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Research of Traffic Flows of the Urban Street Network on Stationarity

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Abstract: In the article, traffic flows on city streets are checked for stationarity during short time intervals (5 seconds) in order to determine the criterion for the isolation of the operation of controlled intersections. It is assumed that with a stationary traffic flow, the controlled intersection can be considered isolated, and the traffic flow approaching it can be modeled using one of the probability distributions. Otherwise, for a locally unsteady flow, trivial approaches to modeling the operation of a road intersection cannot be applied. The possibility of using both a nonparametric test (Mann–Whitney U-test) and a parametric method of analysis of variance is evaluated. The time series transport stream is also checked for autocorrelation with Durbin-Watson test. In conclusion, it is proposed to refine the criterion of "isolated intersection".

1 INTRODUCTION

The increase in the number of vehicles is the main factor in increasing the intensity of traffic in cities and, increasing delays on the road network. In this regard, there is an increasing need to improve the organization and management of traffic. This has been achieved in recent years using intelligent transportation system (ITS). Accurate modeling data is required to justify their use.

Each Country or group of Countries has its own methods for determining the capacity of highways and streets and recommendations for the organization of traffic. These methods are fixed in the relevant regulatory documents [1,2,3,4].

The choice of the type of traffic control (adaptive or coordinated) is assigned based on several criteria, such as the total traffic intensity, traffic intensity at intersections and the distance between neighboring regulated intersections [1, 4, 5]. In documents [1 and 5], such a concept of a regulated intersection as an "isolated intersection" is proposed. It is proposed to apply strict regulation at isolated intersections with relatively low traffic intensity. At the same intersections with a high level of loading of the methodology, recommendations are given on the use of adaptive traffic flow management to be able to thus increase throughput and reduce overall delays by 15-30% [5,6]. Coordinated traffic light regulation (the so-called "green wave") will be more convenient and effective at closely located nodes.

In a similar situation, assigning the type and configuration of the intersection [1, 2] gives clear, reasonable recommendations for choosing the type of intersection (intersection at the same level, ring, interchange at different levels). The situation is also confused by the fact that the term "isolated intersection" means an intersection located far enough from neighboring nodes [1], so it works without considering neighboring nodes [5], which is equivalent to the synonym "tight regulation". In the norms [1], 1.6 km which is equal to 1 land mile, is taken as an isolation criterion. When applying this criterion to the urban road network, all urban regulated nodes automatically become uninsulated.

All the above allows us to formulate the purpose of this study – to clarify the concept of "isolated intersection" and to consider the possibility of effective adaptive control of traffic light regulation at regulated intersections located relatively close to each other at distances of 100-600m.

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This problem arises in the process of modeling traffic at regulated intersections and in assessing the effectiveness of traffic flow management.

2 FORMAL STATEMENT OF THE PROBLEM

The research proposes to separate the work of "isolated" intersections located earlier during traffic from "uninsulated" ones. To do this, it is necessary to present the traffic flow passing through the cross–section of city streets in short periods of time (5 seconds) as a time series and examine it for one of the most important characteristics - stationarity. The interval of 5 seconds is chosen as the most convenient for modeling the operation of an adaptive controlled intersection [5,6].

The stationarity (non-stationarity) of a suitable transport affects the operation of a controlled intersection. The traffic flow is a stationary time series [7]. The stationarity of a suitable traffic flow is divided into stationarity in the wide sense and stationarity in the narrow sense.

A series $x_t$is called stationary in the narrow sense if $F\left(x_{t_1},\ldots,x_{t_m}\right) = F(x_{t_{1+k}},\ldots,x_{t_{m+k}})$ for any moments $t_1,\ldots,t_m$ and any shift k (Fig.1).

Thus, regardless of the reference point of the series characteristic, the two main parameters of the series (expectation μ and variance σ 2) can be determined at any point in this series. The accuracy of finding these values depends on only on the size of the segment of the series, and not the reference point.

Stationary flows in a wide sense include cyclostationary flows. According to the authors of the article, the movement of traffic flows along city streets will be mainly a cyclostationary process with peaks during the passage of "bundles" of cars and local minima, where the flow will have only a random component (Fig. 2).

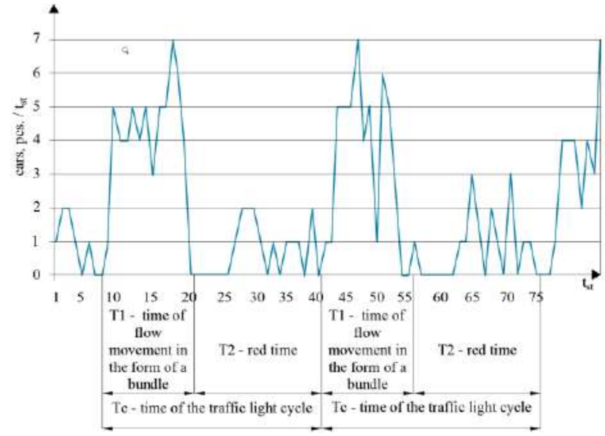

Figure 1: A typical picture of stationarity in a wide sense - cyclostationarity (the presence of a closely located previous regulated intersection that sends the flow in "bundles") – Profsoyusnaya Street.

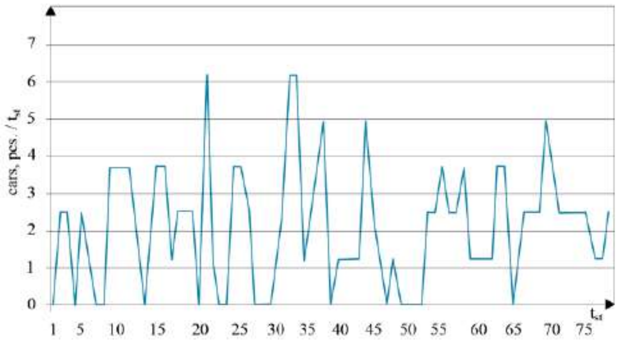

Figure 2: There are no significant differences between T1 and T2 (strict stationarity).

A random process (t) is called cyclostationary in a wide sense [8] in the case when its mathematical expectation and autocorrelation function are periodic functions in time with the period T:

$$m_x(t+T) = m_x(t),$$
$$R_x(s+T, u+T) = R_x(s,u), \quad (1)$$

for all t and u. The expression for the autocorrelation function $R(s, u)$ can be rewritten as a function of two independent variables t and τ , determined by the middle and duration of the time interval (s, u):

$$t=\frac{s+u}{2},$$
$$\tau=s-u, \quad (2)$$

The difference between a cyclostationary process and a stationary one in the wide sense [8] is that a random process exhibits the property of cyclostationarity in the wide sense when there is a correlation between versions of this process arbitrarily shifted in the frequency domain. In the frequency domain, this means that the spectral components located at different frequencies are statistically dependent. A random process can be called stationary in a wide sense when there is no correlation between randomly shifted versions of the random process in the frequency domain: $Rf(x_t) \equiv 0$ for all $\alpha \neq 0$. Thus, cyclostationarity can be considered as a special case of stationarity in a wide sense since the mathematical expectation with increasing length of the time series tends to the desired one.

Describing traffic with short intervals as a time series, it can be assumed that traffic on all sections of city streets during the day will be stationary in a wide sense, and with intervals of 60-150 seconds equal to the duration of traffic light cycles, local non-stationarity may be observed. At those intersections where the appropriate flow will be strictly stationary, it can be called isolated.

In the publication [9], the concept of stationarity for air transport is considered. To check the stationarity, the Dickey-Fuller tests (ADF test) and Philippe-Perron (PP test) are used. When testing a time series of traffic at short intervals, the test results will show the stationarity of the series without dividing it into stationarity in a wide and narrow sense. To do this, you will need to find a cyclic autocorrelation function that smooths the values of the series and leaves "white noise" as the remainder.

3 MATERIALS AND METHODS

To research the traffic flow for local stationarity, according to the authors, the methods of analysis of variance, comparison of sample medians according to the Mann-Whitney U-test, as well as the Durbin-Watson test for the significance of autocorrelation are suitable.

R-4.0.3 can be selected as the software environment.

When conducting statistical analysis, a null hypothesis is put forward, which assumes that the stage is considered stationary if the stationarity of the flow does not go beyond the values of the confidence intervals.

4 EXPERIMENT

In the process of conducting a study based on monitoring the traffic flow on the streets of Tyumen using street webcams, several stages were selected, a sample of data on the flow of cars was measured and formed by traffic lanes for 100 measurements with an interval of 5 seconds.

It is impossible to describe unsteady flows using any one probability distribution (Poisson, Weibull, normal, beta distribution), since in this case a superposition of processes will be observed, and this must be taken into account when constructing a model of a controlled intersection.

The article suggests using the analysis of variance and the nonparametric Mann-Whitney U-test for this purpose. Variance analysis is a parametric method, and its use is recommended for the normal distribution of the general combination.

In the theory of traffic flows, it is assumed that the movement of cars can obey different types of distributions (Poisson, Weibull, exponential, etc.) and in most cases there is no reason to consider it normal. With a significant sample (more than 100), the statistics of the F-criterion asymptotically tends to the norm and it is recommended to use quantiles of the normal distribution to make decisions on statistical models.

Further, 23 different sections of the main streets of Tyumen were selected in the work to conduct research on statistical characteristics. The sample for the study was 100-180 values. The parameters of the traffic flow approaching the regulated intersection in tst were compared according to the Fisher criterion and the Student's t-statistics for time intervals T1 and T2 (Fig. 1-2). The choice of the considered intervals was determined by the presence of a visually fixed "bundle" formed during the resolving phase of the traffic light (interval T1) and during the rest of the cycle of the traffic light (T2), previously located in the direction of the regulated intersection.

For the null hypothesis (local stationarity of the flow), it is assumed that the variances of samples T1 and T2 along the studied street stretches and their median are equal, $\sigma_1^2 = \sigma_2^2, \mu_1 = \mu_2$. The 0.05 level was taken as the significance level 0.05

5 RESULTS AND DISCUSSION

In the analysis of the results, the statistics of the F-test will be used as an auxiliary in comparison with the Mann-Whitney test.

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Table 1: Obtained values of the Fisher criterion and Mann-Whitney U-test

The name of the site and the direction of movement	Number of lanes	The value of the Fisher criterion		The Mann-Whitney Value U	
		Current value	Table value (0,05)	Current value	Table value (p<0,05)
50 let Oktyabrya St. (from Profsoyusnaya to M.Gorky St.)	3	**3,2**	**1,6**	**619**	**742**
50 let Oktyabrya St. (from Refrigerating St. to M.Gorky St.)	3	**4,92**	**1,7**	**107**	**1003**
Melnikaite St. (from the overpass to Republic St.)	3	**1,76**	**1,6**	**342**	**965**
Melnikaite St. (from Republic St. to the overpass)	3	**4,73**	**1,61**	**152**	**741**
Trade Union St. (from Lenin St. to Herzen St.)	4	**3,37**	**1,7**	**127**	**723**
Usadebnaya St. (from Shcherbakov St.)	1	1,59	1,65	1187	988
Usadebnaya St. (to Shcherbakov St.)	1	1,27	1,65	1175	1009
Shcherbakov St. (from Velizhansky tr. to Bezymyannaya St.)	2	1,64	1,65	1182	1003
Shcherbakov st. (from Bezymyannaya st. to Vel.tr.)	2	**1,93**	**1,61**	**584**	**1006**
Velizhansky tract St. (from Melioratorov St. to Shcherbakov St.)	2	1,38	1,61	714	608
Velizhansky tract st. (from Shcherbakov st. to Melioratorov st.)	2	1,25	1,61	**593**	**994**
International St. (from ul. Uprisings to Amurskaya St.)	2	**2,59**	**2,7**	**1125**	**1306**
International St. (from Amurskaya St. to ul. Uprisings)	2	1,31	1.7	1590	1407
Magnitogorsk St. (to Moskovsky Trakt st.)	1	1,39	1,7	1026	1009
Moskovsky Trakt St. (from «Kolumb» to Magnitogorsk St.)	3	1,29	1.7	1086	1009
Herzen St. (from Chelyuskintsev St.)	2	1,53	1,87	997	905
Herzen St. (from Griboyedov St.)	2	1,05	1,87	**762**	**1003**
Pervomayskaya St. (from the railway station)	2	1,28	1,87	1144	1003
Shirotnaya St. (from Fedorov St. to Permyakova St.)	3	1,33	1,7	**982**	**1003**
Melnikaite St. (from 30 let Pobedy St. to Shirotnaya St.)	3	**1,81**	**1,7**	1023	887
Melnikaite St. (from Shirotnaya St. to Gnarovskaya St.)	3	1,23	1,7	1176	1003
Zapadnosibirskaya St. (from Yubileynaya St.)	2	1,03	1,7	1138	1003
Zapadnosibirskaya St. (from the Tura river)	1	1,28	1,7	1238	1003

Thus, as can be seen from Table 1, a significant number of the studied crossings showed local unsteadiness of the traffic flow.

For the final determination of the boundary conditions, it is necessary to check the data on the traffic flow on the considered stages for autocorrelation since with a stationary flow (stationarity in the wide sense) there will be alternating bursts of intensity alternating with each other. It is proposed to use the Breusch-Godfrey and the Durbin-Watson. The second criterion is used with a 1st-order autocorrelation check:

$$DW = \frac{\sum(e_i - e_{i-1})^2}{\sum e_i^2}, \quad (4)$$

where e_i is the value of the remainder.

The choice of this criterion is also since the processes of movement of vehicles on the carriageway, according to the author, will be moving average processes (4), and not autoregression processes (5), in which this type of criterion is inapplicable. The process of autoregression in econometric systems is also called the "random walk" process.

Description of the process, moving average (MA1):

$$e_i = \alpha + \rho\varepsilon_{i-1} + \varepsilon_i, \quad (5)$$

Description of the 1st order autoregression process (AR 1):

$$e_i = \alpha + \rho e_{i-1} + \varepsilon_i, \quad (6)$$

Where α is a time series constant; e_i- the value of the car driving function at the moment . Moreover, the value of e cannot be less than 0; ε_i- a random component of a time series. It is accepted in the works on the description of time series for "white noise" $\varepsilon_i \sim N\ (0, \sigma^2)$; ρ- the autocorrelation coefficient. At $\rho = 0$, there is no autocorrelation.

The results are shown in table 2:

Table 2: Obtained values of the Breusch-Godfrey and the Durbin-Watson statistics.

The name of the site and the direction of movement	Number of lanes	The value of the Fisher criterion		The Mann-Whitney Value U	
		Current value	Table value (0,05)	Current value	Table value (p<0,05)
50 let Oktyabrya St. (from Profsoyusnaya to M.Gorky St.)	3	3	4,42	5,99	**1,56**
50 let Oktyabrya St. (from Refrigerating St. to M.Gorky St.)	3	3	**34,5**	5,99	**0,81**
Melnikaite St. (from the overpass to Republic St.)	3	3	**55,2**	5,99	**0,5**
Melnikaite St. (from Republic St. to the overpass)	3	3	**41,6**	5,99	**0,7**
Trade Union St. (from Lenin St. to Herzen St.)	4	4	**54,5**	5,99	**0,51**
Usadebnaya St. (from Shcherbakov St.)	1	1	0,58	5,99	1,82
Usadebnaya St. (to Shcherbakov St.)	1	1	0,44	5,99	1,85
Shcherbakov St. (from Velizhansky tr. to Bezymyannaya St.)	2	2	0,47	5,99	1,85
Shcherbakov st. (from Bezymyannaya st. to Vel.tr.)	2	2	2,52	5,99	1,68
Velizhansky tract St. (fromŚlioratorov St. to Shcherbakov St.)	2	2	2,52	5,99	1,68
Velizhansky tract st. (from Shcherbakov st. to Melioratorov st.)	2	2	**13,7**	5,99	**1,24**
International St. (from ul. Uprisings to Amurskaya St.)	2	2	1,08	5,99	2,18
International St. (from Amurskaya St. to ul. Uprisings)	2	2	0,73	5,99	1,82
Magnitogorsk St. (to Moskovsky Trakt st.)	1	1	4,19	5,99	**1,56**
Moskovsky Trakt St. (from «Kolumb» to Magnitogorsk St.)	3	3	**40,6**	5,99	**0,72**
Herzen St. (from Chelyuskintsev St.)	2	2	**17,8**	5,99	**1,13**
Herzen St. (from Griboyedov St.)	2	2	**6,36**	5,99	**1,48**
Pervomayskaya St. (from the railway station)	2	2	**6,06**	5,99	1,71
Shirotnaya St. (from Fedorov St. to Permyakova St.)	3	3	**48,0**	5,99	**0,61**
Melnikaite St. (from 30 let Pobedy St. to Shirotnaya St.)	3	3	0,2	5,99	1,91
Melnikaite St. (from Shirotnaya St. to Gnarovskaya St.)	3	3	**6,54**	5,99	**1,46**
Zapadnosibirskaya St. (from Yubileynaya St.)	2	2	0,29	5,99	2,06
Zapadnosibirskaya St. (from the Tura river)	1	1	1,81	5,99	1,72

At DW values less than 1.65, autocorrelation was recognized as significant.

The autocorrelation test showed some differences from the local stationarity test. This is since not all stretches of streets with locally unsteady flows will be considered cyclostationary, because not always "bursts" are associated with the influence of closely located regulated intersections. This may be the impact of roundabouts, pedestrian crossings, etc.

6 CONCLUSIONS

Based on the above, it is possible to formulate a definition of an isolated intersection and introduce recommended criteria for its definition. An isolated intersection is an intersection at which the characteristics of the incoming flow do not differ significantly in time (they are strictly stationary).

The Breusch-Godfrey and the Durbin-Watson autocorrelation tests can be suggested as the recommended method for determining local nonstationarity as the most visual methods and for identifying isolated urban street intersections.

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