by the program.

Since the curve has two stressed peaks, it will be divided into two sections and our hypothesis will be tested. The division is made during the noon uniform traffic, e.g. at 12 noon. Thus, two intervals are obtained: the first one from 5 a.m. to 12 noon and the second one from 1 p.m. to 4 a.m. (the following day).

Let us analyse the first interval.

Table 5 - χ^2-test for testing of the partial normal distribution of frequencies from 5 a.m. to 12 noon.

hour	Ord. No. (b)	fp	p	ft	χ^2
5	1	19.25	0.028468	69.35733	36.20014
6	2	142.75	0.052058	126.8288	1.998626
7	3	231.5	0.082992	202.1946	4.247416
8	4	313.75	0.115349	281.0265	3.810422
9	5	335.25	0.139772	340.5264	0.081758
10	6	319.25	0.147655	359.7331	4.555831
11	7	318.5	0.135989	331.3111	0.495381
12	8	296.75	0.109191	266.022	3.549358
Σ		1977	0.811474	1977	54.93893

The results presented in Table 5 are the best approximation of the data to the normal distribution. It has been obtained for the expectation $\mu = 9.9$ and standard deviation $\sigma = 2.7$ (Program). However, since for 5 degrees of freedom, the limit for rejecting the hypothesis with 5% of significance amounts to 11.07, whereas the obtained value for χ^2 equals 54.93893, it is obvious that we can reject the hypothesis. Therefore, the behaviour of the curve in the interval 5 - 12 does not correspond to the normal distribution.

Looking at the results, it is easy to note that the maximum deviation is at the margin, i.e. for the data that refer to 5 o'clock. By neglecting these data, we shall try to determine whether the rest of the "morning" curve has the characteristic of normal distribution.

Table 6 - χ^2-test for testing of the partial normal distribution of frequencies from 6 a.m. to 12 noon

hour	Ord. No. (b)	fp	p	ft	χ^2
6	1	142.75	0.058326	157.89	1.45177
7	2	231.5	0.083084	224.9092	0.193138
8	3	313.75	0.106654	288.714	2.171008
9	4	335.25	0.12338	333.9924	0.004735
10	5	319.25	0.128624	348.1876	2.404988
11	6	318.5	0.120839	327.1133	0.226798
12	7	296.75	0.102306	276.9434	1.416533
Σ		1957.75	0.723213	1957.75	7.86897

The elimination of marginal values has given good results. The Gauss' curve that is best adapted to the values obtained in the interval 6 - 12 a.m. has the parameters $\mu = 9.9$ and standard deviation $\sigma = 3.1$. The obtained value χ^2 amounts to 7.86897, whereas the limit for 4 degrees of freedom and the level of significance 5% equals 9.489. Thus, the hypothesis about the normal distribution in this interval will be accepted.

Let us consider the rest of the day, the interval from 1 p.m. until 4 a.m. of the following day.

Table 7 - χ^2-test for testing of the partial normal distribution of frequencies from 1 p.m. to 4 a.m.

hour	Ord. No. (b)	fp	p	ft	χ^2
13	1	305.5	0.078423	303.0855	0.019235
14	2	306.5	0.088338	341.4026	3.568201
15	3	377.75	0.094022	363.3697	0.569098
16	4	377.25	0.094556	365.4355	0.381964
17	5	348.25	0.089853	347.2584	0.002831
18	6	295.5	0.080678	311.7992	0.85204
19	7	281	0.068448	264.5315	1.025248
20	8	223.5	0.054871	121.0606	0.617089
21	9	156.25	0.041563	160.6285	0.119352
22	10	128.5	0.029747	114.9649	1.593513
23	11	80.25	0.020117	77.74783	0.080528
0	12	45.25	0.012855	49.68111	0.395216
1	13	22.75	0.007762	29.99677	1.750711
2	14	9.25	0.004428	17.11346	3.613179
3	15	8.25	0.002387	9.225315	0.103112
4	16	7.25	0.001216	4.698993	1.3849
Σ		2973	0.769264	2973	16.07622

In the interval from 3 p.m. until 4 a.m. of the following day, the curve of empirical frequencies corresponds to the section of the Gauss' curve with the ex-

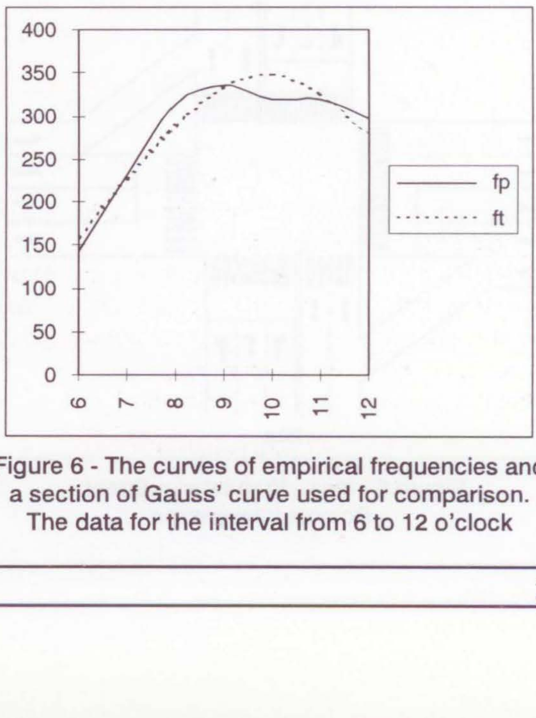

Figure 6 - The curves of empirical frequencies and a section of Gauss' curve used for comparison. The data for the interval from 6 to 12 o'clock

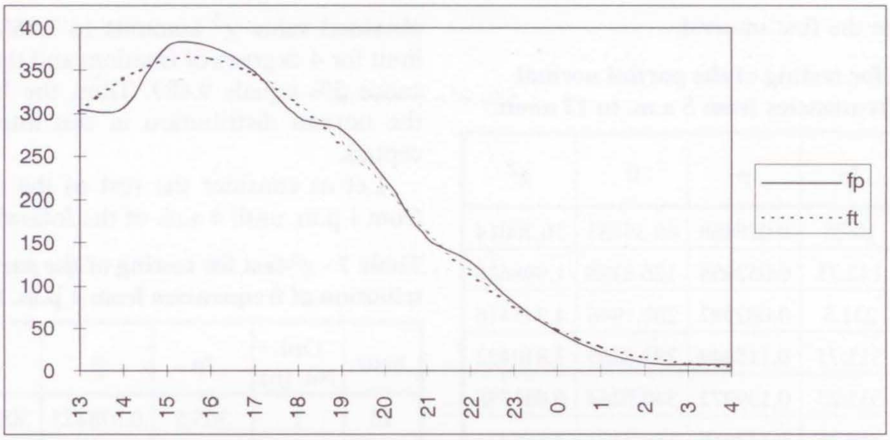

Figure 7 - The curves of empirical frequencies and a section of the Gauss' curve used for comparison. The data for the interval from 1 p.m. to 4 a.m. (the following morning)

pectation of the peak traffic density in $\mu = 15.6$ o'clock and standard deviation $\sigma = 4.2$. For this interval of 16 hours, there are 13 degrees of freedom, and with 5% of significance, 22.36 appears as the limit value. Test in Table 7 has yielded a lower value (16.07622) which means that we can accept the assumption about the partial normal distribution.

The accepted empirical and theoretical frequencies is given in Figures 6 and 7.

5. COMPARISON TESTS

Let us now try to analyse some other intersections.

Example 1

The following data have been obtained for the intersection Ilica - Vrapčanska Street - Bolonja.

This intersection is somewhat more complex than the intersection of Petrova and Bukovačka Street, with a greater number of lanes. Measurements that are used have been carried out on October 1 and 2, 1997. Although the amount of available data is not the same, we will try to compare the available sample obtained on work-days (Wednesday and Thursday) with the average of work-days (Monday - Thursday) from the first part. The daily number of vehicles in the observed direction is approximately the same as the traffic in the considered direction at the intersection of Petrova and Bukovačka Streets. In this case, the data about the vehicle categories is lacking, and all the vehicles up to 18 metres long have been included. This should not present any major problem, since, as already seen in the initial example, the number of longer vehicles is negligible within the overall number of the counted vehicles.

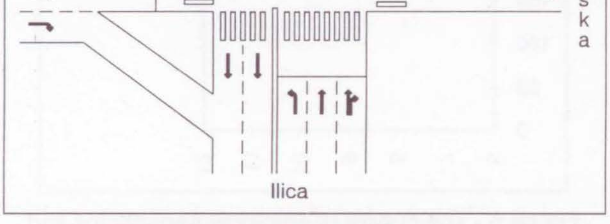

Figure 8 - Ilica - Vrapčanska Street - Bolonja intersection

The traffic density in the considered period is presented in Figure 9.

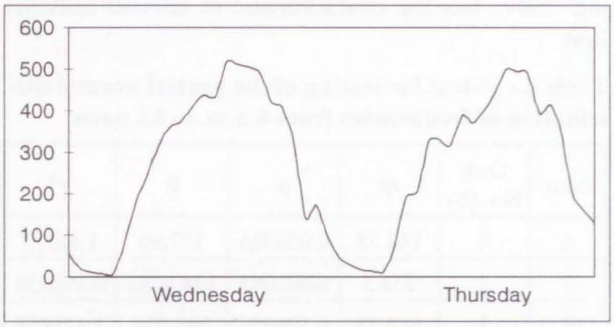

Figure 9 - Vehicle length up to 16 m at the intersection of Ilica - Vrapčanska Street - Bolonja

A certain regularity in behaviour can be noted in the Figure. Table 8 offers also the numerical confirmation of the uniform daily flow of vehicles with the previous acceptable interval from 5 a.m. to 4 a.m. of the following day.

The obtained results in Table 8 show that the hypothesis about uniform distribution of frequencies over the observed two days may be accepted, since the obtained value of the χ^2-test is 23.354169, and with 5%

Table 8 - Data about the vehicle arrival at intersection during the measured time and the corresponding χ^2-test (Ilica - Vrapčanska Street - Bolonja intersection)

hour	Ord. No. (b)	Wed.	Thu.	fp	χ^2 (Wed.)	χ^2 (Thu.)
5	5	10	15	12.5	0.5	0.5
6	6	78	78	78	0	0
7	7	184	188	186	0.0215054	0.0215054
8	8	245	209	227	1.4273128	1.4273128
9	9	316	329	322.5	0.1310078	0.1310078
10	10	361	331	346	0.650289	0.650289
11	11	376	318	347	2.4236311	2.4236311
12	12	411	388	399.5	0.3310388	0.3310388
13	13	437	372	404.5	2.6112485	2.6112485
14	14	434	400	417	0.6930456	0.6930456
15	15	517	446	481.5	2.6173416	2.6173416
16	16	511	500	505.5	0.0598417	0.0598417
17	17	505	494	499.5	0.0605606	0.0605606
18	18	489	492	490.5	0.0045872	0.0045872
19	19	420	394	407	0.4152334	0.4152334
20	20	408	413	410.5	0.0152253	0.0152253
21	21	314	346	330	0.7757576	0.7757576
22	22	140	203	171.5	5.7857143	5.7857143
23	23	172	158	165	0.2969697	0.2969697
0	24	97	128	112.5	2.1355556	2.1355556
1	25	46	56	51	0.4901961	0.4901961
2	26	28	23	25.5	0.245098	0.245098
3	27	18	11	14.5	0.8448276	0.8448276
4	28	14	8	11	0.8181818	0.8181818
		Σ		6415.5	23.354169	23.354169

of significance the hypothesis is not rejected if the obtained value is less than 35.17.

The question now is about the kind of behaviour this involves. The curve in Figure 9 has only 1, instead of 2 peak maximums. The analysis can be made whether these frequencies are normally distributed. By running the program in Mathematica, with the input list fp which contains the whole series of obtained average frequencies, the following output data are obtained:

`himin` = 218.65; `mimin` = 15.1; `sdmin` = 5.

This minimum value of the χ^2-test (himin) is too big and the hypothesis about the normal distribution of frequencies cannot be accepted. (The enclosed Table shows that the limit value for rejecting the hypothesis with 5% significance and 21 degrees of freedom equals 32.671). Therefore, the hypothesis is rejected.

It can be concluded that regular behaviour is present in the considered example, but it cannot be described by the Gauss' curve (or its sections).

Example 2

The following data have been obtained at the intersection of Ilica - Vrapčanska Street - Bolonja, as in the first example, but in the different direction. The measurements have been performed at the same time.

The traffic density in the considered period is presented in Figure 10.

The Figure indicates that there is a similarity in behaviour. Table 9 offers also the numerical confirmation of the uniform daily movement of frequencies in

Table 9: Data about the vehicle arrival at the intersection during the measured time and the related χ^2-test (Ilica - Vrapčanska Street - Bolonja intersection)

hour	Ord. No. (b)	Wed.	Thu.	fp	χ^2 (Wed.)	χ^2 (Thu.)
5	1	9	14	11.5	0.5434783	0.5434783
6	2	68	65	66.5	0.0338346	0.0338346
7	3	208	201	204.5	0.0599022	0.0599022
8	4	281	311	296	0.7601351	0.7601351
9	5	222	205	213.5	0.3384075	0.3384075
10	6	189	171	180	0.45	0.45
11	7	178	170	174	0.091954	0.091954
12	8	201	167	184	1.5706522	1.5706522
13	9	166	213	189.5	2.914248	2.914248
14	10	175	204	189.5	1.1094987	1.1094987
15	11	188	195	191.5	0.0639687	0.0639687
16	12	200	173	186.5	0.9772118	0.9772118
17	13	166	200	183	1.579235	1.579235
18	14	185	183	184	0.0054348	0.0054348
19	15	209	252	230.5	2.005423	2.005423
20	16	194	193	193.5	0.001292	0.001292
21	17	121	161	141	2.8368794	2.8368794
22	18	70	110	90	4.4444444	4.4444444
23	19	93	65	79	2.4810127	2.4810127
0	20	45	39	42	0.2142857	0.2142857
1	21	21	14	17.5	0.7	0.7
2	22	8	8	8	0	0
3	23	8	5	6.5	0.3461538	0.3461538
4	24	2	3	2.5	0.1	0.1
		Σ		3264.5	23.627452	23.627452

the interval from 5 a.m. until 4 a.m. of the following day.

The obtained results in Table 9 show that the hypothesis about the uniform distribution of frequencies during the considered two days can be accepted, since the obtained value of χ^2-test is 23.627452, and with 5% significance the hypothesis is not rejected if the obtained value is less than 35.17.

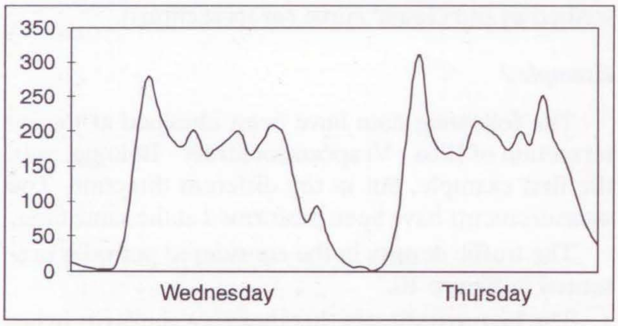

Figure 10 - Vehicle length of up to 16 m at the intersection Ilica - Vrapčanska Street - Bolonja

The question is now what kind of behaviour is involved. The curve in Figure 10 has the form that does not correspond to the Gauss' curve nor its sections. If, however, we try to relate the curve sections to the normal distribution, we obtain the following results:

for the input list fp which contains average frequencies (per time units that have been studied in the main example - intersection of Petrova and Bukovačka Streets):

- from 5 to 12 noon:

  himin = 129.5323; mimin = 9.2; sdmin = 2.2
- from 6 to 12 noon:

  himin = 97.10212; mimin = 9.1; sdmin = 2.6.

– from 1 p.m. to 04 a.m.:
himin = 55.58876; mimin = 16.7; sdmin = 4.1.

These minimal values of the χ^2-testa (himin) are greater than the limit values for the appropriate degrees of freedom. Therefore, the hypothesis about the normal distribution is rejected.

It can be concluded that the considered example indicates regular behaviour, but it cannot be described by the Gauss' curve (nor its sections).

Example 3

The intersection of Gundulićeva and Varšavska Streets has been taken for comparison.

The total volume of daily traffic at this intersection is approximately equal to the intersection of Petrova and Bukovačka Streets. In the measured direction, during the 7 days at the intersection of Petrova and

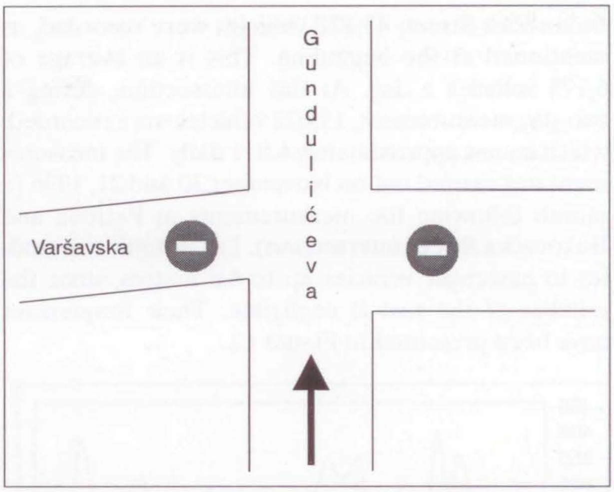

Figure 11 - Gundulićeva and Varšavska Street intersection

Table 10 - Data about the vehicle arrival at the intersection during the measured period and the related χ^2-test (Gundulićeva and Varšavska Street intersection)

hour	Ord. No. (b)	Wed.	Thu.	fp	χ^2 (Wed.)	χ^2 (Thu.)
5	1	40	42	41	0.02439	0.02439
6	2	163	140	151.5	0.872937	0.872937
7	3	281	297	289	0.221453	0.221453
8	4	356	203	279.5	20.93828	20.93828
9	5	272	136	204	22.66667	22.66667
10	6	397	172	284.5	44.48594	44.48594
11	7	217	117	167	14.97006	14.97006
12	8	179	210	194.5	1.235219	1.235219
13	9	94	311	202.5	58.13457	58.13457
14	10	160	295	227.5	20.02747	20.02747
15	11	235	243	239	0.066946	0.066946
16	12	100	215	157.5	20.99206	20.99206
17	13	346	170	258	30.0155	30.0155
18	14	323	322	322.5	0.000775	0.000775
19	15	307	377	342	3.581871	3.581871
20	16	348	144	246	42.29268	42.29268
21	17	298	196	247	10.53036	10.53036
22	18	242	266	254	0.566929	0.566929
23	19	162	229	195.5	5.740409	5.740409
0	20	106	126	116	0.862069	0.862069
1	21	68	56	62	0.580645	0.580645
2	22	36	23	29.5	1.432203	1.432203
3	23	30	13	21.5	3.360465	3.360465
4	24	13	13	13	0	0
		Σ		4544.5	303.5999	303.5999

Bukovačka Street, 43,222 vehicles were recorded, as mentioned at the beginning. This is an average of 6,175 vehicles a day. At this intersection, during a two-day measurement, 13,622 vehicles were recorded, which means approximately 6,811 daily. The measurement was carried out on November 20 and 21, 1996 (a month following the measurements at Petrova and Bukovačka Street intersection). Let us limit our studies to passenger vehicles up to 4.6 metres, since the number of the rest is negligible. Their frequencies have been presented in Figure 12.

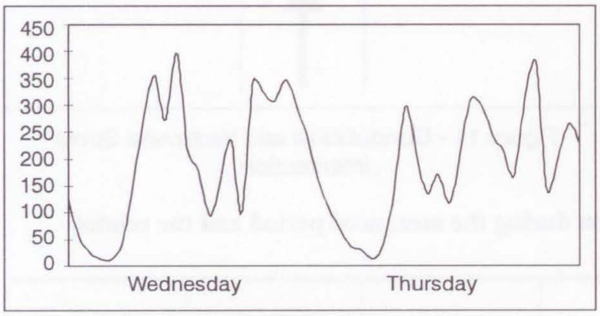

Figure 12 - Vehicle length up to 4.6 m at the Gundulićeva and Varšavska Street intersection

Figure 12 shows that there is quite an oscillation in traffic. Since this is an intersection in the very centre of the city, the traffic throughput is to a great extent determined by the current traffic density in the surrounding area. The falls in the curve do not have to mean reduced number of vehicles, but a traffic congestion in the direction of the vehicle flow.

Table 10 contains the data presented in the Figure. They will be divided into intervals from 5 a.m. to 4 a.m. (the following day). The initial data for Wednesday (0 - 4 a.m.) will be used as the final ones for Thursday.

Table 10, which contains also the results of the test about the uniform traffic distribution per days, shows that there is no regularity in behaviour which could describe the daily traffic at the considered intersection. The values of χ^2- test are far from acceptable. (For 23 degrees of freedom and the level of significance of 5%, the values should be below 35.17 in order not to reject the hypothesis about accordance with the average.)

There is no sense here in comparing the curves with the Gauss' curve.

6. CONCLUSION

The presented examples show that an intersection can but needn't show regularity in behaviour regarding the number of vehicles that pass through it during a certain part of day.

The regularity in behaviour of the Gauss' type, has been determined for one intersection. In order to use the obtained results for the traffic analysis at some other intersection, the similarities and differences of the particular intersections should be taken into consideration first. This includes the form of the intersection (number of traffic lanes, the allowed directions of traffic flows), its location (city centre, suburb, vicinity of a major facility...), the organisation of the intersection (whether it is controlled by traffic lights or not, whether there are pedestrian crossings or underpasses...) etc.

The aim of such analyses is to determine the traffic flows individually or in groups (in case of similar intersections), in a wider urban area, in order to reach the optimum in intersection throughput capacities, thus avoiding saturation and waiting. When traffic congestion occurs repeatedly at the same locations, the solution needs to be sought in changing the traffic light operation regime, and in re-directing the traffic to the often less loaded secondary routes.

Further work regarding this problem will continue in two directions: the selection of quantitative indicators for determining the similarity of two intersections and the gathering of data at these selected intersections with the aim of proving the obtained results.

SAŽETAK

ANALIZA DOLASKA VOZILA NA ODABRANO RASKRIŽJE U GRADU ZAGREBU

Analiziramo statistiku dolaska vozila na odabrano raskrižje u gradu Zagrebu. Raskrižje ima sve elemente kretanja: ravno, skretanje lijevo i skretanje desno. Statistička analiza u ovom radu temelji se na mjerenjima provedenim pomoću uređaja za prikupljanje podataka o prometu HI-STAR Model NC-90A.

Pokazali smo da četiri dana (ponedjeljak - četvrtak) imaju istu statističku zakonitost. Izdvojena su dva intervala u kojima se može prihvatiti normalna distribuiranost i to: 6 - 12 sati i 13 - 04 sata. Interval 6 - 12 sati ima Gaussovu distribuciju s očekivanjem najveće gustoće prometa u = 9,9 sati (tj. 9 sati i 54 minute) i standardnom devijacijom = 3,1. Interval 13 - 04 sata ima Gaussovu distribuciju s očekivanjem najveće gustoće prometa u = 15,6 sati (15 sati i 36 minuta) i standardnom devijacijom = 4,2. Rezultati se mogu koristiti za reguliranje prometa na tom raskrižju odnosno za semaforizaciju raskrižja.

LITERATURE:

[1] Serdar. V.; Šošić. I.: *Uvod u satistiku*. Zagreb. Školska knjiga. 1989.

[2] Program Microsoft Excel. Microsoft

[3] Program Mathematica. Wolfram Research

[4] Podaci, Gradski ured za promet. Zagreb

SUPPLEMENT

degrees of freedom	limit values for χ^2 with 5% significance
1	3.84
2	5.99
3	7.82
4	9.49
5	11.07
6	12.59
7	14.07
8	15.51
9	16.92
10	18.31
11	19.68
12	21.03
13	22.36
14	23.69
15	25.00
16	26.30
17	27.59
18	28.87
19	30.14
20	31.41
21	32.67
22	33.92
23	35.17
24	36.42
25	37.65
26	38.89
27	40.11
28	41.34
29	42.56
30	43.77