ZUZANA BĚLINOVÁ*
Czech Technical University
Faculty of Transportation Sciences
Konviktská 20, 110 00, Praha 1, Czech Republic
**Corresponding author*. E-mail: belinova@lss.fd.cvut.cz

SELF-ORGANIZING PROCESSES IN TRANSPORTATION – CAN WE USE THEM TO IMPROVE TRAFFIC CONTROL?

Summary. The goal of traffic control is to influence the traffic in the way it becomes more effective and safe. At present traffic control is working with the traffic flow considering it a quantity that is possible to regulate and control. The fact that each vehicle represents an independent intelligence is usually not taken into account. In fact each vehicle's driver decides in dependence on many different factors – from his knowledge and information he possesses to his actual state of mind. When all individual reactions of drivers are combined, self-organizing processes may arise and these self-organizing tendencies may sometimes contribute to the improvement of traffic situation but sometimes they may counterwork and cause more traffic problems.

SAMOORGANIZUJĄCE SIĘ PROCESY W TRANSPORCIE – CZY MOŻEMY JE WYKORZYSTAĆ W CELU POPRAWY STEROWANIA RUCHEM?

Streszczenie. Celem sterowania ruchem jest wpływ na ruch w taki sposób, aby stał się bardziej efektywny i bezpieczny. Obecnie sterowanie ruchem działa na strumień ruchu, uważając go za ilość, którą można regulować i kontrolować. Fakt, że każdy pojazd przedstawia niezależną inteligencję zazwyczaj nie jest brany pod uwagę. W zasadzie kierowca każdego pojazdu decyduje w zależności od wielu różnych czynników – od własnej wiedzy i informacji, jakie posiada, po aktualny stan umysłu. Kiedy połączone zostaną wszystkie indywidualne reakcje kierowców, mogą wystąpić procesy samoorganizujące się i te tendencje do samoorganizacji mogą czasem pomóc w usprawnieniu sytuacji ruchowej, aczkolwiek czasem mogą działać wręcz odwrotnie i powodować dalsze problemy z ruchem.

1. INTRODUCTION

The road traffic volume is continuously increasing and this trend has speeded up markedly during last 50 years and is expected to continue. For this reason the traffic control and modelling is becoming more important as there is a need to increase the capacity of existing traffic routes. In order to reach the best possible traffic control results it is important to have the traffic models that describe the behaviour of traffic elements with very good accuracy. For this reason the traffic modelling has been and always is the subject of interest of many research works and science papers. In this paper I would like to contribute to the traffic modelling problematic with a rather unusual view – the attitude based on the behaviour of individual vehicles that are interacting each other and thus create mutual effect that can be described as self-organizing.

2. SITUATION

2.1. WHAT DO WE MEAN BY SELF-ORGANIZATION?

In order to be able to work with the self-organization in transportation area it is important to define what is meant by the term self-organization. According to Haken[1] *System is self-organizing if it acquires a spatial, temporal or functional structure without specific interference form the outside. By specific we mean that the structure or functioning is not impressed on the system, but that the system is acted upon from the outside in a non-specific fashion.*

The self-organization aspects can be find in many areas – as self-organizing can be described behaviour of animals – e.g. herds of cattle, shoals of fish, ant colonies, processes in physics – the growth of crystals, in the human areas social behaviour, processes in economy, and also the street traffic.

2.2. MODELLING OF TRAFFIC FLOW

The traffic models are an important part of traffic control. The traffic modelling is intensively evolving from the mid of 20th century. During this time several main types of models have been created and used.

The types of traffic modelling can be divided in these areas [Helbing[2]]:

1) Fluid-dynamic
   These models were the first traffic models largely used, it was in the 1950s. They are derived from physics of liquids and gases and they were used for modelling of the propagation of shock waves.
2) Microscopic follow-the-leader models
   These models were mainly used in the 1960s. Vehicles are viewed as separate objects. The behaviour of each vehicle is counted from the behaviour of other vehicles, mainly the foregoing one – the leading vehicle.
3) Gas-kinetic traffic models
   These models use the vehicle density and the distribution of vehicle speeds for traffic modelling and were popular in the 1970s.
4) Macroscopic simulations
   These models experienced the main development in the 1980s. Main quantities are the vehicle density, traffic flow and the average velocity of vehicles.
5) Cellular automata models
   Cellular automata were developed mainly in the 1990s for the simulation of traffic congestions. They were widely use for their relative simplicity. In these models the road is divided into cells that can be either occupied by a vehicle or empty.

Nowadays thanks to the fast advancement of computer performance the theoretic models of all kinds are innovated and combined with real data gained from traffic.

Each approach is convenient for modelling of different part of traffic problematic, uses different parameters and is suitable for another part of street traffic control and modelling.

---

[1] Haken, H.: Information and Self-Organization, Springer-Verlag, Berlin, 2000, p. 11

[2] Helbing D.: Traffic and Related Self-Driven Many-Particle Systems, Rev. Mod. Phys. 73, Issue 4, 2001, p. 1067-1141

3. SELF-ORGANIZATION IN TRANSPORTATION

In most traffic models traffic is described as a quantity with several parameters (traffic flow, density, velocity, etc.). On the other side each vehicle can be considered an independent element behaving according to its own decisions – driven by its intelligence represented by its driver. Each driver is making a lot of decision in the street traffic, chooses practically from infinite possibilities and is limited only by the boundary condition and his abilities. The boundary conditions are either invariant – the traffic regulations, or changing – the actual road conditions. The decisions a driver takes is based on the knowledge and character of the driver. Generally we may presume that every driver wants to reach its destination the fastest. As all the vehicles pursue the same goal – to find the shortest way, in the time of unexpected circumstances they may start to behave differently form usual traffic behaviour. If they are sufficiently informed they may be able to adjust their route and attempt to reach their target using different ways.

Typical traffic areas that have high probability of appearance of self-organizing processes are traffic situations where fluent traffic is broken and where the actual conditions for the drivers are sharply worse than usual and thus inspire the drivers to use their ability and knowledge to try to solve the situation themselves – typically traffic congestions, traffic in proximity of traffic accidents, etc. Another traffic situation that has self-organizing features is the traffic on traffic circles and similar. Here vehicles organize themselves without direct inputs from outside on the basis of boundary conditions - the road traffic law.

3.1. DESCRIBING SELF-ORGANIZATION IN TRANSPORTATION

Based on the above mentioned definition of self-organization we consider system self-organizing when it acquires structure without external intervention. To describe self-organization it is important to be able to recognize and describe these new structures.

There are two possible attitudes that can be used for the description of self-organization in transportation – using the transport characteristics or using the entropy principles.

When dealing with the transport characteristics the main traffic parameters we use are the traffic flow, traffic density and average velocity. On the basis of these parameters we can judge the origination of the self-organizing processes. If the traffic parameters are improving (increasing of traffic flow, increasing of average velocity, etc.) with the same initial conditions kept (without external interference), it is the evidence of beginning of self-organization processes.

The other approach uses as the measure of organization the information entropy. In the information theory the information entropy is a measure of the uncertainty associated with a random variable. In general (according to one expression of the second law of thermodynamics) every system tends to its most probable state – state with maximum entropy. In the terms of thermodynamics it is the thermal equilibrium. In the information entropy, the maximum entropy is reached by the random variables for the uniform distribution and the minimum entropy for the binomial distribution.

In the traffic science we can use as the variable the traffic flow. As the most probable state we consider the state when all the vehicles show the same parameters – travelling on the same road, with the same average velocity, stable traffic flow, etc. When the drivers use their knowledge and decide to try to change this state – e.g. when driving in the congestion some of them use the roadside to overtake the congestion, choose another road, etc. and thus change the equilibrium to more ordered state – different from the original uniform distribution.

3.2. HOW TO FIND SELF-ORGANIZATION IN TRANSPORTATION

Due to the fact that each vehicle is making its individual decisions there are a lot of traffic situations where this leads to occurrence of self-organizing processes.

In general all unexpected events form a base for independent decision making (congestions, accidents, etc.) and secondly the situations where the drivers are acting on the basis of given rules (e.g. traffic circles).

To confirm these presumptions it is necessary to create traffic models of these various traffic situations and to identify the self-organizing tendencies.

In traffic science there are several types of traffic models used. For the purpose of finding and observing the self-organization, traffic model that works with the complex traffic parameters is suitable. For this reason the best type of models are the macroscopic models working with the traffic flow, average velocity, traffic density, etc. In these models it is possible to examine the variations in the characteristics for the same input parameters but different boundary conditions.

Afterwards from the traffic models created the similarities in parameters that lead to increasing order are determined and used for the definition of typical circumstances leading to self-organizing processes.

4. HUMAN ASPECTS

When dealing with self-organization in transport, the key aspects influencing the processes are people (drivers) and their behaviour.

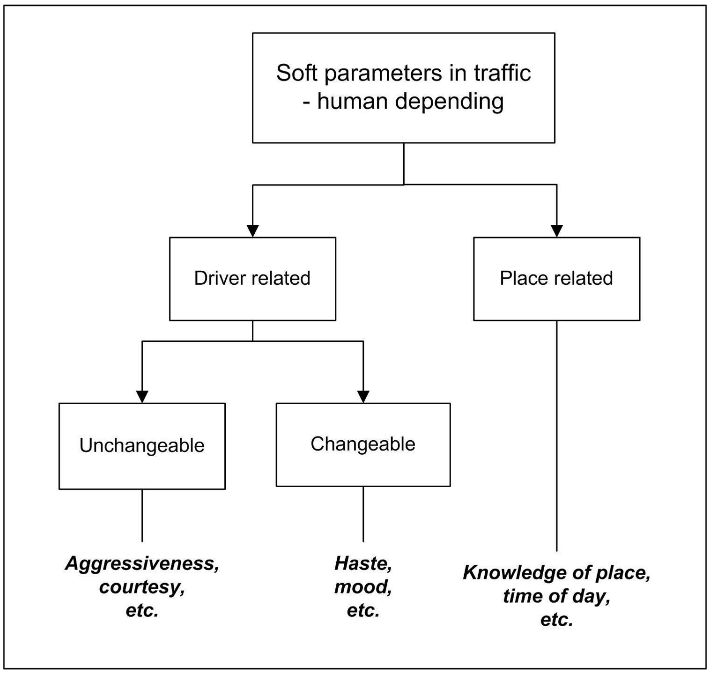

Fig. 1. Soft parameters in traffic science
Rys. 1. Parametry programu w dziedzinie ruchu

Human behaviour depends on many factors. Some of them are related to drivers and some of them are related to the actual situation and place.

The parameters related to drivers are either unchangeable - typical for each individual – its willingness to risk, inclination to aggressiveness, etc. or changing - the drivers' actual state of mind – upset, nervous, in good mood, etc.

The other sort of parameters is parameters related to the actual place and situation the driver is dealing with. The driver's behaviour is different in the areas he knows very well and in quite unknown areas. This is an important factor that determines the behaviour. Drivers familiar with the surroundings will with much more probability e.g. try an alternative route to reach their target than drivers totally strange to the area. The other fact is driver's evaluation of the actual situation and his need to get to its destination place in time. When the traffic flow is slowing down from some values the alternative routes begin to be profitable.

And finally the driver's decisions are directly proportional to the amount of information he has. The more precise information, the more probable is he to try another solution. However each driver is making decision on a basis of partial information.

Today the main sources of information are the traffic information on variable message signs, on radios and also there are in several cities maps available on the internet with schemas of actual traffic flow on main communications.

From all these parameters it is necessary to choose the parameters that are the most important for the self-organization. As these parameters are soft, their determination must be based on real measurement and tests.

5. TRAFFIC MODELS INCLUDING SELF-ORGANIZATION ASPECTS

After identification of traffic situations that have self-organizing features, creation of improved models takes place.

There are a lot of parameters (soft) that influence the vehicles' (drivers') behaviour in the street traffic. Not all of them have to prove to be important for the modelling. To judge the importance of each parameter the examination of each one is needed. This can be done on driver simulator rather then in real traffic where it is impossible to distinguish particular inputs.

To work with the soft parameters some simplification will have to take place. To include them to the macro-models it will be necessary to define mean values to describe average driver's behaviour and by fluctuations around those averages the rest of drivers can be described. Generally it can be said that most fluctuations are minor as most drivers like to drive at ease and do not unnecessarily undergo risks.

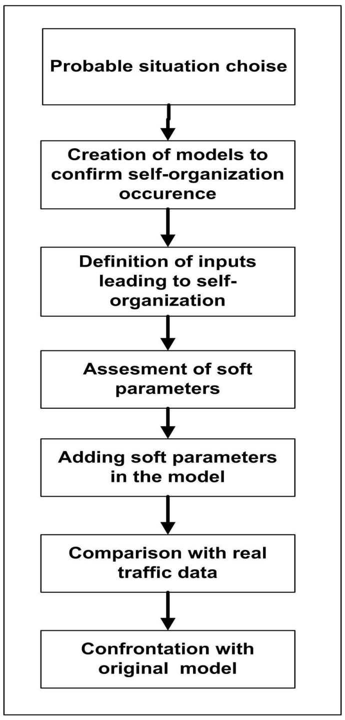

Fig. 2. Process of model creation
Rys. 2. Proces tworzenia modelu

The models have to be compared with the traffic surveys to check their relevance with reality. Furthermore the now model have to be confronted with original models without the soft human-depending parameters to ensure that inducing new parameters caused increase accuracy of the model.

6. CONCLUSION

Traffic in an area directly depending on human behaviour. Despite this fact the traffic flow as a whole can be considered a mathematical quantity and the prediction can be based on physical laws.

Nevertheless the human aspects of traffic are always present and including the soft and human depending parameters to the traffic models will contribute to better prediction of traffic situation and thus to better traffic control results. These improvements will be mainly for the critical amounts of traffic flow when the traffic network is saturated and drivers start to behave heterogeneously – e.g. look for alternative routes.

To do this careful assessment of the probable parameters is necessary. Due to their soft nature the human depending parameters are difficult to determine and use and require lots of tests, models and measurements to judge their influence to traffic flow.

It is the continuous task of author's PhD. study.

Literature

1. Ball P.: *Critical Mass – how one thing leads to another*, London, 2004.
2. Haken H.: *Information and Self-Organization*, Springer-Verlag, Berlin, 2000.
3. Helbing D.: *Traffic and Related Self-Driven Many-Particle Systems*, Rev. Mod. Phys. 73, Issue 4, 2001, p. 1067-1141.

SPECIAL THANKS

Author's research in this area is realised with a state finance support by means of Czech Science Foundation (GA CR) under project registration no. 102/05/H517.