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FUZZY ANALYSIS OF TRAFFIC FLOWS FOR SAFETY TUNNEL SYSTEM

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Abstract: *Accidents that occurred in major road tunnels of European countries in the past pointed to the deficiency of safety management in these systems. Road tunnels represent a relatively weak link in road traffic communications in respect of safety. Tunnels are, as a matter of fact, relatively closed and not easily accessible places; their walls represent physical obstacles. In case of fire during transportation of flammable goods, freight or fuel, temperatures accumulated in the interior of the tunnel are high and resist for a relatively long time. Tunnel walls make heat dispersion difficult.*

In order to prevent undesirable events or at least reduce their incidence, specialists are trying to improve safety level in road tunnel systems by pursuing a safety policy by planning and making preparation for appropriate action in the event of such an occurrence. Fuzzy decisions allow effective control of safety and related hazards. They are based on the analysis of values that describe the conditions inside and in front of the tunnel, acquired experiences and knowledge of the field of research. Fuzzy logic allows a systems approach to safety and is indicative of the eventual occurrence of serious accidents. Fuzzy logic ensures safety of tunnel systems and efficient management organization at the same time.

Key words: *road tunnel, safety tunnel system, fuzzy logic, traffic flows, detection*

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. INTRODUCTION

From security viewpoint, road tunnels represent a relatively weak link in road traffic communications. The outcome of dangerous events that may occur in road tunnels and the very severity of their consequences depend largely on the basic structural characteristics of individual road tunnels, their technical equipment and type of safety management. Tunnels are relatively closed and not easily accessible places; their walls represent a physical obstacle.

In case of fire during transportation of flammable goods, freight or fuel, the tunnel walls make heat dispersion difficult.

As a result, the temperature inside the tunnel accumulates and achieves high levels that are maintained for a relatively long time. In case of explosion caused by ignition of flammable substances, the tunnel walls intensify the strength of the shock wave resulting from the explosion. In case of escape of gases or vapours, their dispersion is rendered difficult due to insufficient airflow circulation. High concentration of gases/vapours accumulates in the tunnel and causes either direct (toxic and inert gases cause respiratory complications) or indirect harmful effects (smoke reduces visibility inside the tunnel, hinder rescue actions) to the exposed population. Spillage of hazardous liquids may lead to environmental accidents, particularly in cases when spilled liquids are not accumulated in reservoirs built for this purpose through drainage system.

As a result, the past events represent milestones in introducing safer and more reliable

technologies and action procedures in facilities with a higher degree of safety requirements, i.e. road tunnel systems. The operation of systems and facilities with a higher degree of safety requirements always involves a certain risk level; therefore, the fundamental task consists of providing a safe and reliable operation of the system or facility and ensuring an appropriate degree of safety of such system or facility.
The application of the approach to analysis, evaluation and ensuring appropriate road tunnel safety and the use of new technical and technological as well as information technology solutions makes possible the prevention of critical and dangerous events since the very beginning, during the tunnel system conception and construction stage. In using road tunnels, people are subjected and exposed to some hazards and associated risks. And risks as such are particularly expressive of the possibility that a dangerous event might occur at a specified time and under specific circumstances.

2. FUZZY LOGIC FOR INTELLIGENT TUNNEL SYSTEM

Fuzzy logic is becoming an increasingly widespread method in many areas of work. And it has certainly demonstrated its attributes in the management of the system of communications, including corresponding sub-systems. As a matter of fact, fuzzy logic manages a database of simple rules of IF-THEN phrase forms by means of which the management activity is calculated by characteristics of the current situation. In our opinion, fuzzy logic is an appropriate method of managing road tunnel traffic flows since it enables a simple transfer of expert knowledge and approximate nature of human inference by using linguistic variables and rules.
Fuzzy logic actually understands linguistic instructions and thus enables generation of a management strategy of which the basis is verbal communication. At the same time, it also represents a means of translating the linguistic strategy of management expressed in terms of IF-THEN phrases into a management algorithm.

2.1 Variables (linguistic, intermediate and output)

The primary building block of any fuzzy logic system is the linguistic variables, which translate real values into linguistic values. Linguistic terms represent the possible values of a linguistic variable. Here, multiple subjective categories describing the same context are combined.

Type	Variable Name	Min	Max	Default	Term Names
input	ADR	0	4	2	low medium high
input	s_t	0	1	0.5	low medium high
input	traffic_density	0	1	0.5	low medium high
input	v	0	100	50	low medium high
input	v_s	0	16	8	low medium high
input	v_t_f	0	100	50	small medium large
input	vehicle_cat	0	1	0.5	small medium large
intermediate	t_flow	-	-	-	low medium high
intermediate	tunnel	-	-	-	negative zero positive
intermediate	vehicle	-	-	-	negative zero positive
output	r_s	0	1	0.5	false true

Table 1: Description of input, intermediate and output variables

Intermediate variables could be defined without any membership functions and fuzzification. Membership degree of the value corresponding to term is set to 1. The membership degrees of all other terms are set to 0.
The output variable r_s define the ramp state. Defuzzification, of the output variables is produced by CoM (Center of Maximum), which calculate the 'best compromise'. This is the most effective method in control applications like analyse of the traffic flow through a tunnel.

2.2. Fuzzy rule inference, aggregation and defuzzification of output variables

The system is composed by four decision blocks: three intermediate and the central one. The computation of fuzzy rules is called fuzzy rule inference. The inference is a calculation consisting of two main steps: aggregation and conclusion.

Fuzzy-based systems use production rules to represent the relation among the linguistic variables and to derive actions from the inputs. Production rules consist of a condition (IF-part) and a conclusion (THEN-part). The IF-part may consist of more than one precondition linked together by linguistic conjunctions like AND and OR.

In our small control applications, we use MIN operator for AND aggregation of different parts of the condition.

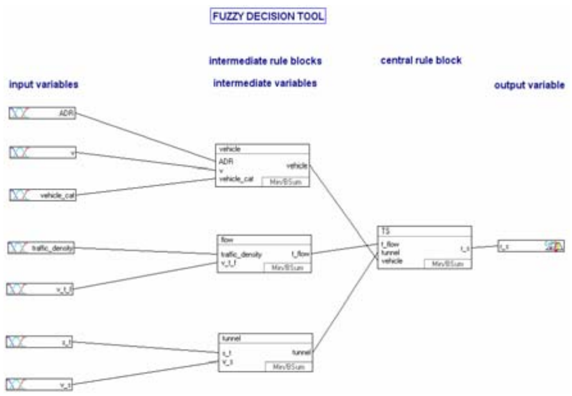

Figure 1: Structure of the Fuzzy Logic System

The conclusion part of each rule is computed by aggregation of results. In our fuzzy system this is done by the BSUM operator (Bounded Sum Fuzzy Operator) for result aggregation:

$$\text{BSUM}: \quad \mu = min\left(1, \sum_i \mu_i\right).$$

The result produced from the evaluation of fuzzy rules is, of course, fuzzy. Such linguistic values are not useful in control systems, so membership functions are used to retranslate the fuzzy output into a crisp value. This retranslation is known as defuzzification and can be performed by using several methods.

Our application uses the Center of Maximum method (CoM) and the result is the "best compromise solution" of all inferred results. The crisp output is a weighted mean of the term membership maxima, weighted by the inference results.

3. SIMULATION

The system of managing traffic flows in road tunnels is based on the information obtained by detectors. The regulator receives first the number of vehicles in a specified time unit from which it separates all vehicles weighing more than 3.5 t. Moreover, video detectors installed in front of the tunnel carefully segment vehicles by categories and, in case of a, determines the type of dangerous substance it transports. The above-mentioned rules are implemented upon receipt of the information.

The output emerges in the form of a command regarding whether the ramp before the tunnel tube portal should be lowered and the traffic flow redirected through an alternative route or whether the traffic flow should remain unchanged. If the output variable is unchanged, the following step consists of verifying all the above-mentioned criteria for maintaining the existing situation and, if these criteria have been met, the ramp remains up. Otherwise, the ramp goes down.

The entire decision- or conclusion-making process is repeated at short time intervals.

Managing road tunnel traffic flows comprises permanent making of decisions, such as (see Figure 2):

a) leave the current traffic situation such as it is and thus,
b) maintain the ramp in its current position and redirect the heavy cargo vehicles via alternative routes, and
c) lower the ramp and redirect the traffic via alternative routes.

Like the majority of management problems, the case of traffic flow management structure also includes some elements of the management system. These are: input, output, objective, assessment criteria and return loop.

The system's operation is based on a system of rules that, given the input data such as:

– ADR (transport of dangerous substances),
– v (speed of the vehicle before the ramp)
– vehicle_cat (vehicle category),
– s_t (particularity inside the tunnel system)
– v_s (wind speed),
– traffic_density (traffic density), and
– v_t_f (speed of the traffic flow),

that makes a decision to leave the traffic flow in the tunnel as it is or to redirect the heavy cargo vehicles only or to redirect it. The output is a result of the processor control as to the moment in which the objective is to define the moment where the risk of accident is still within acceptable limits and where it is not. Assessment criteria represent the process of comparing the output to the objective, which, in this concrete case, illustrates the ramp position and the probability of occurrence of traffic accident or fire.

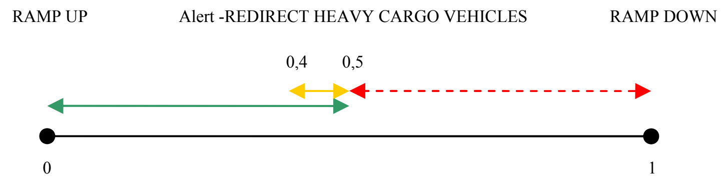

Figure 2: Ramp state

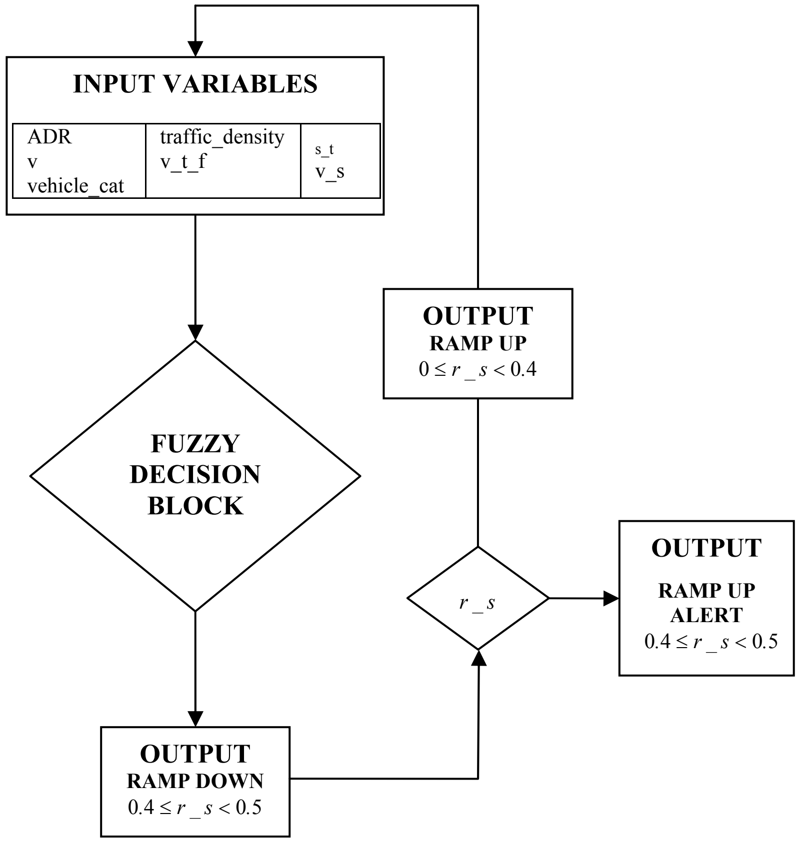

Figure 3: Fuzzy system scheme

ADR	v	vehicle_cat	s_t	v_s	traffic_density	v_t_f	r_s	ramp_state: **0**-ramp up **1**-ramp down **0***-alert
0	100	0.2	0.16	3	0.65	90	0.16666	0
0	100	0.2	0.8	10	0.85	40	0.43332	0*
0	100	0.2	0.8	10	0.85	37	0.51332	1
0	100	0.8	0.16	3	0.65	90	0.16666	0
3	100	0.8	0.16	3	0.65	90	0.16666	0
2	100	0.8	0.5	3	0.55	40	0.35712	0
1	90	0.6	0	1	0.45	85	0.16666	0
0	100	0.1	0.4	16	0.85	70	0.16666	0
1	100	0.7	0.1	3	0.85	80	0.16666	0
2	100	0.7	0.1	3	0.85	80	0.16666	0
3	100	0.7	0.1	3	0.85	80	0.16666	0
4	100	0.7	0.77	3	0.85	38	0.53744	1
3	100	0.7	0.1	3	0.85	80	0.16666	0
2	100	0.7	0.1	3	0.85	80	0.16666	0

Table 2: results of simulated flow throw a tunnel in different conditions

Above are presented calculation details of the output variable r_s when:
ADR=0, v=100, vehicle_cat=0.2, s_t=0.8, v_s=10, traffic_density=0.85 and v_t_f= 37.

Rule block: VEHICLE

IF ADR=*low* & v=*higt* & vehcle_cat=*small* **THEN** vehicle=*positive*

vehicle=(0,0,1)

Rule block: TUNNEL

IF s_t=*higt* & v_s=*higt* **THEN** tunnel=*negative*

tunnel=(1,0,0)

Rule block: FLOW

IF traffic_density=*higt c* **THEN** t_flow=*low*
IF traffic_density=*higt* & v_t_f=*small* **THEN** t_flow=*medium*

t_flow=(0.47998,0.52002,0)

Rule block: TS

IF t_flow=*low* & tunnel=*negative* & vehicle=*positive* **THEN** r_s=*false*
IF t_flow=*mediumt* & tunnel=*negative* & vehicle=*positive* **THEN** r_s=*true*

r_s=(0.47998,0.52002)
μ =(0.166,0.835)

CoM gives the final crisp value of r_s:

$$r\_s^* = \frac{\mu_1 \cdot r\_s_1 + \mu_2 \cdot r\_s_2}{\mu_1 + \mu_2}$$

$$r\_s^* = \frac{0.166 \cdot 0.47998 + 0.835 \cdot 0.52002}{0.166 + 0.835} = 0.513$$

CONCLUSIONS

In this paper, we analyse the variability of traffic flow and present the connections between dates from sensors and fuzzy logic decision tool for incident detection. Specifically, this paper addresses a novel approach to of fuzzy logic to traffic flow through tunnel system analyse. The paper discusses the development of a new approach to safety in road tunnels.
The system of managing traffic flows in road tunnels is based on the information obtained by detectors and use measurements from a station to detect anomalies or character of traffic flow. The paper shows a new approach that identifies potential accidents and prevention this. The system works according to the principle of enabled disabled or conditionally enabled passage through the tunnel. In this regard, it is important to stress that the fuzzy logic system takes into consideration both: traffic density and vehicle category before the tunnel portal itself, particularity, wind speed and traffic flow inside the tunnel. Special attention being made to the transport of dangerous substances.

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FUZZY АНАЛИЗ НА ТРАНСПОРТНИТЕ ПОТОЦИ ЗА СИСТЕМА НА БЕЗОПАСНИ ТУНЕЛИ

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СЛОВЕНИЯ

Резюме: *Катастрофите, които са станали на главните пътни тунели в европейските страни, показват недостатъци в управлението на безопасността в тези системи. Пътните тунели представляват сравнително слаба връзка в пътните съобщения по отношение на безопасността. Тунелите всъщност са сравнително затворени и недостатъчно достъпни места, техните стени представлява физически препятствия. В случай на пожар при превозване на запалими стоки, товари или гориво, получените температури във вътрешността на тунела са високи и се запазват сравнително дълго време. Стените на тунелите правят трудно разпръскването на топлината..*

За да се предотвратят нежелани събития или поне да се намали тяхното настъпване, специалистите се опитват до подобрят равнището на безопасност в системата на пътни тунели чрез политика за безопасност посредством планиране и подготовка за подходящи действия при възникване на такова събитие. Fuzzy решенията позволяват ефективен контрол на безопасността и съответните рискове. Те се базират на анализ на стойностите, които описват условията вътре и пред тунеланатрупания опит и знания в областта на изследвания. Fuzzy логиката позволява системен подход към безопасността и е показател за евентуално възникване на сериозен инцидент. Fuzzy логиката осигурява безопасност в тунелните системи и същевременно ефективна управленска организация.

Ключови думи: *пътен тунел, безопасна система на тунелите, fuzzy логика, транспортни потоци, откриване.*