Design of Algorithms for Payment Telematics Systems Evaluating Driver's Driving Style

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ABSTRACT: This article and its issue fall into the area of payment telematics systems in the transportation domain, with specific focus on the evaluation of driver's driving style. The aim of the described research is a suggestion of an algorithmic method of the evaluation of the driving style of the driver for payment telematics systems. This, in its result, allows comprehensively to take into account the differences in drivers' behaviour and therefore also the probability rate of a traffic accident. The output of the algorithm is a projection of the evaluation into insurance payment. The article points out the weaknesses and shortcomings of the Pay As You Drive systems, which do not cover the behaviour of the driver and de facto only focus on the count of the driven kilometres.

KEY WORDS: Driver behaviour, PHYD, fuzzy logic, driving style, payment telematics systems.

1 INTRODUCTION

The systems Pay As You Drive (PAYD)/ Pay How You Drive (PHYD) represent potentially a very strong tool for internalisation of the damage caused by traffic accidents, based on the principle “you drive less, you pay less”. In the time of the increase of road transport, this represents a positive trend.

The systems PAYD are predominantly used around the world. The reason is that the use of these systems does not claim such requirements for the intelligence and set up of the input parameters, which depend on many variables and influence the final evaluation of the driving style. The PHYD systems are quite the opposite. These systems provide a wide potential of use, but due to high requirements for the algorithm and the whole internal logic of the onboard devices, they are currently only in use in limited numbers. The important fact is that at present, none of the implemented and used systems covers the given issues in a really complex way, but only rather marginally.

Today, the PAYD/PHYD systems are offered by insurance companies all over the world. Only in Europe there are 18 of them, in the USA there is more than 15. However, the majority of insurance companies calculate the insurance payment based only on the number of kilometres driven, the mentioned driver behaviour or driving style is not taken into account at all.

The collection of the data needed for functioning of these systems may be carried on automatically or manually, using the onboard device installed in the vehicle. In the case of manual collection of data needed for the calculation of the insurance payment, there are no additional costs in the form of an installation fee. There are also no legislative obstacles pointing terms of privacy. However, this method is rather risky concerning the possible fraudulent actions of vehicle owners and it is impossible to distinguish when and where such vehicle was driven (e.g. during weekend or in peak hours, on a motorway or in the city, etc.). On the other hand, the automatic data collection offers more variability, e.g. concerning the possibility to set up different parameters corresponding with the different times of day, types of roads used by driver, etc. Thanks to the inbuilt GNSS positioning system, the insurance companies can offer more services, such as searching for stolen vehicles, etc. Some negative impacts of the automatic data collection include a potential misuse, i.e. the possibility to find out when and where the driver was to be found – which means the issue of privacy.

Looking at the described current situation from mathematic-algorithmic point of view, we can talk about the following generalized and simplified calculation. The last member of the formula differentiates the standard Pay As You Drive systems from the Pay How You Drive systems.

$$\begin{matrix} Price\ car \\ insurance \end{matrix} = C + k_1 . P_{km} \left(\frac{k_2 .\%\, D_{DAY} + \cdots + k_n .\%\, D_N}{100} \right) \left(\frac{k_3 .\%\, P_1 + \cdots + k_n .\%\, Pn}{100} \right) . (driver's\ driving\ style) \qquad (1)$$

Where C = lump sum insurance fee; $k_1,..k_n$ = constant, P_{km} = number of driven kilometres; $D_{DAY/NIGHT}$ = drive during day/night; D_n = arbitrary daytime; $P_1,...P_n$ = position of the vehicle/type of road the vehicle is moving on.

In its other parts this article focuses on the weaknesses and shortcomings of the current Pay As You Drive systems, which do not cover the behaviour of the driver and actually focuses only on the number of driven kilometres. All around the world, these systems, known as Pay How You Drive, are only represented in minority. They do not take into account the differences between the driving styles of drivers, and therefore also the higher possibility for a traffic accident as a result of aggressive driving style of drivers, etc. The extension by the element of driver's behaviour has the potential to minimize operator's costs and indirectly even costs of the insurance company which holds the insurance for the vehicle, and therefore it is the object of this scientific article (Troncoso et al., 2011; Bolderdijk et al., 2011; Ferreira & Minikel, 2013).

2 THE ALGORITHM FOR THE EVALUATION OF DRIVING STYLE (Kantor, 2013)

The following chapter represents the issues in question in the form of a comprehensive algorithm for the evaluation of driving style of driver, which aims towards the possibility of charging the driver based on his driving style. The algorithm consists of six component algorithmic steps.

The order and the linkage between the particular steps are to be seen on the following scheme. The first step taken must be the one concerning the data collection. After this, the steps 2–4 may follow all at once or one by one. After these steps are completed, the step 5 will be executed, i.e. the evaluation of the style of a manoeuvre based on the processed input parameters. Step 5 is followed by step 6, i.e. the assignment of the number of penalty points and determination of the driving style charges.

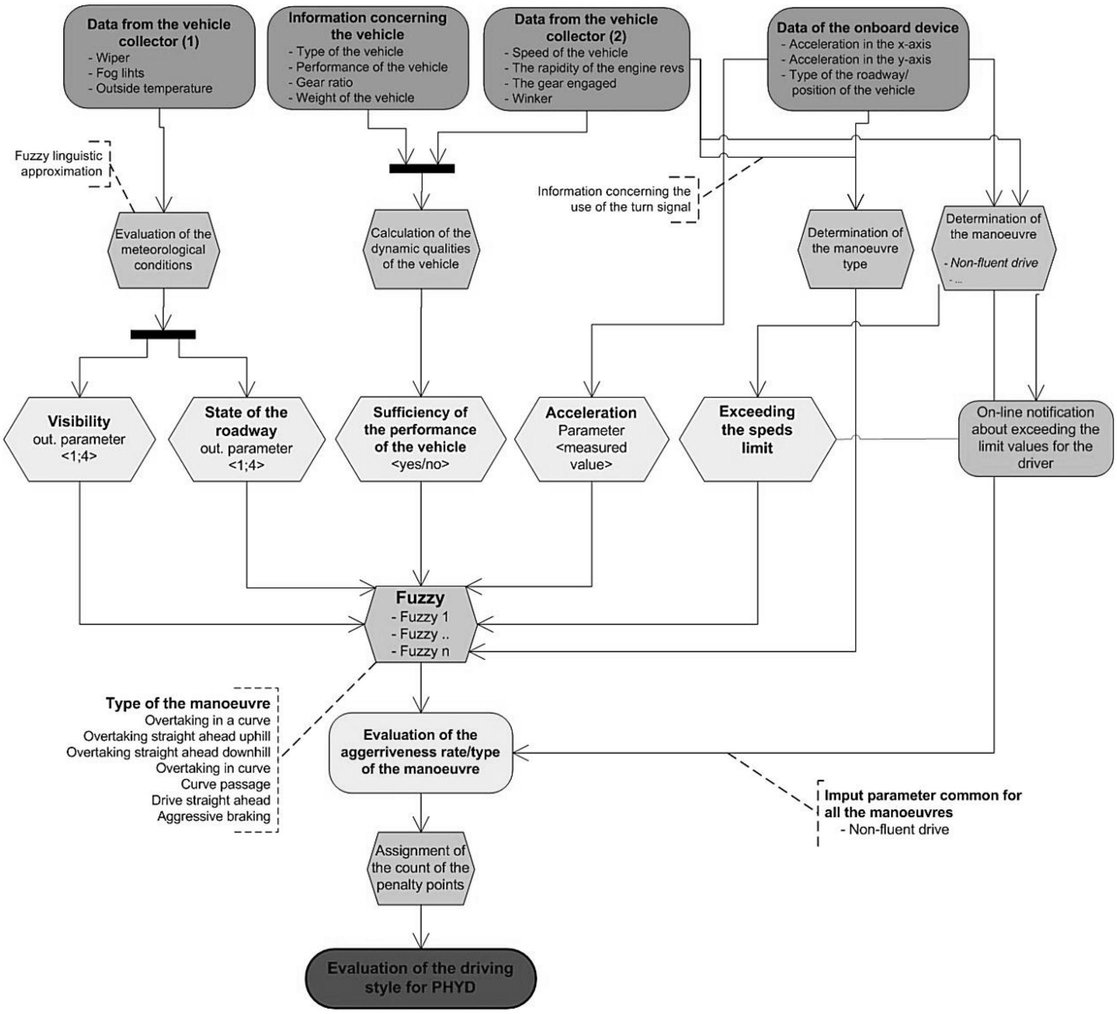

Figure 1: Scheme of the algorithm for the evaluation of the driving style.

2.1 Step 1 – Data collection

The first step leading to the evaluation of the driving style is the collection of data and information that will be entering particular component calculations and algorithmic operations. These are as follows:

- Information concerning the vehicle – type of vehicle, performance of vehicle, gear ratio, weight of vehicle;
- Data of the onboard device – the acceleration in the x and y axis, information concerning the position of vehicle;
- Collected data concerning the vehicle – information about the windscreen wipers and fog lights switched on, outside temperature, engine revolutions, the speed of vehicle, the gear engaged, the information concerning the use of indicators.

All data and information must be marked by a time stamp, which will allow the following matching of particular types of data.

2.2 Step 2 – Evaluation of meteorological conditions

An important factor, which to a large extent influences the driving style, is meteorological conditions, since they may significantly increase the risks related to safe driving of vehicle. The main risk coming from the deteriorated meteorological conditions is the longer braking distance (worse adhesion of tyre), the estimation of speed in consideration to the given conditions on road, and the estimation of distance of vehicles driving in front and in the opposite direction when overtaking. Regarding the probability of a traffic accident occurrence, the behaviour of driver in good or bad weather is very important. The increase in the severity of traffic accidents, also caused by deteriorated meteorological conditions, can be demonstrated by the means of statistical recording of the amount of the total material damage.

The evaluation of meteorological conditions is carried out with the use of a model using the methods of fuzzy linguistic approximation, based on a combination of three input parameters. These are: the parameter of the frequency of windscreen wipers, ambient temperature, fog lights switched on/switched off. All these parameters can be collected from the vehicle itself. The output of the fuzzy linguistic model of the evaluation of meteorological conditions represents two parameters – visibility and road condition. These parameters are used as an input into the fuzzy model evaluating the style of the manoeuvre (step 5).

2.3 Step 3 – Determination of vehicle dynamic qualities

The determination and evaluation of current dynamic attributes of vehicle is, in its result, a composition of a traction diagram extended with the values of the maximum possible acceleration of vehicle in a given driving mode (on a flat road, uphill, with current speed, etc.).

The parameters entered into the calculation are described in step 1, and they are mainly a combination of the data collected from vehicle and information concerning the vehicle.

The output of the step of determination of dynamic qualities of vehicle is the ratio of currently used performance of vehicle and the maximum reachable performance in the given driving mode. The output values are determined based on the calculated traction diagram and further presented in the form of a maximum possible and current acceleration of the vehicle. The result of the calculation is afterwards in subsequent steps of evaluation of the driving style stated in the binary form as a sufficiency or insufficiency of performance in a given driving situation.

2.4 Step 4 – Determination of manoeuvre type

Using the type of manoeuvre it is possible to decompose the drive as a whole to the smallest valuable units. The evaluation of the manner of manoeuvre performance is the key issue of the research.

Based on the values of the parameters defining the individual manoeuvres, it is possible to determine the rate of the risk with which they were conducted from the point of view of traffic safety. For the needs of the evaluation of driving style, the following types of manoeuvres are taken into account: driving straight, turning, overtaking, speeding, aggressive deceleration, non-fluent driving (frequent acceleration and deceleration).

The determination of the manoeuvre type is based on the specification of the parameters defining a given manoeuvre type. For example the manoeuvre of overtaking actually consists of two turns, or turning left, driving straight ahead, and turning right. The sequence of the steps defining for example the manoeuvre of overtaking on a straight road segment is as follows:

- Step 1. – Left turning signal indicating the change of direction (indicator) – Information from the CAN collector of the vehicle;
- Step 2. – Positive value a_y from the accelerometer in y axis (turning left – represents the manoeuvre of deviation from one lane to the lane in which the driver will be overtaking);

- Step 3. – Positive value a_x from the accelerometer in x axis, the speed the same or higher than in step 1. (overtaking the vehicle);
- Step 4. – Right turning signal indicating the change of direction (indicator) – Information from the CAN collector of the vehicle;
- Step 5. – Negative value a_y from the accelerometer in y axis (turning right – the manoeuvre represents return to the previous lane);
- Throughout the whole time the increase in the values from the GPS unit in the z axis is zero.

2.5 Step 5 – Evaluation of manoeuvre style

The determination of the manoeuvre style of driver is primarily evaluated by the means of models of fuzzy linguistic approximation. To estimate the determination of manoeuvre style it is not possible to describe the consequent individual rules in the form of a combination of the input parameters, therefore, a fuzzy system Mamdani was used for the estimation of the manoeuvre style. This system is labelled as a fuzzy system with fuzzy conclusions.

In the fuzzy system of Mamdani type the output variable y is defined on the universe Y and the input variables xi on universes X_i (Jura, 2003).

Let the universe Y be covered by the array of the fuzzy sets B_j and the universes X_i by the arrays of the sets A^j_i. Then it is possible to approximate the non-linear function f by the fuzzy system with a set r of the rules of the following type.

$$\text{If } \left(\mathrm{x}_1 = \mathrm{A}_1^{jk}\right) \text{and } \dots \text{and } \left(\mathrm{x}_n = \mathrm{A}_n^{jk}\right) \text{ then} \left(\mathrm{y} = \mathrm{B}^{jk}\right) \;\; \mathrm{k} = 1,2,\dots,\mathrm{r} \tag{2}$$

The manoeuvre style is being evaluated for these manoeuvres: driving straight, turning, overtaking and aggressive braking. The parameters entering into particular models are the following: visibility, deteriorated road conditions, sufficient vehicle performance, acceleration in x and y axes, speeding, motorways and roads (directions separated or not separated).

Table 1: Overview of monitored input parameters in relation to manoeuvre type.

Type of manoeuvre	Input parameters for fuzzy model					
	Speeding	Reduced visibility	Motorways	Style manoeuvre	Vehicle with sufficient power	Deterioration of road conditions
Overtaking on straight road segment	x	x	x	x	x	x
Overtaking on straight uphill	x	x	x	x	x	x
Overtaking on straight downhill	x	x	x	x		x
Driving on straight road segment	x	x				x
Driving in a curve	x	x	x	x		x
Overtaking in a curve	x	x	x	x		x
Aggressive braking				x		x

The particular parameters influence the evaluation of the manoeuvre style in different degrees. This fact can be demonstrated e.g. on an example when the risk rate of overtaking during low visibility is higher than under good visibility.

An individual fuzzy model was compiled for every manoeuvre. From the outputs of this model we will acquire the information concerning the rate of aggressiveness with which a given manoeuvre was carried out. Particular fuzzy models were set up individually both regarding the interferential rules, and regarding the set up individual partial functions corresponding with individual fuzzy sets. The following figure represents the process of the creation of the fuzzy model.

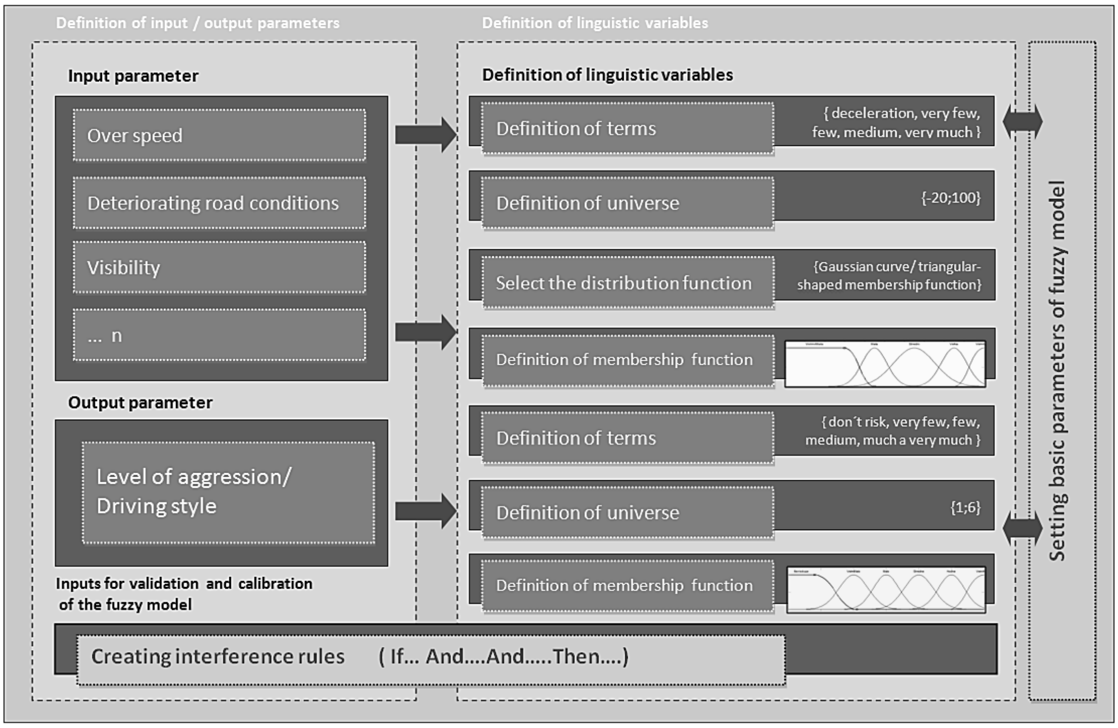

Figure 2: Basic steps leading to determination of manoeuvre style.

The values of the output of the fuzzy models may assume values in the interval <1; 6>. The value 1 represents the manoeuvre style when the driver takes no risks and drives fluently. The value of 6 then represents a very aggressive style of performing the given manoeuvre.

2.6 Step 6 – Assignment of the number of penalty points and determination of driving style sanctions

The final step includes heading towards the possibility of assessment of the fees related to the driving style in which vehicle moves through the road network. These fees are taken into consideration as a variable component of motor vehicles insurance, which represents another level of diversification of evaluation of individual drivers. The resultant amount of the fee will be derived from an assignment of so-called penalty points. These penalty points are used for transporting of the results of the evaluation of the rate of aggressiveness of particular manoeuvres defined in the interval <1; 6>, i.e. outputs of the fuzzy linguistic approximation. The value of 1 represents a fluently performed manoeuvre and the value of 6 a extremely aggressive driving style.

It is important, from the point of view of determining the penalties for driving style, that this “penalisation” was only performed for the manoeuvres with a certain rate of aggressiveness. This means that the introductory point value, which matches the output of the fuzzy model of the value of <0; 1>, is 0 penalty points. The outputs of the evaluation of the manoeuvres ranked in the interval of (1; 2> will correspond with 0-1 penalty point, the outputs of the evaluation of the manoeuvres falling into the interval of (2; 3> will correspond with 1-2 penalty points, etc., up to the value of 5 penalty points.

The total number of penalty points must subsequently be related to the number of kilometres driven or a time period. The resultant amount of the penalty related to the driving style will then be derived from the ratio of penalty points to the number of kilometres driven or the time period. However, the determination of this ratio and the related fee was not the object of the research. This ratio will be determined by the insurance company itself, in relation to its business model, and can also be used as an incentive tool to acquire new clients. For example, speeding in deteriorated weather conditions, which according to statistics means 25% more financial compensation, may be penalized (by insurance companies) more than a traffic accident in good weather conditions.

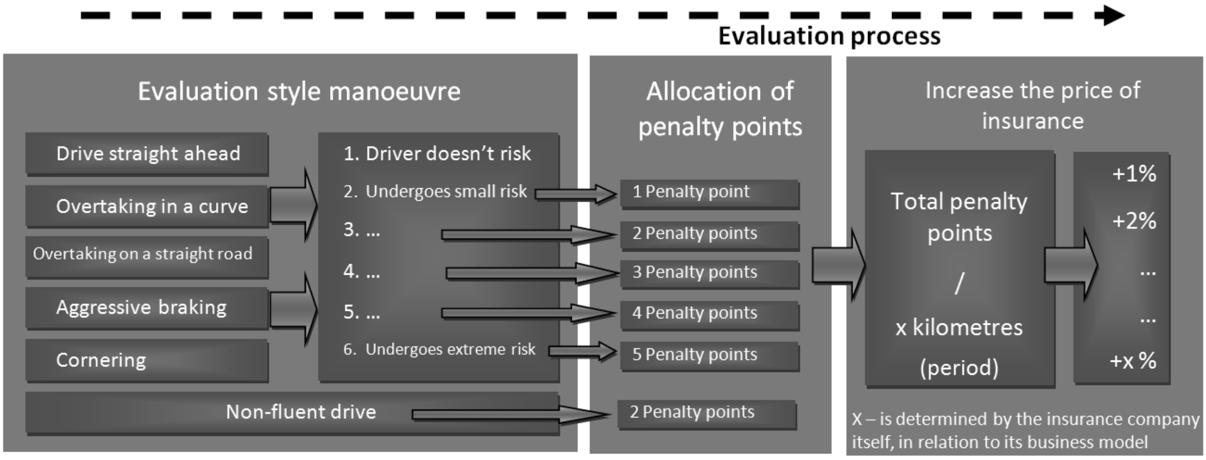

Figure 3: The process leading to determination of penalty points.

The evaluation of driving style may be performed in two reciprocally independent ways, which correspond with the method of processing the input data and information. The first method is the evaluation "during the ride". This method only focuses on speeding, exceeding the side acceleration and aggressive deceleration. When speeding, the driver may be informed immediately (e.g. by an acoustic signal), and therefore he can adjust his driving style. The reason for including only a limited number of parameters is the fact that for the comprehensive evaluation of driving style, it is necessary to have the information and data from different data sources, and these must be evaluated in longer time lines (for the needs of determining the manoeuvre type, etc.). Therefore, the key method for processing the driving data and information is the off-line evaluation, which allows performing a more profound data analysis that is inevitable for the needs of the complex evaluation of driving style.

3 THE POTENTIAL AND BENEFITS OF THE PERFORMED RESEARCH

The benefit is the extension of the Pay As You Drive system with a relevant element taking into consideration the height of paid vehicle insurance in relation to driving style and therefore higher probability of a traffic accident occurrence. The outputs of the research promote these systems to the full-size Pay How You Drive systems. In this sense, the partial benefits may be described in a following way:

- Taking into consideration the difference in the amount of insurance according to the behaviour/driving style of driver: introducing the full-size Pay How You Drive system brings in so far neglected element or parameter usable for fair charging of drivers;
- The motivation of vehicle owners to drive more considerately and less risky: insurance companies will motivate drivers to drive more carefully and not to take risks, and penalize drivers who drive aggressively, take risks and, therefore, increase the risk of a traffic accident and gravity of its consequences;
- More competition on the insurance market: a new product on the vehicle insurance market will lead to a stimulation of the competitive environment between particular

insurance companies and better options in the choice of the type of insurance by customer;
- Decrease in accident rate: vehicle owners will drive more carefully, will be taking less risks and therefore the probability of traffic accident occurrence will decrease indirectly. The safety of road users will improve.

4 CONCLUSION

The motivation for the performed research was based on the weaknesses and shortcomings of the Pay As/How You Drive systems, which currently do not cover the behaviour of driver and actually focus only on the number of driven kilometres.

A proposal of a comprehensive algorithm for the payment systems evaluating the driving styles was stated in this article. This enables take comprehensively into consideration the differences in the behaviour of drivers, and therefore, also the probability of traffic accident occurrence. The output of the algorithm is a projection of the evaluation into the insurance premium. The proposed method uses the fuzzy-linguistic approximation apparatus, which is a suitable tool regarding the insufficient exact knowledge and a large amount of combinations of the input parameters. The values of the input parameters are substituted by setting up partial production functions and expert rules which suitably combine these functions. The process of the evaluation of the driving style was integrated into a comprehensive algorithmic procedure. In general, it is a set up of a sequence of specific steps leading to the evaluation of parts of a ride, on which basis the amount of the final payment is calculated.

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