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EVALUATION OF THE BASIC CHARACTERISTICS OF THE TRAFFIC FLOW BY MATHEMATICAL ANALYSIS

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Abstract

Today, traffic is an integral part of every active human life. People prefer individual car transport to public transport. This fact increases the number of cars on the roads. This article focuses on the basic characteristics between moving vehicles on the road, traffic flow characteristics - intensity, speed and density. Their values are obtained from traffic survey and radar Sierzega. In addition, a simulation was made from the measured values and the basic characteristics of the traffic flow were evaluated using mathematical statistics.

Keywords: simulation, junction, traffic, road

1 Introduction

Transport in cities is usually realized via roads in the traffic flows of vehicles or pedestrians. From the life of citizens, it is the realization of the movement of persons or material, i.e. their transfer from sources to goals. Transportation is a complex stochastic process.
At present, transport is an integral part of each of us, whether travelling for work, leisure, transportation of goods, etc. This factor has a particular impact on the growth of vehicles on the roads, which often causes congestions in cities. Nevertheless, it can be managed and regulated, through measures and laws. However, an important task is to design and build roads that handle the traffic flow as well as future traffic intensity. Before the actual construction of roads, it is necessary to conduct traffic surveys and find out the current intensity of traffic on a given section of the road network. Each transport survey aims to obtain quantitative and qualitative data on transport [1]. It is also important to know the basic characteristics of the traffic flow, i. j. intensity, speed and density and their interrelationships.
Theoretically, traffic flow can be understood as a flow composed of different types of vehicles that have their own specific properties. These properties distinguish it from similar phenomena (flows) known, for example, from physics, and therefore it is necessary to examine it separately. A number of factors affect the traffic flow [1](1).

2 Traffic flow

Traffic flow theory is a very broad area. In mathematics and traffic engineering, it is the observation of the interaction between passengers (includes pedestrians, cyclists, drivers and their vehicles) and infrastructure (motorways, roads, markings) to understand and develop an optimal transport network with efficient traffic movement and minimal congestion problems.

The traffic flow is understood as the unity of temporal and spatial conditions, but at the same time traffic and movement conditions of vehicles on the traffic area of the road. Traffic flow is the flow of individual vehicles that move in certain conditions and in a certain direction. It, therefore, depends on the width arrangement and the overall guidance of the route. The movement of vehicles in traffic flow is affected by other vehicles in the traffic and is therefore monitored as a whole and not as the movement of an individual vehicle. His research is a very interesting and current issue. Traffic flow is a nonlinear dynamic phenomenon. This nonlinear behaviour is most noticeable at high traffic flow densities. The traffic flow can be divided into homogeneous and inhomogeneous in terms of composition. Homogeneous traffic flow is characterized by the homogeneity of types of vehicles that have the same driving characteristics (passenger cars, trucks, heavy, light, slow, fast). The inhomogeneous traffic flow contains proportions of different types of vehicles with different driving characteristics. The ratio of these vehicles is expressed as a percentage of the total number of vehicles in the traffic flow. Traffic engineering calculations can convert all vehicles in the traffic flow into unit vehicles and thus obtain a theoretical homogeneous traffic flow.

2.1 Basic characteristics of the traffic flow

Basic characteristics of the traffic flow are three interdependent characteristics, namely speed v, intensity M and density H. All these quantities depend on place and time. The quantity of the traffic flow is its intensity and quality expresses the speed and fluency in the given conditions. A change in its acceleration and deceleration, a speed gradient or a change in the ripple of a traffic flow can be considered as the flow of a traffic flow. This ripple is intended as a change in intensity and density over time CITATION LEI \l 1051 [2](2). The search for and description of the relationships between these three quantities is the basis of the traffic flow theory.
The speed v depends directly on the path s and indirectly on the time t. It is most often stated in the basic units of the SI system, i.e. in $m.s^{-1}$, but more commonly used units are $km.h^{-1}$ CITATION Kap \l 1051 [3](3). A formula for calculation of speed (1) is simple.

$$v(s,t) = \frac{\partial s}{\partial t} \quad \left[km.h^{-1}\right] \tag{1}$$

Where:
v - the speed of traffic the flow [$km.h^{-1}$],
s - the distance of the monitored section [km],
t - the time [s].

Intensity is the most important characteristics of the traffic flow because the greatest intensity that the road can transmit is the capacity of the road. This is important for its design and assessment. Intensity is defined as the number of vehicles that pass a given profile per unit time, in either one or both directions. Number of vehicles and the time is necessary for calculation (2).

$$M(s,t) = \frac{N}{t} \quad \left[veh.h^{-1}\right] \tag{2}$$

Where:
N - the number of vehicles on section at certain moment [vehicle],
t - the time [s].

Density is the number of vehicles located in the unit section l at a given time t (3). At low densities, vehicles are allowed to move freely and drivers can choose the speed of their choice. Conversely, at high densities, the driver is affected by other road users and congestion occurs.

$$H(s,t) = \frac{N}{l} \quad [veh / km] \tag{3}$$

Where:
N - the number of vehicles on section at certain moment [vehicle],
l - selected section [km].

2.2 Basic characteristics of the traffic flow

There is a relationship between the basic characteristics and it is given by the equation of continuity relationship (4),

$$M = v \cdot H \tag{4}$$

the natural relationship of speed to density is verified, because there is a maximum speed at the minimum density and, conversely, a maximum density at which speed is zero. It follows that density also depends on intensity.
Fundamental diagrams are commonly used to express the relations in steady traffic flow, i.e. to describe the relationship between the basic quantities of the traffic flow given by the continuity equation (4).

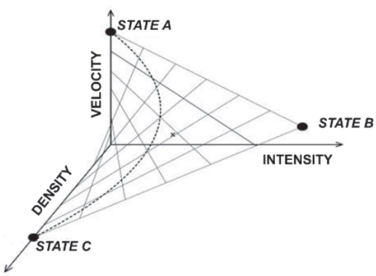

Figure 1 Three-dimensional model of traffic flow characteristics CITATION Kap \l 1051 [3](3)

The relationship of these characteristics is well illustrated in figure 1. This representation in the 3D graph is not entirely clear, and therefore the representation using three graphs is used, which are the projection of this curve into all three planes. The basic diagram is the relationship between density H and speed v, from which the relationships density H - intensity M and speed v - intensity M are derived (figure 2).

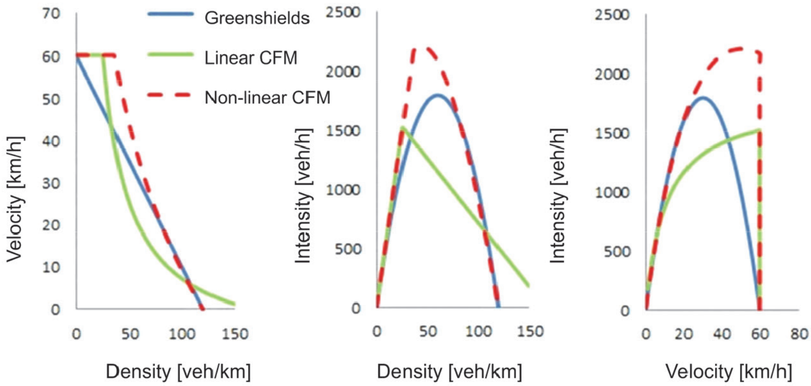

Figure 2 Comparison of fundamental diagrams CITATION MIK \l 1051 [4](4)

Stationary models of homogeneous traffic flow working with the stationary hypothesis. According to it, the speed field v (H) has rapidly stabilized at a constant value identical for all vehicles, and the same applies to the density or the distances between the vehicles. The system does not evolve over time. The hypothesis does not address the mechanism of stabilization, although it would probably not be as trivial as the trivial assumption of stabilization itself. Both empirical and simulation results suggest that the stationary hypothesis is too strong a simplistic assumption that is inconsistent with reality CITATION VKo \l 1051 [5](5). Nevertheless, it is very often used [3]. The most commonly used models are CITATION Hab \l 1051 [6](6):

- Greenshield model - assumes a steady and homogeneous flow, where the speed of individual vehicles and the density of the traffic flow are constant. It is characterized by a linear dependence of the speed of the traffic stream on its density.
- Constant time interval model - this model is not based on a theoretical description of the traffic flow, but on recommendations for safe driving. A well-known rule states that the vehicle should maintain a safety distance Δt from the previous vehicle of two seconds, regardless of speed.
- Linear CFM - A linear "car-following model" (CFM) is equivalent to a constant time interval model. It is based on the assumption that the acceleration of the i-th vehicle depends on its relative speed to the previous i-1 vehicle.
- Non-linear CFM - linear CFM can be improved by including the assumption that the driver is more sensitive to the behaviour of the previous vehicle at a smaller relative distance.

3 Modelling of traffic flows

Modelling of traffic flows by means of suitable software equipment represents an effective working method in the fields of traffic engineering as well as traffic construction. However, such modelling does not only include traffic simulation, but represents a wide range of auxiliary tools, from relatively simple single-purpose applications to complex tools for performing complex analyzes of transport networks and processes on them. One of the most important theoretical tools of these specialized software products are traffic flow models. These models form one of the basic input parameters in the analysis and optimization of the target behaviour of road users CITATION HEN \l 1051 [7](7).

The TSS (Transport Simulation System) simulation program - Aimsun was used to create the simulation. Aimsun software helps thousands of international users model future smart mobility networks. Aimsun is traffic simulation software that allows users to model everything from a single bus lane to an entire region in both 2D and 3D views.

4 Traffic survey

The analysed data come from a survey performed on Tuesday, September 17, 2019 near the city of Martin on road I/65. It was cloudy with occasional rain in the morning and this continued until the afternoon, when the clouds decreased and partly cloudy. The temperature ranged from 8 to 15 °C. The survey lasted a total of 12 hours, from 6 o'clock a.m. to 6 o'clock p.m. In addition to the use of measuring technology, counters were also present at the measuring site. Based on this fact, it is possible to compare the intensity of vehicles recorded by measuring equipment (radar) and counters (persons). The maximum permitted speed on the monitored section is 50 km.h^{-1}.
During the traffic survey the intensity reached 13,505 vehicles in both directions in 12 hours. The highest intensity (peak) for a quarter of an hour (326 vehicles per 15 minutes) was recorded between 6:30 and 6:45, for an hour (1248 vehicles per hour) it was determined between 6:30 and 7:30 (Table 1).
According to a survey carried out by counters, the composition of the traffic flow is as follows: 76.3 % of passenger cars, 10.5 % of trucks, 12.5 % of heavy trucks, 0.37 % of motorcycles, 0.25 % of buses and 0.07 % of bicycles. In this case we speak on inhomogeneous traffic flows, as it is assumed that a homogeneous traffic flow must make up at least 80 % of vehicles that have similar characteristics, e.g. passenger cars.

5 Results

The following chapter shows the processed results from the measured values using Sierzega radar and simulation.

5.1 Results from traffic survey

The ideal diagram showing the behaviour of the transport system is the so-called fundamental diagram. This is a graphical dependence between the basic characteristics of the traffic flow (intensity, speed, density) was determined for each 15-minute interval for each lane separately and together. These dependencies are shown in the figure 3.

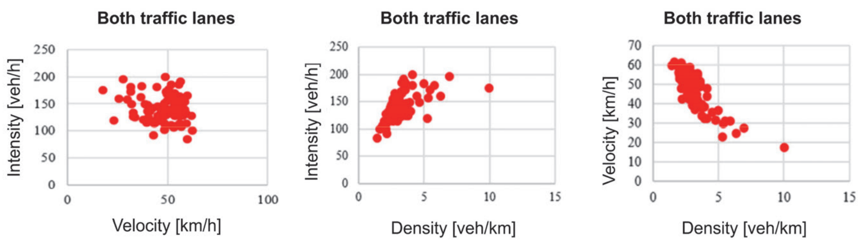

Figure 3 Graphical dependence between basic characteristics of traffic flow as output from measured values

According to the relationship between intensity and speed (figure 3), the dependence should form a parabola. However, with increasing speed, the intensity should also increase, which would represent a linear course. It is clear that each intersection and each road section has the specific maximum capacity CITATION MPo1 \l 1051 [8](8). If it is exceeded, the intensity should logically still increase, but this fact causes a decrease in speed because the capacity has been exceeded. The maximum intensity is achieved at the optimum speed. The reduction of speed leads to a reduction in the distance between vehicles, which is reflected in increasing density. Therefore, the relationship between intensity and speed is expressed as a parabola, that is, as the square of speed. The same rule applies to the relationship between

intensity and density. The correlation coefficient has the linear dependence. Its value was around - 0.037, which corresponds to a negative very weak linear dependence.
It is interesting that the dependence between intensity and density reached a positive linear dependence with a high correlation coefficient of 0.653, so it is the medium correlation. The dependency can also be read from the graph CITATION Ond \l 1051 [9](9).
According to the general diagram, the relationship between speed and density is expressed as a linear dependence. However, the fact is that in this case, the dependence between density and speed has an exponential course with a degree of reliability of almost 80 %. In principle, if the speed of vehicles decreases, the density in the monitored section will increase, and the opposite is also true. The correlation coefficient was also calculated for the course of speed and density. In this case, the value of the coefficient of dependence between the two variables is 0.950, which corresponds to a very strong negative correlation CITATION Ryb \l 1051 [10](10).

5.2 Results from simulation

The simulation lasted 12 hours, as did the traffic survey. The load on the lanes was based on traffic surveys and Sierzega radar records. A total of 10 simulations were performed, from which an average was made, which was the basis for the resulting values, namely the resulting values of intensity, density and speed.

5.3 Probability of vehicle occurrence

The figure 4 is a graphical representation of the incidence of the number of vehicles per minute resulting from a survey that follows the Poisson distribution CITATION Med \l 1051 [11](11). According to statistics, this is a discrete distribution of the probability of occurrence of rare events in a series of large numbers of independent experiments. Based on the survey, it was found that an average of 18.8 vehicles was intercepted in 1 minute. Thus, the highest probability is that in 1 minute 18.8 (λ) vehicles will pass through the monitored section of the road in both, and with the increasing or decreasing number of vehicles, this probability decreases CITATION MPo \l 1051 [12](12).

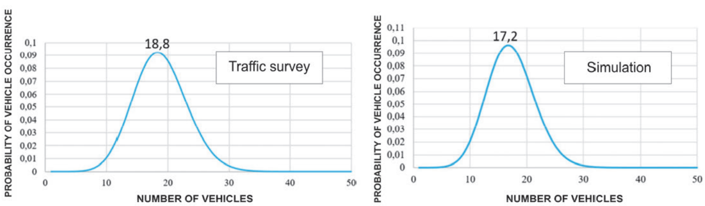

Figure 4 Occurrence of vehicles during 1 minute

In contrast to the actual measurement, the results from the simulation showed that in this case, the highest probability of arrival is that in 1 minute it will pass the monitored section on average 17.2 vehicles. Thus, the decrease represents 1.6 vehicles less than in the evaluated measurement results.

6 Conclusion

As the number of road traffic increases, the density increases and the speed of the traffic flow decreases. This fact has the effect of increasing the residence time, standing and travel time and other variables. The mentioned characteristics of the traffic flow vary significantly depending on the time and volume of traffic, often reaching maximum values. Intersections are an important point of road network permeability.

The evaluation of the traffic survey showed that the largest number of vehicles was recorded between 6:30 and 6:45 with an intensity of 326 vehicles. The average intensity according to the traffic survey is 1200 vehicles per hour and according to the simulation it is 1035 vehicles. The strongest correlation was calculated in the relationship between density and speed with a value of -0.95, which represents a strong linear dependence.

Our results confirm difference in probability of vehicle occurrence. The difference between simulation and real measurement were 1.6 vehicles.

Acknowledgment

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