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HOW TO ANALYZE TRAFFIC WAVES

HOGY VIZSGÁLJUNK FORGALMI HULLÁMOKAT

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Abstract

The main problem with city traffic is the vehicles stuck in the junctions. The network disturbances cause the problem [1]. The network disturbance has significant effect from disaster prevention point of view. In case of disturbance the critic infrastructure [2] has an effect on the economic process, the social prosperity, the public health, the public safety. It is vital to recover the traffic flow on the critic infrastructure as soon as possible in this case. I suppose if the disturbance happen in downtown, where there is signalized junction, then this problem can be treated with signal program.

When happen an unexpected event on the network then appear a wave which disturbs the traffic flow. This wave is called oscillation and arises only in queue. The wave spread speed about 15 to 19 kilometers per hour according the measuring method.

In my article I analyzed wave propagation speed with three different methods, which brought different results. To analyze the traffic wave propagation process, we must have a reliable analyzing method. Whether which method the more reliable? I want to give an answer to this question with my investigation.

Keywords: *oscillation, traffic dense, traffic congestion, traffic wave propagation.*

Absztrakt

Városban a fő problémát a csomópontban bennragadt járművek jelentik. Ezt a problémát hálózati zavar okozza [1]. Katasztrófavédelmi szempontból jelentős hatása van a hálózati zavarnak. Egy zavar esetén a kritikus infrastruktúra [2] ideiglenesen hatást gyakorol a gazdasági folyamatokra, a szociális jólétre, a közegészségre és a közbiztonságra. Létfontosságú tehát, hogy ilyen esetben a kritikus infrastruktúrán levő forgalom minél előbb helyre álljon. Amennyiben ez belvárosi környezetben történik, ahol jelzőlámpás forgalomirányítás van, akkor ez a probléma kezelhető a jelzőlámpa programmal.

Amikor egy váratlan esemény következik be a hálózaton, akkor megjelenik egy hullám, amely zavarja a forgalom áramlását. Ezt a hullámot oszcillációnak nevezik és csak sorban alakul ki. Ezen hullámok terjedési sebessége 15 és 19 km/h körül alakul, függően a mérési módszertől.

A cikkemben három különböző mérési módszerrel vizsgáltam a hullámterjedés sebességét, amely különböző eredményeket hozott. A forgalmi hullám terjedési folyamatának vizsgálatához megbízható mérési módszerre van szükség. Vajon melyik módszer megbízhatóbb? Vizsgálataimmal erre a kérdésre kívánok választ adni.

Kulcsszavak: *oszcilláció, forgalomsűrűség, forgalmi dugó, forgalmi hullámterjedés*

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INTRODUCTION

Several theoreticians have endeavoured to construct mathematical models to explain observed phenomena in traffic dynamics. These models have two main approaches. The first model is a car-following (microscopic), the second model is a "Traffic fluid" (macroscopic) which based on the equation of continuity. At present these models construct a considerable part of literature. The principal papers have been summarized in three published books [3,4,5].

I will show three different analysing methods which give three different results in this paper.

I created a simple simulation environment for the analysis of traffic oscillation. I made the analysis with traffic plan software. According to my thesis, if an unexpected incidence happen between two junctions, the cars stuck in the previous junction, which reducing the capacity, not only on the way it happened, but in the transverse direction as well.

The signal program can be treating the changed traffic conditions. The traffic volume specifies the green time. The traffic volume is zero, if the density is zero. Firstly, we speak about lower traffic density, while the traffic volume is low initially. Then the vehicle can move with free speed. The vehicle gets interacted with each other with increasing the traffic volume. Increasing density increase the traffic volume. There is a maximum point which is the maximum of the permeability of the link.

In the changed condition the traffic density is increased and the velocity is reduced. The traffic oscillation will be more because of traffic density, and congestion appears at the junction.

The traffic volume determines the signal program in the practice, but when we modifying a signal program then we must take account the oscillation. In the moving coordinate-system the density is constant in time. So the perturbation in the homogeneous traffic spreads with c velocity. Therefore, we say that the density moves as a wave. I will show how spread the oscillation caused wave in the next chapter.

THE EXAMINATION METHODS OF TRAFFIC WAVES

Fundamental diagram (macroscopic)

By the 1930s, vehicular traffic in the USA had already reached the level that required management. The first step towards this was to collect traffic data. Empirical data were collected by using photographic measurements at cross section, and the data were summarized by the so-called flux-density or fundamental diagram, where the flux (number of vehicles passing the cross section in unit time) was plotted as a function of traffic density (Greenshields 1935). Since then, FDs have been used to characterize traffic behaviour [6].

Lighthill and Whitham and later Richards presented a theory of flow. This theory is about a long crowded highway modelled with a continuous "traffic fluid" instead of individual vehicles [6]. This is the fundamental hypothesis, which has been created by Greenshields. He measured traffic on a highway then he presented the measured results in various diagrams.

The next connection exists between the traffic volume and density.

$$q(t,x) = \rho(t,x)v(t,x) \qquad (1)[7]$$

Thus the (1) equation creates a contact between the common macroscopic traffic variables, ρ, v. There are numerous velocity-density relationships demonstrated in the literature, e.g. GreenShields (1935), Greenberg (1959) [7]. Péter T. says that classical literature does not pay attention to the environmental factor, but the velocity is determined by another environmental parameterization [8].

In case of a macroscopic model, the spatial average speed is equal with the equilibrium speed.

$$v(t, x) = V(\rho(t, x)) \quad (2)[9]$$

Therefore, the (2) LWR hypothesis declares that the traffic dense unambiguous define the average speed in steady state [9]. This relation describe immediately reaction, thus it doesn't take attention for the driver's finite reaction time and the vehicles acceleration and deceleration time. We can describe the traffic's properties with this traffic variable.

Luis Albert Pipes [10] says that shock wave spread speed is a S border line which divides two distinct concentrations of traffic ρ_1 and ρ_2 along a straight highway **Fig.1**. The vertical line S, which has velocity c, is assumed to be in the positive x direction. The mean speed of the vehicles in region A is v_1 and that in B is v_2 . It is easy to see that $(v_1 - c)$ is the relative speed in the region A to the moving line S and $(v_2 - c)$ is the relative speed of the vehicles in region B to the moving line S.

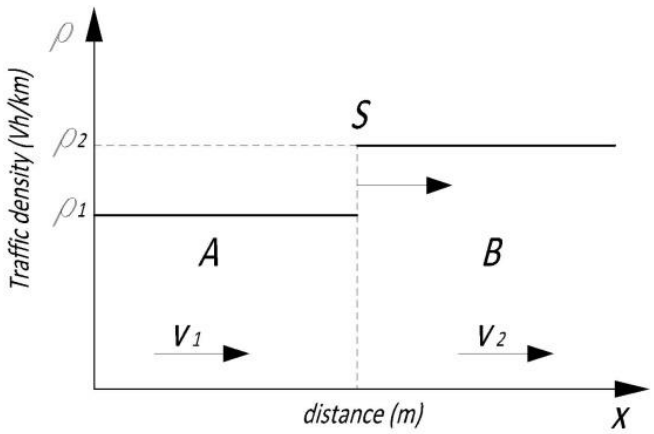


Fig. 1 The S line movement (own editing)

The shock wave velocity c as

$$c = (\rho_2 v_2 - \rho_1 v_1)/(\rho_2 - \rho_1) \quad (3)[10]$$

The equation (3) may be written in terms of the flow rates

$$c = (q_b - q_a)/(\rho_b - \rho_a) \quad (4)[10]$$

What is not other than the steepness of the fundamental diagram's two points line joining **Fig. 2.**

$$c = \Delta q(\rho)/\Delta\rho \quad (5)[10]$$

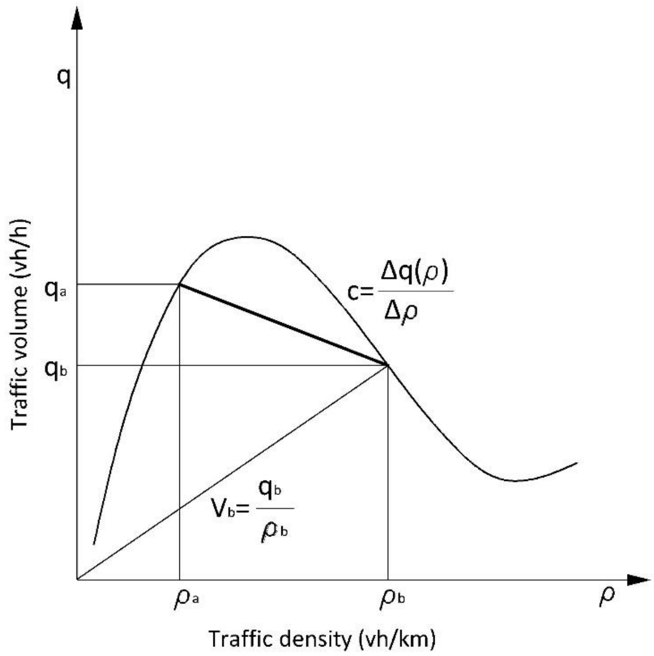


Fig. 2 The shock wave velocity (own editing)

In **Fig. 2** we can see a typical fundamental diagram [11]. We can see, that the place of $x = a$ is rare and place of $x = b$ is dense. So the wave speed line steepness is negative, therefore the wave spread back in space.

The velocity of the free flow is known. We must be defined the velocity of the flow belonging to the crowded area. Then we can read the value of the traffic volume and density at places $x_a(t)$ $x_b(t)$. After that we can calculate the c wave speed from the (4) equation.

Deviation curves (macroscopic)

Oscillation can be analysed with multi section measured traffic volume, thus the volume can be seen at different places at the same time. Furthermore, we can see how moving the traffic in space and in time. The maximum value of the traffic, time to time backs off in space. M. Mauch, M. J. Cassidy had completed an examination with this method. They said that the propagation of the wave speed is about 22 to 24 kilometre per hour, independent of the location within the queues and the flow measured there [12].

In my analysis six pieces of detectors were located on one lane road counting the vehicles passing. I modelled the network disturbance with a reduced speed area **Fig.3**. The distance between the first and the last detectors is *L=1km*.

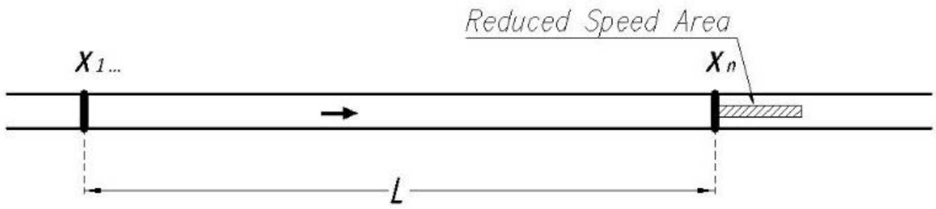


Fig. 3 Traffic lane with the detectors and the reduced speed area (own editing)

The traffic volume is a vehicle quantity, which overpassed under a time unit at the cross-section (5). The simulation software fixes the vehicle's time. See **Fig. 4**.

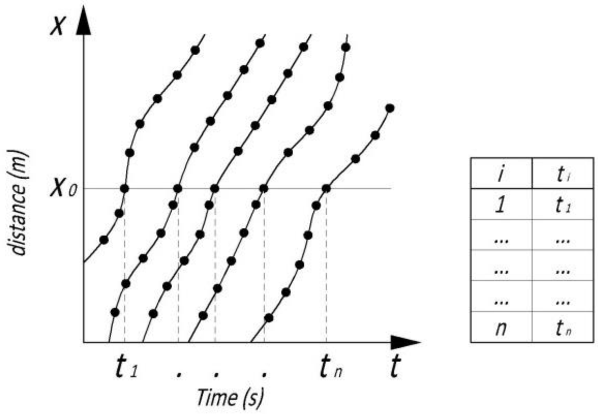


Fig. 4 The overpassed vehicles time (own editing)

$$q(x_0) = \frac{N_y(x_0)}{T_y} \tag{6}$$

Where,
$q(x_0)$: *the traffic volume*
$N_y(x_0)$: *number of vehicles at* x_0 place
T_y: *the time interval* (20sec)

I summarized the traffic in every twenty seconds, then I multiplied one hundred eighty times (6) thus I receive the hour traffic volume. After that I get a time series what I smoothed with a moving average (7).

$$Q_y(x_0) = N_y * 180 \tag{7}$$

$$Q_y^{(5)}(T_y) = \frac{Q(T_{y-2}) + Q(T_{y-1}) + Q(T_y) + Q(T_{y+1}) + Q(T_{y+2})}{5} \tag{8}$$

I sign the time interval with *Ty* and the number of vehicles *Ny*. I presented the interval in **Fig. 5**, and I counted the vehicle between two time points and I collected this data in a table.

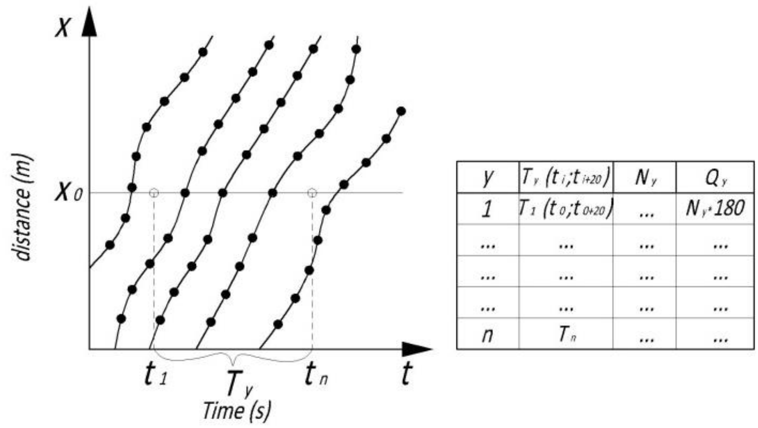


Fig. 5 The time interval (own editing)

The c traffic wave spread speed can be defined, with connecting the detector's graph deep points. I defined the graph's deep points at the first and the last measuring places, and I got the time when the wave starts. I defined the Q_l value, which is the minimal traffic value. Obviously there is some value under this limit, but it has a small deviation from the Q_l value. I considered one measuring hour, which is divided into 180 parts because of the time basic. I got t_i, where I cut the data series at Q_l value, then I chose the last one of the values.

I made the deviation curves from the measured data. The wiggles made prominent on some of the deviation curves are the oscillations themselves.

Fig. 6 shows the minimum point on the deviation curve. I connected the minimum points at the first and the last place, and I drew line which steepness gives the wave speed.

The dashed line traces the motion of oscillation **Fig.10**. This line is shown connecting the pit of wiggles. The line shows the oscillations propagated upstream against the flow of traffic.

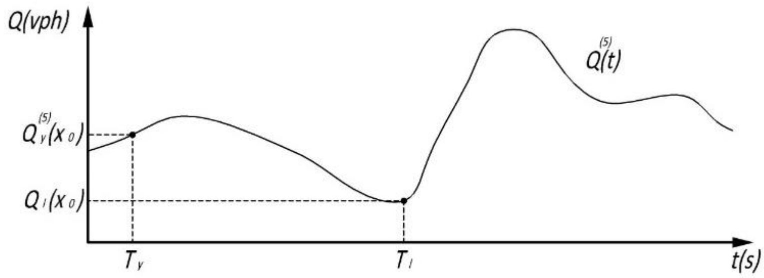


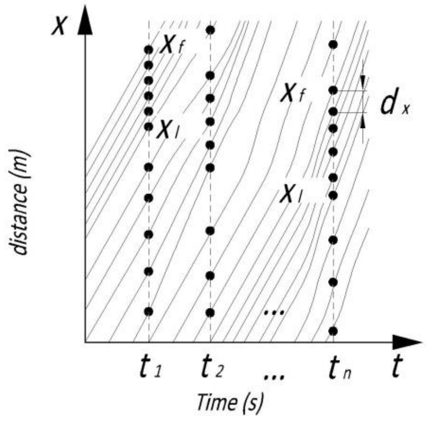
Fig. 6 The minimum point on the deviation curve (own editing)

After I had defined the first and the last time at the two measuring places, I calculated the c wave spread speed with the following formula.

$$c = \frac{1000}{t_i(x_1)-t_i(x_6)} * 3{,}6 \left[\frac{km}{h}\right] \tag{9}$$

Vehicles trajectory (microscopic)

I considered a car moving on a given track and I analysed this moving. When in motion, I recorded the position of the car in every s, which position was signed *x(t),* then I got a line, which is the vehicle trajectory **Fig.7**.



i	t_i	x_f	x_l
1	...	...	...
...	...	...	...
...	...	...	...
...	...	...	...
n	...	...	...

Fig. 7 Vehicle trajectory (own editing)

If I look one t_1 time moment, I can see the spatial distribution of the vehicles. The distance between two cars is defined by the (10) formula. I defined the minimal following distance and I signed it with d_{xmin}. Thus vehicles belong to a crowded area of which following distance is equal to or less than d_{xmin}.

$$d_x = (x_k - x_{k+1}) \tag{10}$$

I signed the first car x_f, and the last x_l in the crowded raw at t_1. I collected the position data at each $t - th$ s. Getting data in every twenty seconds is sufficient. From the fixed data I calculated the regression straight (11) and I divided it by twenty and multiply it with 3,6 so I got the c wave speed (12) in km/h. The wave speed can be calculated at the step out (x_f) and the step in (x_l) points.

$$a = \frac{\left(\overline{t_\iota * x_f(t_\iota)}\right) - \bar{t_\iota} * \overline{x_f(t_\iota)}}{\left(\overline{t_\iota^{\ 2}}\right) - (t_i^{\ 2})} \tag{11}$$

$$c = \frac{a}{20} * (-3{,}6) \left[\frac{km}{h}\right] \tag{12}$$

DESCRIPTION OF THE CASE STUDY

Building the model

First of all, I was must run a simulating process with the software and I got the data from it. I indicated the measurement places with Det.1-6. The distance between the detectors is 250m and the reduced speed area is placed after the sixth detector. This latter is needed because I can induce a traffic wave. I chose the distance of *1km* between the first and the last measuring points because I can calculate with it simply. I was must set up the traffic parameters and the measuring points and built up the model in the program **Fig. 8**. I set up the following parameters: the traffic volume was set up 2000vph, the RSA (Reduced Speed Area) time 300s-420s, the RSA desired speed 5km/h. The traffic flow speed is a variable.

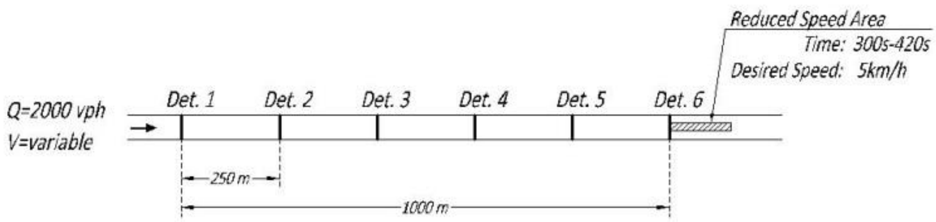


Fig. 8. The built of the model (own editing)

From the simulation I got raw data which contain the t(entry), vehicle number, vehicle speed data belong to data collection point and I got the network data which contain the vehicle number, position and speed belong to simulation seconds.

The data processing with the fundamental diagram

From the measurement I got the data illustrated in **Fig.9** below, by a point diagram. The fundamental diagram defines traffic volume in the function of traffic density. Onto this point flock can be fit a cubic polynomial and I can determine the wave speed with this.

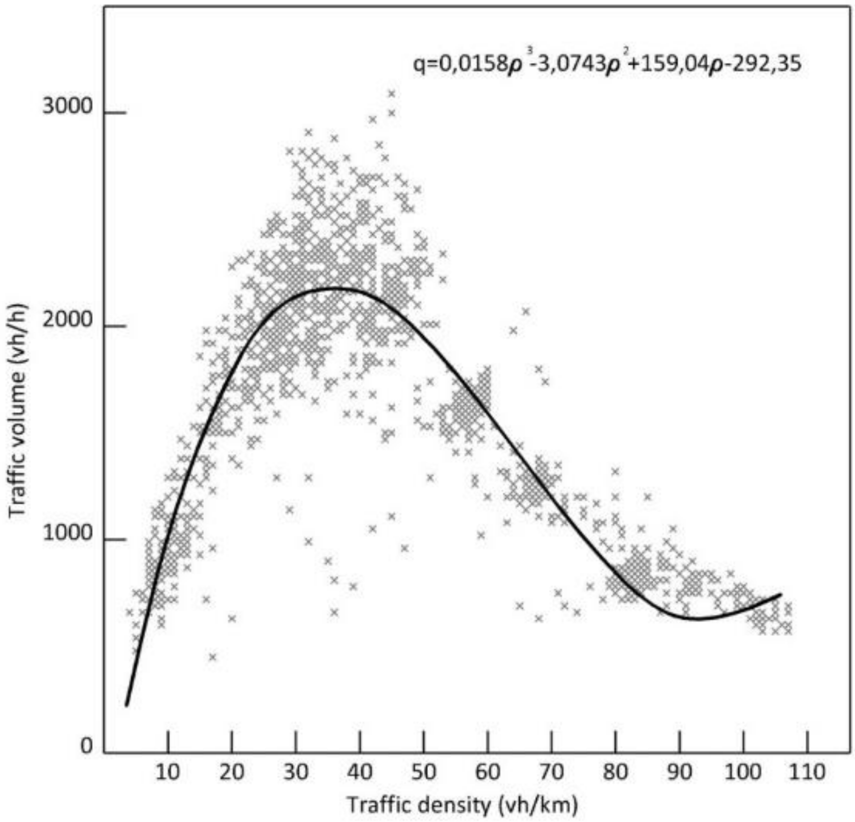


Fig. 9 The fundamental diagram (own editing)

The variable value is the traffic speed. Therefore I changed the speed from 20 km/h to 90 km/h. I calculated the wave speed with formula (5) and summarized with the analysis results in **Table 1.**

V(km/h)	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
q1	1331.0	1710.0	1970.0	2126.0	2185.0	2150.0	2016.0	1760.0
r1	66.0	57.0	49.0	42.0	36.0	31.0	25.0	19.0
V1	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
q2	617.0	2617.0	617.0	617.0	617.0	617.0	617.0	617.0
r2	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
V2	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
c (km/h)	**-24.6**	**-28.8**	**-29.4**	**-28.5**	**-26.6**	**-24.0**	**-20.0**	**-15.0**

Table 1. Traffic waves speed from the fundamental diagram (own editing)

The data processing with the deviation curves

The curve was decreased unambiguously at the fourth minute. It can be seen at **Fig. 10.** Because of extend reasons I presented the wave speed at 50km/h traffic speed.

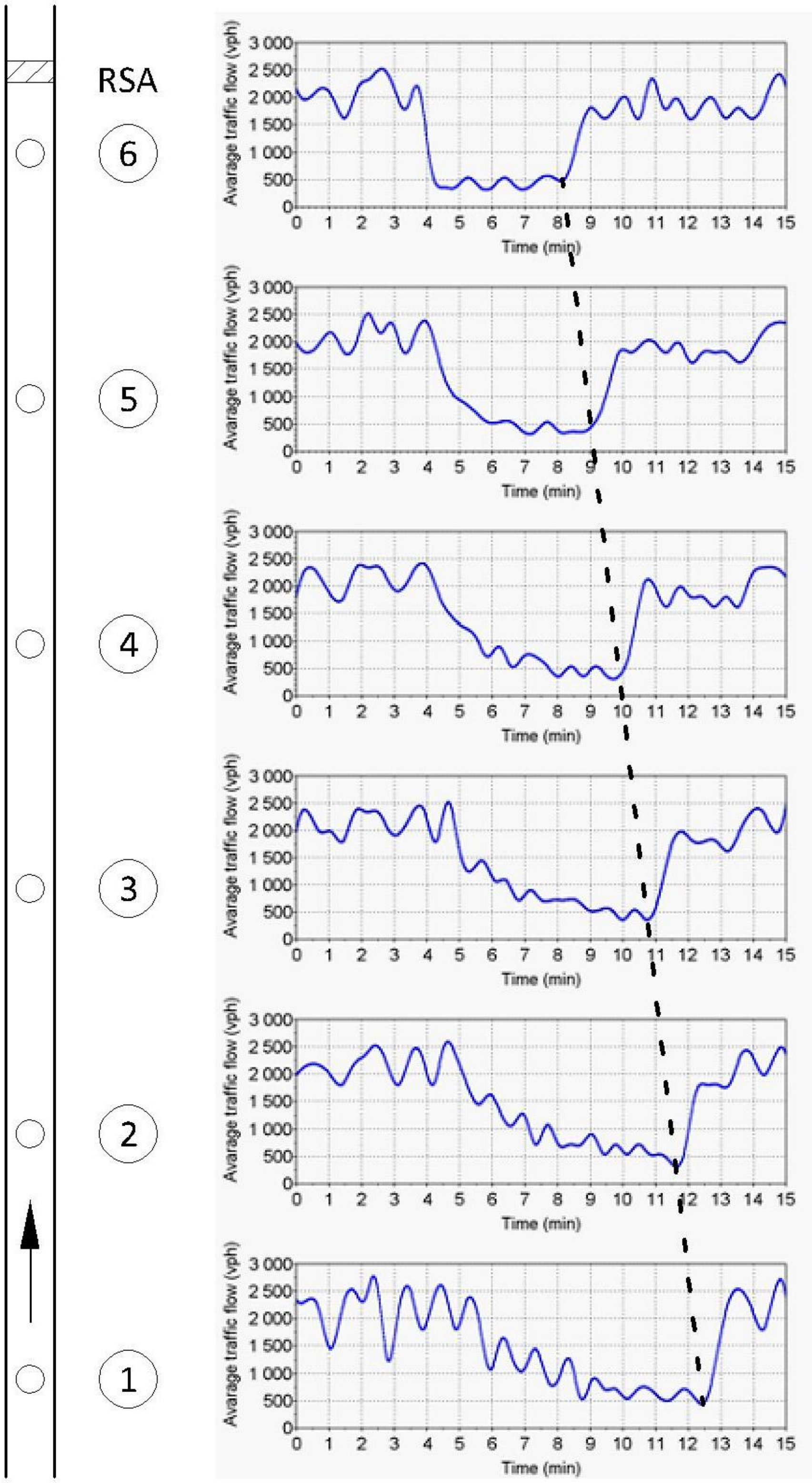


Fig. 10 The deviation curves at 50km/h (own editing)

I connected the visible lower points with a dashed line. At the lower points there is smaller traffic volume and high traffic density which means a traffic jam. The oscillation formed and spread can be shown with this method.

I identified the point where the graph starts to increase at each measurement point and connect each deep point with a dashed line. This line steepness gives the *c* wave spread speed. I summarized the wave speed in **Table 2.**

Detector number \ V(km/h)	20	30	40	50	60	70	80	90
1	739	722	739	736	730	717	732	730
2	682	666	675	693	682	677	690	695
3	600	602	633	630	622	618	653	653
4	530	540	567	565	574	576	586	593
5	446	475	501	521	514	513	546	551
6	380	413	441	457	465	470	491	501
c (km/h)	**-10,0**	**11,7**	**-12,1**	**-12,9**	**-13,6**	**-14,6**	**-14,9**	**-15,7**

Table 2. Traffic wave speed of the deviation curves (own editing)

The data processing with the vehicle trajectory

With this method it is allowed that the traffic dense distribution in a particular road section and a given time moment to be observed. The individual vehicle position, which is called the vehicle trajectory, can be seen on **Fig. 11**. The picture below shows the wave emerging at 300s and exiting at approximately 800s. So I analysed this between just two time moments.

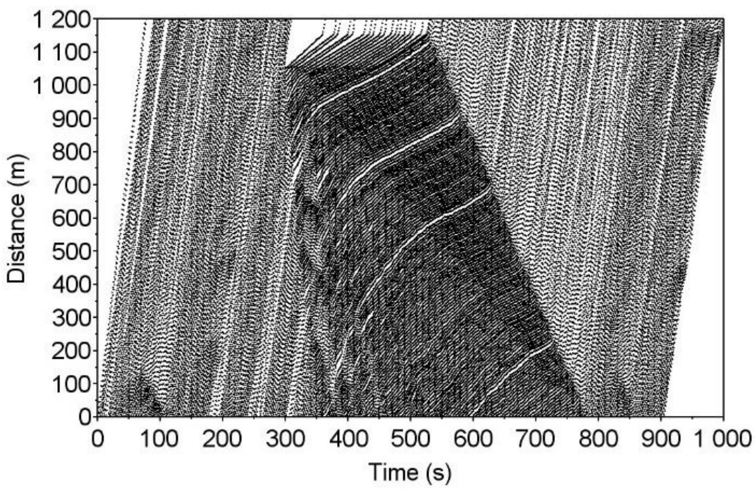


Fig. 11 Vehicle trajectory at 50km/h (own editing)

The steepness of the regression straight at the backside of the wave gives the wave spread speed. **Fig.12** depicts the wave spread speed with a red line. Because of the extend reasons just one picture is depicting, but I summarized all measured data in **Table 3.** Furthermore, if I would like to know where the wave is over, both speed lines are needed to get an intersection point which signs the end of the wave.

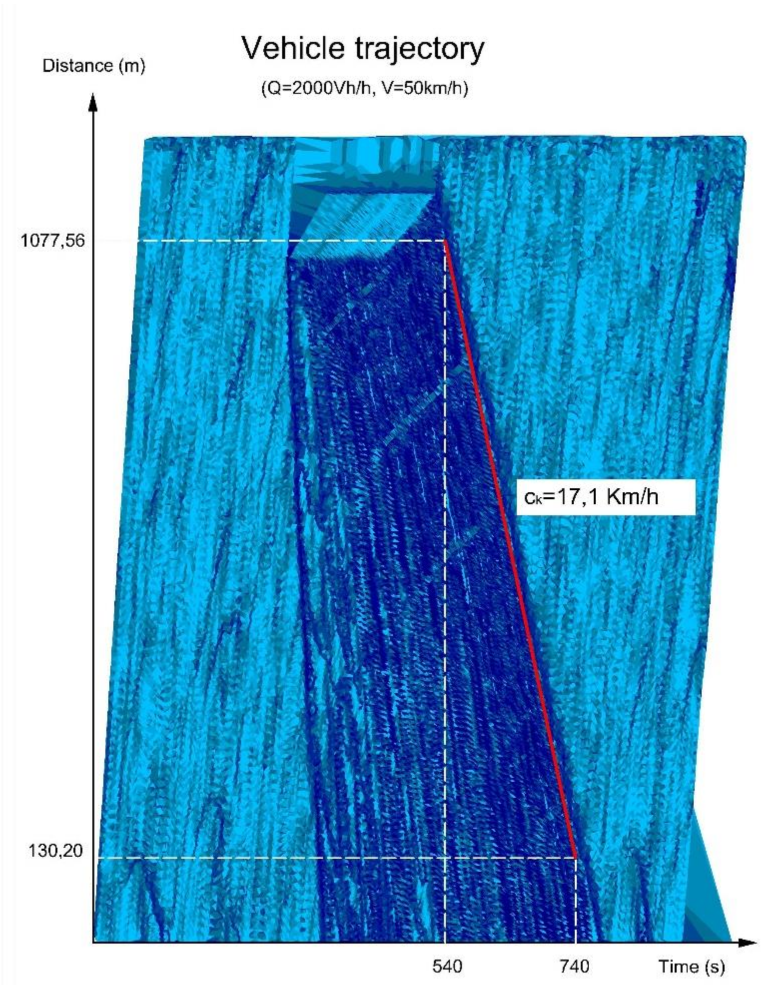


Fig.12 Steepness of the speed line (own editing)

The wave comes to an end when the wave spread speed at the wave front is more than on the “backside” of the wave. **Table 3** summarizes the wave spread speed at each traffic speed.

I defined the following distance $d_{xmin} = 10m$ and I considered a crowded area which contains minimum ten pieces of vehicles. **Table 3** below shows the c wave spread speed at difference traffic speeds.

V(km/h)	20	30	40	50	60	70	80	90
a	-85.90x +1132.30	-90.64x +1128.10	-92.88x+ 1166.00	-94.73x +1172.30	-97.34x +1155.50	-100.15x +1148.70	-101.75x +1195	-104.98x +1210.4
X1	1046.40	1037.46	1073.12	1077.56	1058.16	1048.55	1093.25	1105.42
X2	187.40	131.01	144.30	130.20	84.70	47.05	75.75	55.62
ΔX	-859.00	-906.45	-928.82	-947.36	-973.45	-1001.50	-1017.50	-1049.80
T1	540.00	540.00	540.00	540.00	540.00	540.00	540.00	540.00
T2	740.00	740.00	740.00	740.00	740.00	740.00	740.00	740.00
ΔT	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
c (km/h)	**-15.5**	**-16.3**	**-16.7**	**-17.1**	**-17.5**	**-18.0**	**-18.3**	**-18.9**

Table 3. The wave spread speed from the trajectory (own editing)

COMPARING THE ANALYSIS RESULTS OF THE THREE METHODS

In this chapter I compared the results obtained from the three difference methods. The diagram below **Fig.13** shows the three curves. It can be seen that the first method is definitely different from the other two measuring methods. It is seen too, that it has got a minimum of 40km/h traffic speed. It can also be seen too that 20km/h and 70km/h has the same value. Meanwhile the other curves show that the wave speed direct proportion with the traffic speed.

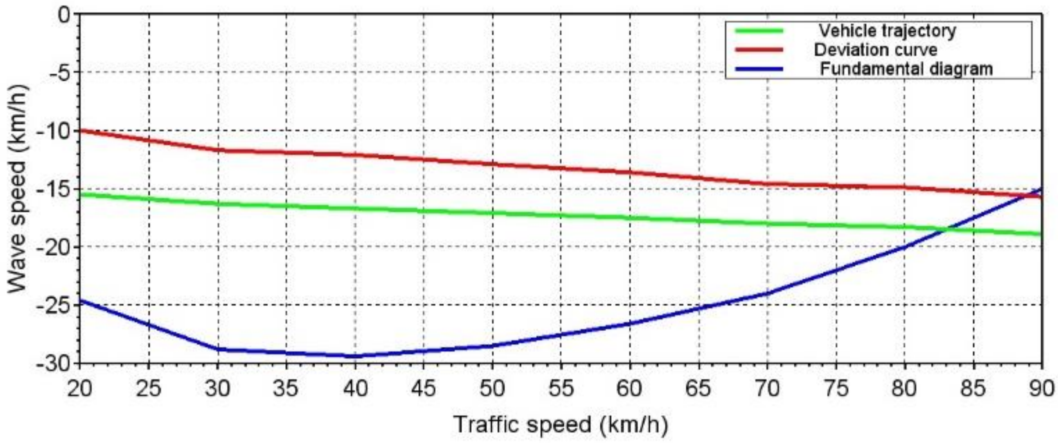


Fig. 13 The wave spread speed function as the traffic speed (own editing)

I identified that the speed difference is 5km/h between the vehicle trajectory and deviation curves. It means that the distance between two junctions for example 100m and the wave speed at the one 10km/h and 15km/h the other one then the wave arrives at junction 14 seconds earlier according to vehicle trajectory. Both curves are linear characteristic and mildly increase the absolute value. The wave speed extends in this case from 10 to 20km/h.

CONCLUSION

It turns out from the analysis that the oscillation can be shown from the measured traffic volume. I identified in this analysis that oscillation formation and propagation can be shown from the different place measured traffic volume. I regard the Vehicle Trajectory method the more reliable.

The curve from the fundamental diagram is definitely different from the others. There is a significant difference between the vehicle trajectory and deviation curve. Why the fundamental diagram is different from the other diagrams? I think to be that in the case a fundamental diagram, where the traffic is considered to be homogenous. The further examinations may shed light on this issue.

Another research opportunity is to analyse the territorial dispersion of the vehicles at a given road section. My next examination is how to mitigate the traffic wave with signal lamp.

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