A Systems Approach to Designing a Traffic Collision Avoidance Early Warning System

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ABSTRACT

This article examines and evaluates the systems view of the concept of the collision avoidance early warning system (will be referred to as "the early warning system" in all further instances) which uses traffic accident data and data mining algorithms. Principles of the General Systems Theory are used in describing the system and elaborating upon its attributes.

Connections to other current telematic systems and its location in the hierarchy of state traffic safety units are discussed steadily and gradually in the article.

It also describes the principles of the collision avoidance early warning system, along with its inputs and outputs and the elements and connections it is formed out of.
With regard to the principles of the General Systems Theory isomorphism's are searched for and the feedback and the goals of the system are discussed within.

Keywords: system, early warning, general systems theory, data mining.

1. INTRODUCTION

A great number of modern information and communication technologies exists nowadays which increase the comfort and safety of the passengers of motor vehicles. But even so, many traffic accidents occur daily in the Czech Republic and according to the latest police statistics the number of accidents is not decreasing. In fact, it is marginally increasing.

The Road Crash statistics for the year 2016 which can be viewed on the Czech Autoclub website [1], say that the number of accidents increased again compared to 2015.

In 2016, exactly 5797 more accidents happened than in 2015 which equals to a 6% growth in the number of accidents. Even the total material damage rose by approximately 6% compared to the year 2015.

Such unfavorable statistics are unfortunately not exclusive only to the Czech Republic - the proof of this could be the substantial amount of traffic collisions in Slovenia and Egypt which happened at the end of January, 2016 [2].

In today's automobiles, a whole range of elements increasing the safety of its passengers during a potential traffic collision exists. Correspondingly, modern automobiles are equipped with technologies such as ABS, ESP, front assistant and many others, which are designed to prevent any potential accidents. from happening. More information about these particular technologies can be found in [3] or in [4].

Another matter of high importance is to warn the driver of possible potential dangers on the planned route. For example, to warn the driver of the aforementioned dangerous situations info boards and radio announcements or the RDS TMC technology is used currently. We have written about the capabilities of these types of early warning systems in [3]. The main problem of contemporary warning systems is that they attempt to solve the situation only after the accident has already happened, moreover, drivers receive the information with a great delay.

We assume that informing the driver of the location where problematic situations may occur (the locations of frequent traffic accidents with their typical traits) would help in improving this situation.

The goal of this article is to describe an early warning system using the systems approach. In the following text the location of the described system in the hierarchy of systems will be elaborated upon, the connections to other existing systems will be defined and the individual elements of the system and their mutual connections will be characterized. Furthermore, the goals of the system and the processes ensuring their fulfillment will also be defined.

2. THE SYSTEM'S PLACE IN THE HIERARCHY OF TRAFFIC SAFETY UNITS AND OTHER SYSTEMS INCREASING THE SAFETY OF TRAFFIC

A system can be defined technically as a set of interrelated purpose driven components and a set of their mutual connections with dynamic behaviors, which together define the attributes of the whole system. In the process of breaking down the given system to its elements we can isolate individual subsystems.

We consider a subsystem to be a subset of system elements and connections which are for some reason isolated out of the system and can be taken as a new system or an element.
Thus, every system then contains elements and connections which form the foundation of the system's structure. In terms of system maintenance and its further development, the early warning system should exist as a part of (and be a subsystem of) a higher authority, such as the Ministry of Transport, the Ministry of Internal Affairs or Police of the Czech Republic.

Due to the fact that an inseparable part of the system is the traffic accident data which is in the possession of the Ministry of Transport, it seems logical that the Ministry of Transport should largely participate in supervising the system.
Although the data itself is gathered by Police of the Czech Republic which collects the data about every traffic accident (since the year 2008, about every traffic accident with material damages exceeding 4,000 USD).

The police would contribute to the system not only by providing the traffic accident data, but also by being responsible for the quality and format of the data along with collecting particular attributes of interest during traffic accident investigations. Therefore, it is simply not possible to exclude the police from partaking in the early warning system. Figure 1 illustrates this point.

The Ministry of Transport also handles other systems which are designed to increase traffic safety. Among the most important telematic systems which aim to increase the safety of roadways in the Czech Republic belongs the “variable message signs system” and the system of distributing traffic related information using the RDS-TMC technology.

The early warning system differs from the aforementioned systems primarily in that it aims to actively prevent the accidents from happening, whereas other systems only attempt to solve the situation after it had already happened.

All mentioned systems can exist in parallel to each other, though, and the proposed early warning system could theoretically use the data from the RDS-TMC system or variable message signs.

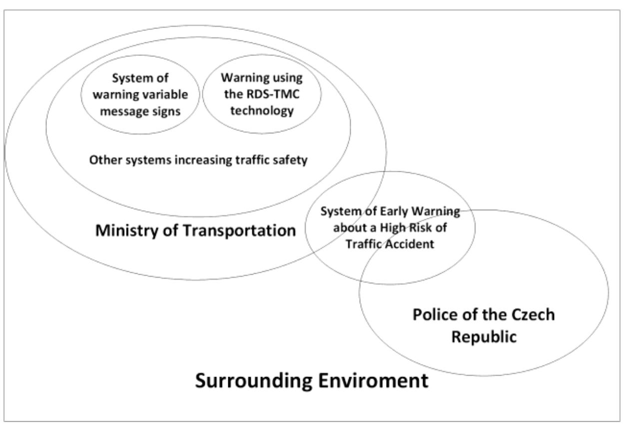

Figure 1. The early warning system and its place in the hierarchy of traffic safety authorities

3. THE ELEMENTS AND INNER CONNECTIONS OF THE EARLY WARNING SYSTEM

The early warning system is an element in certain suprasystems, but on the other hand it also consists of particular elements and their mutual connections, while some processes can be defined as subsystems of the early warning system.

The borders of the system are on one side comprised of inputs in the form of external data sources and on the other end warn the driver in real time and location.
The conceptual model of the early warning system can be described as a complex system that uses existing prediction models based on the location of the vehicle at the time and other relevant attributes to predict the risk of an accident in real time. The early warning system is comprised of two elementary parts.

The first (Control) part ensures the collection, processing and distribution of the data about past traffic accidents. It's second goal is to create and distribute prediction models. The user part of the system evaluates situations in real time and in a meaningful way informs the driver about any substantial risks of a possible traffic accident happening. More information about the Control and User parts can be found in [5]. In Figure 2 the imaginary border between the Control and User parts of the system is illustrated as a dotted line.

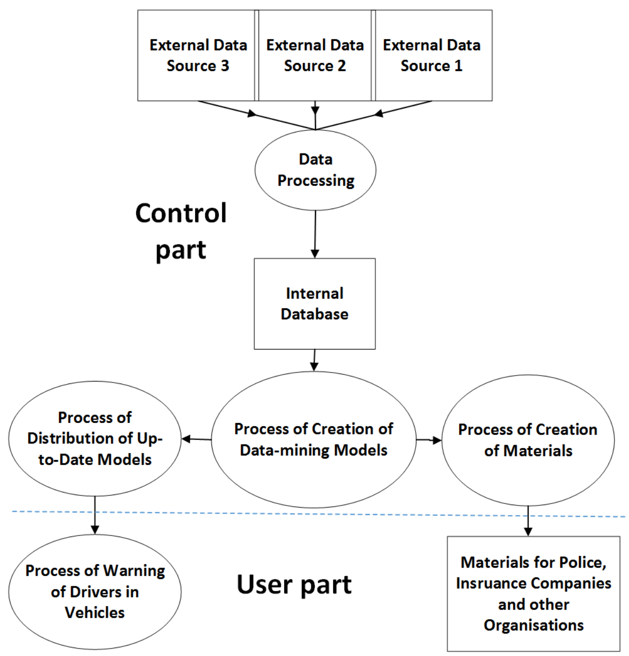

Figure 2. The elements of the early warning system

In Figure 2 the data from external sources refer to e.g. the Database of Traffic Accidents of Police of the Czech Republic, although this is not necessarily the only data source of the system in question. There are about 600,000 records about traffic accidents, that happened on the territory of the Czech Republic, available to be used in creating prediction models, while each record contains 44 attributes.

Among the available attributes describing the details of any particular accident are for example the GPS coordinates, the time and date of the accident, the cause of the accident, the culpability of the accident, the number of killed people and the number of the heavily or lightly injured.

Other interesting attributes which we could potentially use to create prediction models is the data about the condition of the road, visibility and wind conditions at the time of the accident.
Due to the diversity of all the possible other data sources it is necessary to process the data (through the data processing procedure) and save it into the internal database of the system.
As was mentioned earlier the data about traffic accidents provided by the police does not necessarily have to be the only data source the system would use.

Another example of an external data source might be the database of the results of the national traffic census - every 5 years a traffic census takes place on the roads of the Czech Republic.

Basic results of the census, including the methodology used to collect the data, can be found in the online presentation of the project [6]. Individual roadways are divided into sections and in these sections the frequency of individual means of transport are enumerated (automobiles, buses, trucks etc.). The calculated relative density of traffic in the specific section is also available.

But the data is not easily available and it is necessary to cross reference the data to the individual traffic accident records. We are currently striving to assign a record about the number of traffic accidents in the specific location - or rather the density of traffic in the location - to each traffic accident record.

The reason for this assignment is the fact that the parameters of the algorithms used for finding traffic collision clusters need to be set to different values depending on the density of traffic in the given location - incorrectly set values would for example fail to detect any clusters in locations with low traffic density. E.g. - highways have high traffic density while local roadways are an example of low traffic density.

The subsystem that creates data mining models which will be used to predict dangerous locations is absolutely vital for the operation of the early warning system. For the system to resemble a hard system as closely as possible, it would be necessary to automate most of the system, but this cannot quite be realised since the human factor always needs to be present in the process of creating the prediction models - in this procedure of creating data mining models, it is necessary to download information from the traffic accident database and create a modelling matrix (denormalise the data).

The data in the modelling matrix are analyzed by e.g. a data mining tool, and subsequently the data would get scanned for patterns that could be used for future predictions. We elaborated upon the algorithms that are used for this purpose in [7].

The resulting prediction models then need to be distributed into the User part of the system, and that is facilitated by the Process for Distribution of Current Models. The transmitting of the information should be possible through several alternative transmission channels.

The User part of the system (the processes that warn the driver of the vehicle) assumes that prediction models will be used in a special device placed in the vehicle in question, which would evaluate the risk of an accident in real time, depending on the time, location, road and vehicle conditions, the weather conditions and other relevant attributes describing the situation at any given time.

Most of this data is easily available in modern automobiles thanks to the sensors the vehicles are equipped with. The device in the vehicle would compare all the data gathered by the sensors with the results of the prediction models and in the event of high levels of similarity, the driver would be warned of the potential dangers. In short, the driver of the vehicle would be warned if a number of traffic accidents happened in the same conditions as those detected by the sensors at any given time [5].

4. THE INPUTS AND OUTPUTS OF THE SYSTEM

Based on his observations of organic systems, Bertalanfy in [8] discovered that all systems are open due to the fact that they cannot exists without exchanging matter and energy with their surrounding environments - a two-way exchange. The streams going into the system are the inputs of the system. The streams that leave the system are its outputs. Thanks to the procedures which process or modify the inputs or remove specific elements necessary for the existence of the system from them, the outputs differ from the inputs. In other words, the inputs of a system can be seen as a set of connections or variables through which the environment affects the system in question, and vice versa, the outputs can be seen as a set of connections or variables through which the system affects its environment.

If we want to discuss the inputs of the early warning system, we should first define the most noteworthy inputs of the system. The first of the noteworthy inputs are the extraordinary events, accidents or other occurrences (Figure 3) which are mostly unpredictable in their character and thus could be compared to soft systems. Although, these events occur under specific circumstances which can be roughly described using specific variables.

Another notable input of the early warning system is Police of the Czech Republic, which creates records about all reported traffic accidents - the quality of these records is influenced by numerous factors. The police officer in charge of collecting the information about the specific attributes of the accident in question plays a huge role. Another contributing factor are the rules and higher authorities of Police of the Czech Republic which determine what information is to be noted down in the records.

Increasing the number of recorded attributes and accurate assessment of their importance would, if done today, also increase the accuracy of all future prediction models based on them. Along with Police of the Czech Republic, the Ministry of Transport would also contribute as a supervisor and provider of the data.

Among the remaining noteworthy inputs belong the up to date weather conditions and traffic participants. The information about these and any other occurrences would actively enter the system in real time at the time when the device in the automobile (which is a part of the User part of the system) were evaluating the situation at the time and comparing it with the prediction results.

The outputs of the system are mostly materials for the police, insurance agencies and other organizations. These materials could help the aforementioned subjects in evaluating particular situations. The outputs of the early warning system can also be inputs of other systems. But the main output of the early warning system should be the warning regarding potential substantial dangers on the route sent to the driver, which is to be issued in the event of high similarities between the situation at the time with the prediction results.

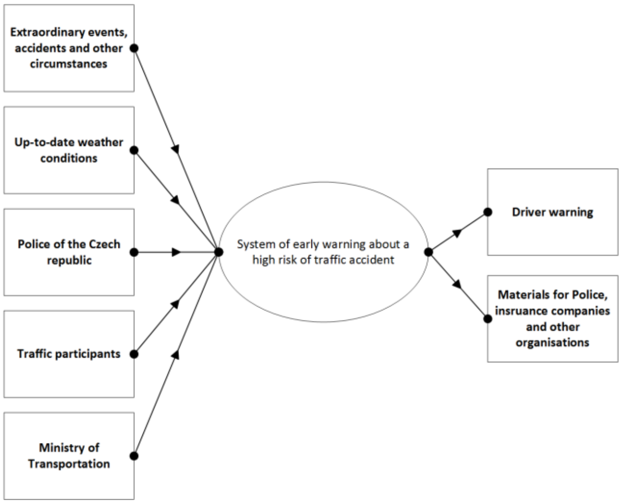

Figure 3. - Inputs and outputs of the early warning system

5. SEARCHING FOR ISOMORPHISMS

The mutual correspondence between objects, which also preserves the relations between them, is called an isomorphism. If we try to find any similar systems comparable to the proposed early warning system, we will find, for example, the tsunami warning systems. Or alternatively, a similar system to the one described in this document could search for patterns in data collected in terror attacks and warn people headed into dangerous locations - were it equipped with adequate data.

If we continue our search for isomorphisms, we can find similar systems in the kingdoms of certain mammal species. In Figure 4 you can find a general schematic which will be used to describe the correspondence between the early warning system, and a warning system specific mammalian species use to avoid dangers. Similar behaviour to the early warning system can be seen e.g. in Meerkats, Marmots and Ibexes.

Meerkats, for example, are social animals living in groups of around 10-30 specimen, and they have at least one member at the center, which guards the group from predators - even such ones as birds of prey.

The guardians of the pack stand tall on high grounds or bushes and from these locations inform the group of any incoming dangers by using warning signals in the form of screeching or whistling - the greater the danger the more intense and sharp the produced sounds.

This warning system can be compared to the early warning system described in this document - both systems employ learned patterns in their function.

In the case of Meerkats, these patterns are those of potential dangers which the guardians observe in their environment. In the case of the described early warning system, the patterns are those of dangerous locations and the situations related to them. But in both cases data enters the systems in real time and location and under specific circumstances. The data is then compared with the previously learned patterns. Both the described system and the Meerkat guardians evaluate the input data and compare it to the learned patterns and calculate the risk of any given situation.

In the case of high similarities between the learned patterns, the meerkat guardian alerts the group by producing the adequate warning sound. And likewise, the described early warning system creates an adequate warning for the vehicle driver (using the special device in the vehicle). [9]

Figure 4 does not depict the process of updating the learned patterns used for evaluating real time data. Among the Meerkats and similarly behaving animals, the patterns are updated with new dangers which the guardian observed in its environment and this knowledge then becomes a part of the learned patterns of dangerous behaviours. In the early warning system, the updated patterns are the updated data from the traffic accident database.

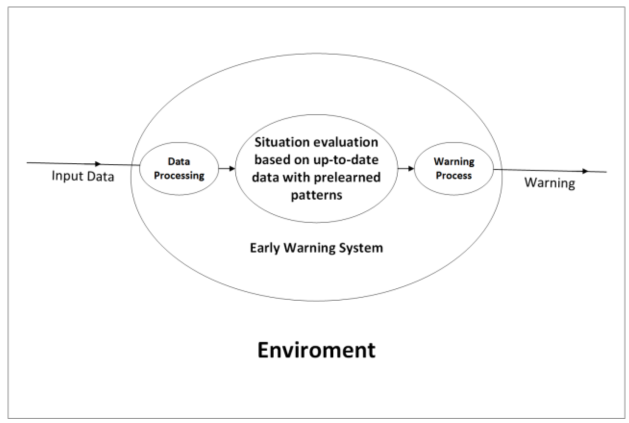

Figure 4. Generalized schematic of the early warning system [9]

6. THE GOAL OF THE EARLY WARNING SYSTEM AND A VIEW OF THE SYSTEM FROM THE PERSPECTIVE OF HARD AND SOFT SYSTEMS

The behaviour of systems is always directed towards a specific goal or goals - any given system can have multiple goals - on every level of the hierarchy of systems. Every system is directed by several goals at once - the goal which the suprasystem wants to reach, the goal which the elements of the system are directed by, and last but not least, it is influenced by the goal which the system itself is trying to fulfill.

The primary purpose of the early warning system is to increase the safety of traffic. Its suprasystem, which it would belong under, is the Ministry of Transport, along with Police of the Czech Republic - which also aim to increase traffic safety and improve all related aspects of traffic, such as decreasing the number of deaths and light and heavy injuries in traffic accidents. The goals of its individual subsystems (for example the data processing procedure or the model creation processes) of the early warning system have already been described in this document.

Using General Systems Theory, we can divide systems into two categories - soft and hard systems. Each of these two categories requires a different analytical approach and provides a different level of modelling/prediction - for current or future behaviors. The processes occurring in soft systems cannot be easily structured or automated, due to the fact that many factors affect the elements of the system, many of which are not quantifiable. Their control requires frequent human interventions.

On the other hand, the processes occurring in hard systems solve well-structured tasks which can easily be automated.
From the moment a system of this type is created, it is mostly automatically controlled and does not require any large human interventions. Every system primarily gravitates towards only one of the two categories, although the mentioned approaches are supplemental and therefore both can be applied to one system simultaneously.

The early warning system resides primarily in the category of hard systems, due to the fact that we are able to quantify the quality of the outputs, the inner processes can be structured well and its tasks can be easily algorithmized.
Even though, by principle, the proposed system does not really require frequent updates or interventions by human hands, we can find characteristics of soft systems within this system as well. Some elements of the system - such as the process of creating prediction models, or data preparation and data matrix modification (in case the data format is changed) - require human interventions. In its essence, any traffic accident itself always remains to be a sum of factors, many of which are unquantifiable.

7. FEEDBACK AND ITS ROLE IN THE EARLY WARNING SYSTEM

We can understand feedback as a set of functions, which direct the system, in which a specific variable is permanently observed and compared to a control variable and modified to make it approach the set variable as closely as possible.

According to Boulding's classification, the early warning system could be labeled as a cybernetic system, and thus it is possible to track feedback - both within specific subsystems of the system - and of the system as a whole as well. An example of feedback in the model creation subsystem could be the necessity for evaluation of the models created based on the data and if necessary, retrospectively correcting the modelling matrix.

Another example of feedback, in the early warning system as a whole, is the necessity to regularly evaluate the quality of the prediction models - in case the traffic density in specific locations within the observed roadways changed.

For example, a new road bypass in a city could mean a decrease of the traffic density in its vicinity. Thus, it is necessary to regularly update not only the information regarding the density of traffic, but to subsequently generate new prediction models as well, in respect to the new circumstances.

8. CONCLUSIONS

Thanks to the usage of the principles of General Systems Theory and a Systems approach, the described early warning system can be scrutinized in a complex manner. The advantage of the proposed solution is that it actively tries to prevent dangerous situations. It would be possible to predict any dangerous situations - in real time and location - using data mining techniques and algorithms, thanks to the existence of large data sets containing traffic accident data. The described system would be useful mainly in situations where the driver goes through the seemingly safe location for the first time. Expected launch of the described system could take place within five years.

9. ACKNOWLEDGMENT

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