CAR DRIVER BEHAVIOR DURING PRE-CRASH SITUATION: ANALYSIS WITH THE BCD MODEL

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ABSTRACT
Today, few data allow estimating the driver posture and movements during crash situation. These precious data could provide the possibility to define criteria to trigger driving assistance to control the vehicle in the case of active safety or to protect the driver in the case of passive safety. So we tried to link the different accidentology approaches by conducting a study about the feasibility to evaluate the behaviour of the driver during a pre-crash situation with a driving simulator.
The first experimental phase performed on a fixed-base driving simulator underlined the interest of the approach (Pacaux et al., 2010), so the second experiment was conducted with a strong experimental protocol and on a motion-base driving simulator. Participants drove during thirteen minutes on motorway and a-roads. At the end of the scenario, an unpredictable frontal collision with a truck was triggered.
First results stemming from second experiment reinforce results from the first one, i.e., all the drivers react faced with the accident. Even if drivers known that they are in a driving simulator, drivers tried to avoid the collision or to protect them.
In order to identify driver behaviour according to all the type of data we tried to use the so-called BCD model (i.e., Benefit/Cost/Deficit model) (Pacaux-Lemoine & Vanderhaegen, 2007). The objective of current analysis is the detection of a risky driving situation and the time of its occurrence in order to evaluate the possibility to trigger safety systems.

Keywords: Crash situation, Human-Machine System, BCD Model

INTRODUCTION

Attaining safety is one of the major issues for automobile design. Many studies deal with the communication between a driver and driver assistance systems to assist the driver in various situations including not only normal driving situations but also critical ones. Large improvement in active and passive safety technologies for vehicles has helped to reduce the number of accidents and the damage due to an accident significantly. Active safety systems work before a crash occurs and nowadays have preventive functions (e.g., Anti-lock Brake Systems, Electronic Stability Control systems, and Automatic Emergency Brake Systems etc.) to avoid a crash. Passive safety, on the other hand, concerns the period after the crash in order to protect occupants or to reduce the occupant injuries. Main examples of passive safety systems are airbags and seat-belts. These restraint systems are designed to minimize injuries

due to an impact by smoothly absorbing the kinetic energy of the occupant (Murad et al., 2008).
In order to quantify the efficiency of the passive safety systems, European normalised crash tests (European Commission, 1999) are performed with crash test dummies. The injury level is evaluated using specific criteria, such as the Head Injury Criteria (HIC) and the Thoracic Trauma Index (TTI), for each critical body segment. Precise rules are imposed by the European norm to position the dummy, whose posture must represent a seated and restrained driver. In particular, the hands of the driver are on the steering wheel and the superior part of the torso leans against the backseat. Thus, the tests of the passive systems efficiency does not take into account a large panel of driver anthropometries, the real comfort driving position and the real driver reactions facing a crash.
Currently, the configuration of passive restraint systems is almost universal (driver cushion inside the steering wheel, passenger airbag in the dashboard, side airbags in the seats, and curtains in the roof). This configuration is determined by the architecture of the cars but also by specific requirements in terms of time to position (TTP); very quick time for position side airbags due to late detection of side impact and proximity of the door; higher time for frontal airbags due to earlier detection of frontal impact, higher volume to inflate and risks of Out Of Position (OOP). Having detected the crash and triggered the Airbags earlier, Time To Position is no longer a determinant requirement for the design of the protection systems. In that case, the way to protect the occupants could be imagined completely differently. For instance, mixing the protection of a curtain and front and rear side airbags in a single airbag unit could lead to great savings in terms of number of generators, wiring, electronic equipment, and consequently savings in price and weight.
Recent publications mentioned the possibility to trigger Airbag units approximately 100 ms before a crash really occurs (Delange, 2007). Pre-crash detection will permit a slower inflation of the cushion thus preventing the risk of severe damage in the case of OOP situation (Hault et al., 2011). The main difficulty is to detect when the trigger operates. This paper proposes an attempt to detect pre-crash with the BCD model approach.

The BCD MODEL

The so-called BCD (Benefit/Cost/Deficit) model is based on indicators that assess the consequences of deviated human behaviours on several criteria related to technical or human performance or state (Vanderhaegen, 2004; 2010). These consequences can be positive or negative. Whatever a given deviated human behaviour status (i.e., intentional or unintentional deviations), the corresponding human action occurrence is supposed to be estimated by distinct consequences on several evaluation criteria:

- The benefits due to the success of the control of a given situation.
- The acceptable costs due to the cognitive or physical effort to control a given situation in order to make it successful.
- The unacceptable possible deficit related to the potential occurrence of a hazardous situation, in case of unsuccessful control of a given situation.

The BCD model requires several functions to identify the positive and negative consequences of a given human behaviour (Vanderhaegen et al., 2011). These functions are based on the gain and the loss and on the severities of the studied situations.
Let $s_i(a(t_a))$ be a real-valued function on severity of situation a at time t_a concerning a criterion i. When the severity, concerning the criterion i, of situation decreases as a result of the change of the situation from a to b, it is regarded as a gain, which is expressed by a logic function, denoted as $G_i(a,b)$:

$$G_i\,(a, b) \leftrightarrow (s_i\,(a(t_a\,)) > s_i\,(b(t_b\,))) \quad (1)$$

The severities, $s_i(a(t_a))$ and $s_i(b(t_b))$, can be acceptable or unacceptable. Such an acceptability of a given situation *a* is obtained by a logic function of tolerance denoted as $TOL_{X,i}\,(a)$, where *X* represents the point of view of a decision maker: a user or a designer of the system. Given a predefined threshold of acceptability, a situation is acceptable for *X* if its severity is less than or equal to the threshold; and it is unacceptable for *X* if the severity is greater than the threshold.

$$TOL_{X,\,i}\,(a) \leftrightarrow (s_i\,(a(t_a\,)) < \; TH_{X,\,i}) \quad (2)$$

When both the situations are acceptable, the corresponding decreasing of severity is called a benefit, noted $B_i\,(a, b)$:

$$B_i\,(a, b) \leftrightarrow G_i\,(a, b) \wedge (TOL_{X,\,i}\,(a) \wedge TOL_{X,\,i}\,(b)) \leftrightarrow G_i\,(a, b) \wedge TOL_{X,\,i}\,(a) \quad (3)$$

An increase of the severity of a situation *b* compared to the severity of the situation *a* is a loss denoted as $L_i\,(a, b)$:

$$L_i\,(a, b) \leftrightarrow (s_i\,(a(t_a\,)) < s_i\,(b(t_b\,))) \quad (4)$$

An acceptable increase of the severity is regarded as a cost, denoted as $C_i\,(a, b)$:

$$C_i\,(a, b) \leftrightarrow L_i\,(\mathrm{a, b}) \wedge (TOL_{X,\,i}\,(a) \wedge TOL_{X,\,i}\,(b\,)) \leftrightarrow L_i\,(a, b) \wedge TOL_{X,\,i}\,(b) \quad (5)$$

Such an acceptable cost implies that both situations can be acceptable even if there is a cost. An unacceptable increase of severity between two situations is called a deficit or a danger, denoted as $D_i\,(a, b)$. This deficit, $D_i\,(a, b)$, relates to the occurrence of an unacceptable situation *b* regarding an acceptable situation *a*:

$$D_i\,(a, b) \leftrightarrow L_i\,(a, b) \wedge (TOL_{X,\,i}\,(a) \wedge \neg TOL_{X,\,i}\,(b\,)) \leftrightarrow TOL_{X,\,i}\,(a) \wedge \neg TOL_{X,\,i}\,(b) \quad (6)$$

A deficit is potential in a sense that it relates to a possible occurrence of a future unacceptable situation.
The logic values of the B_i, C_i and D_i can be transformed into a numerical value given by the function $K_{J,\,i}\,(a,b)$:

$$K_{J,\,i}\,(a, b) = s_i\,(b(t_b\,)) - s_i\,(a(t_a\,)) \quad (7)$$

$$K_{J,i}\,(a,b) = \begin{cases} K_{B,i}\,(a,b)\; if\;\; B_i(a,b) \\ K_{C,i}\,(a,b)\; if\;\; C_i(a,b) \\ K_{D,i}\,(a,b)\; if\;\; D_i(a,b) \\ 0 \quad otherwise \end{cases} \quad (8)$$

Such a BCD model was applied to different domains:

- To analyse pre-crash of car driving situations (Robache et al., 2006; Pacaux and Vanderhaegen, 2007).
- To analyse railway barrier removals (Vanderhaegen et al., 2009; Zhang et al., 2004).

- To analyse car driving barrier removals (Vanderhaegen et al., 2011).
- To analyse competitive or cooperative activities (Vanderhaegen, et al., 2006).
- To analyse the resilience of a human-robot system (Zieba et al., 2011).

This BCD model was adapted in order to identify relationship between the occurrence of hazardous events and the associated human reactions regarding the evolution of the three parameters B, C and D.

ADAPTATION OF THE BCD MODEL FOR DYNAMIC CHANGE OF SITUATIONS

The new application of the BCD model concerns an iterative approach considering an initial situation as neutral, i.e. there is no benefit, cost or deficit and it is the normative situation, as shown in Table 1. The assessment of the BCD parameters can lead to different acceptability function (i.e., the $TOL_{X,i}$ function adapted for the B, C or D identification respectively). This study only took into account the point of view of the system designer.

Table 1 Adaptation of the BCD model

Criterion	Neutral values or intervals of neutrality	Acceptability values or intervals	Thresholds
1	Val_{min} or $[Val_{min}, Val_{max}]$	Rules for B_1, C_1 or D_1	TH_1
…	…	…	…
N	Val_{min} or $[Val_{min}, Val_{max}]$	Rules for B_N, C_N or D_N	TH_N

Table 1 is applied for dynamic change of situations and provided the table 2. But benefit equation had to be corrected according to the definition of benefit used il this study. If the situation s_k has a similar severity to s_0 benefit is true.

$$G_i\,(a, b) \leftrightarrow abs(s_i\,(a(t_a\,)) - s_i\,(b(t_b\,))) < \varepsilon \qquad (9)$$

The initial situation noted s_0 is then compared with another situation noted s_k. The space between [0, k] relates to an interval of time during which hazardous events may occur.

In this paper, two hazardous events are considered: a "pre-crash" event and a "near-accident" event. Several criteria are used for the identification of the BCD parameters during car driving situations. There are several criteria, such as driver workload, comfort, and safety, which are linked with data from the actions on the pedals or on the steering wheel or from the position or the state of the car. Acceptability functions are defined in order to identify the benefit, the cost or the deficit for each given criterion. Table 2 summarizes the criteria and thresholds for each one and for each BCD parameter.

The values of the BCD parameters for each criterion have been defined according to several hypotheses about driver behaviour. As the first step, the objective here is to investigate whether it is possible to characterise driving situation by using the BCD model. The threshold values are given subjectively on the basis of discussions among the authors. Of course there is no evidence that these thresholds stay available for every driver in every driving situation.
The first criterion is the force applied on the brake pedal. If the force is less than 1 N, it implies that the situation does not need to decrease the speed by braking at least in the simulator used in this study. The situation is thus considered comfortable for the driver and

the benefit, $B_1(s_0, s_k,)$, is identified as true (it is obvious that both condition s_0, and s_k, are acceptable for the driver). If the force is between 5 and 10 N, it could be said that the situation needs more attention because the driver has to control the speed according to a limit to respect or a vehicle to follow. So, for these brake pedal force values the cost is identified as true. The deficit is true when the severity of the situation considering the brake pedal force is over 100 N. The driver has to control an emergency situation with a heavy braking.

The second criterion is the moment applied on the steering wheel. The approach is similar to the first one. The benefit is true when the situation is comfortable and does not imply to exert a force on the steering wheel. The cost is true when the value of the moment is between 5 and 15 Nm. In this case, the situation is less comfortable and the driver has to apply a force because she/he is braking or changing seat posture. If the value is over 15 Nm the deficit is true, because the driver is controlling an emergency situation or has a bad posture.

The third criterion is the linear speed of the steering wheel. This criterion is representative of the capacity for the driver to anticipate the situation. If the movement of the steering wheel is slow and continuous, the situation is well controlled and the benefit should be set as true. If the speed increases the situation is considered less comfortable for the driver. In this case the cost should be true. When the value is over 1.5 m/s, it can be regarded that the driver has to avoid an obstacle and in this case the deficit is true.

The fourth criterion is the car speed. Only speed limits are taking into account. If the car speed is more than the authorized speed limit, the deficit is true.

The fifth criterion is the lateral position, i.e. the position of the car in the lane. If the car is more or less in the centre of the lane the benefit is true. If it is more near the centre line or the border line, the cost is true because driver needs to make attention to control the position. If one wheel of the car is on a line (on the right or on the left) the deficit is true. Driver risks to loose the control of the situation; another vehicle can appear on the other lane of the road or the car risks to loose road-holding.

The sixth and last criterion is the time between taking one's foot off the accelerator pedal and beginning of braking. When a driver needs to control an emergency situation, the movement from the accelerator to the brake pedal must be very quick. If the situation is comfortable, no braking is necessary, engine braking is sufficient, and the benefit is true. If the value of the criterion is between 0.5 s and 1 s, the cost is true. If the value is less than 0.5 s, the deficit is true.

Table 2 The criteria and their corresponding thresholds for each BCD parameter

Criterion (and units)	Neutral context s_0	BCD rule identification for s_k	Thresholds
1. Force applied on the brake pedal (N)	0	$B_1(s_0,s_k) \leftrightarrow 0 < s(s_k) \leq 1$ $C_1(s_0,s_k) \leftrightarrow 10 < s(s_k) \leq 100$ $D_1(s_0,s_k) \leftrightarrow s(s_k) > 100$	$TH_1 = 100$
2. Moment applied on the steering wheel (Nm)	0	$B_2(s_0,s_k) \leftrightarrow 0 < s(s_k) \leq 1$ $C_2(s_0,s_k) \leftrightarrow 5 < s(s_k) \leq 15$ $D_2(s_0,s_k) \leftrightarrow s(s_k) > 15$	$TH_2 = 15$
3. Speed of the steering wheel (m/s)	0	$B_3(s_0,s_k) \leftrightarrow 0 < s(s_k) \leq 0.1$ $C_3(s_0,s_k) \leftrightarrow 0.5 < s(s_k) \leq 1.5$ $D_3(s_0,s_k) \leftrightarrow s(s_k) > 1.5$	$TH_3 = 1.5$
4. Car speed (km/h)	$Speed_{limit}$ (50 km/h or 90 km/h)	$D_4(s_0,s_k) \leftrightarrow s(s_k) > Speed_{limit}$	$TH_4 = Speed_{limit}$
5. Distant from line crossing (m)	Centre of the lane (c)	$B_5(s_0,s_k) \leftrightarrow c - 0.5 \leq s(s_k) \leq c + 0.5$ $C_5(s_0,s_k) \leftrightarrow 0.8 < s(s_k) < c - 0.5$ or $c + 0.5 < s(s_k) < 2.7$ $D_5(s_0,s_k) \leftrightarrow s(s_k) \leq 0.8$ or $2.7 \leq s(s_k)$	$TH_{5\ max}=2.7$ $TH_{5\ min}=0.8$ $TOL_5(s_k) \leftrightarrow (s_5(s_k) < TH_{5\ max}$ or $s_5(s_k) > TH_{5\ min})$
6. Time to move from the accelerator pedal to the brake pedal (s)	0	$B_6(s_0,s_k) \leftrightarrow s(s_k) = 0$ $C_6(s_0,s_k) \leftrightarrow 0.5 \leq s(s_k) \leq 1$ $D_6(s_0,s_k) \leftrightarrow s(s_k) \leq 0.5$	$TH_6=0.5$ $TOL_6(s_k) \leftrightarrow (s_6(s_k) > TH_6)$

In order to evaluate these criteria, we conducted an experiment on a driving simulator. The BCD parameters of each criterion are extracted from the obtained data. This experiment is presented in the next part.

METHOD

Participants

39 participants with full French driving licences (i.e., not learners or restricted licences) were recruited from the students and the staff of the University of Valenciennes and the local region. All the participants have normal or corrected vision. The sample was composed of 28 men and 11 women, with an average age of 25.97 years, ranging in age from 18 to 52 years (S.D. = 8.28 years) and an average years of licensure of 7.89 years, ranging in years from several months to 29 years (S.D. = 7.23 years). The average yearly kilometres reported by the participants was 14930 km, ranging from 780 to 40000 km (S.D. = 10224).

Apparatus

The study was conducted using the University of Valenciennes' driving simulator called SHERPA (the French acronym for "*Simulateur Hybride d'Étude et de Recherche de PSA Peugeot Citroën pour l'Automobile*") (Figure 1), which is an interactive motion-base driving simulator with a complete Peugeot 206 car.
The driving simulator was positioned in front of three angled projection surfaces. The centre projection surface was located at 3.3 m in front of the driver with two peripheral surfaces connected to the central surface at 60° angles. The entire projection image was produced a 180° (horizontal) x 45° (vertical) forward view of the simulated road way from the driver's position at resolutions of 1280 pixels x 1024 pixels. This semicircular set up provides a realistic view of the road and the surrounding environment (Bella, 2005). The centre rear view

mirror and both wing mirrors were replaced with three small colour LCD screens (at resolutions of 800 pixels x 480 pixels). The update rate of these images was 60 Hz.
The control devices were the steering wheel, the manual gearbox, and pedals (brake, accelerator, and clutch) of the complete car. Speed and engine data were displayed on the vehicle's dashboard. The vehicle dynamic model was based on ARHMM (Advanced Road Handling Multi-body Model). The steering wheel featured force feedback. Speakers located inside the car and a sub-woofer in front of the car presented realistic engine and road noises, and speakers around the car created Doppler effects to represent crossing traffic. The driving simulator used the motion system, which was a 6 degree-of-freedom hexapod system.

Figure 1 Driving simulator of the University of Valenciennes

Simulation scenario

Participants were required to drive along a route of 50 kilometres, which took approximately 40 minutes to complete, depending on the participant's speed. The simulated road was composed of a motorway with a 130 km/h speed limit and a small number of slow-driving cars and trucks to overtake (13 vehicles for around 15 minutes), a secondary road with a 90 km/h speed limit, and a small village with a 50 km/h speed limit and a small number of on-coming vehicles (6 vehicles for around 10 minutes).
Two stressful situations were introduced: (1) a car cut in the participant's car on the motorway and a car jumped a stop at a crossroad on the secondary road ("stop situation"), and (2) at the end of the run an unavoidable crash situation occurred. At the second stressful situation, an approaching truck, followed by another truck, passed a tractor and came on the participant's lane ("pre-crash situation"). Trees along the road and the two trucks made the crash unavoidable (Figure 2). In order to increase the level of realism, an impact with a real block was added: At the moment of the virtual crash a block moves from the front of the car to the windscreen, a truck horn sound was emitted, and a "jump" was provided by the motion system.

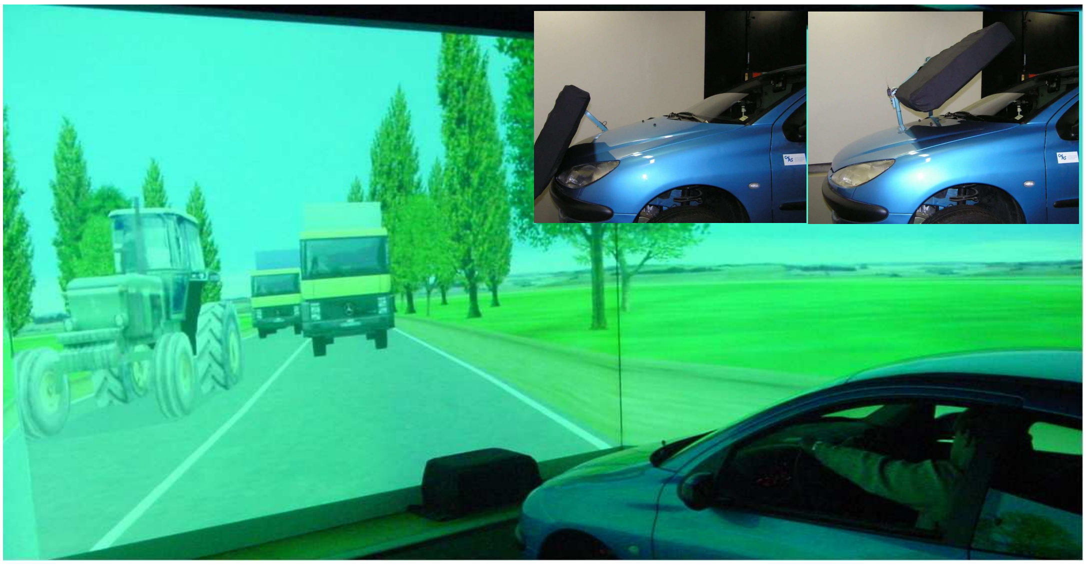

Figure 2 Scenario of the unavoidable crash situation; Sequence of the falling block on the windscreen

Collected data

For the driving simulator, objective parameters (e.g., relative position with respect of the road axis, speed and accelerations, steering wheel rotation angle, pedal positions) were recorded at a frequency of 60 Hz.
The videos of the front and back screen (Figure 3), as well as the driver views were recorded during the experiments. Spontaneous verbalizations of the participants were recorded as well.

Figure 3 Screenshots of recorded video information

Procedure

Each participant was tested individually. On arrival, they were briefed on the experimental requirements without mentioning the fact that an accident was planned at the end of the run. All read and signed an informed consent document and were asked to fill in the brief demographic questionnaire.
Next, the participants practised the various functions of the driving simulator and were allowed to familiarize themselves with the simulator (driving, feedbacks and virtual environment) under neutral conditions for 20 minutes.

After the practice drives, the participants were informed that they would be driving on highway and rural roads on which some disturbances might occur and that they could stop the experiment at any time. The general instructions were as follows: *“Please drive like you would drive in the same situation in the real world. Please, adapt your speed to the driving conditions”*.
At the end of the run, a method of self-observation reports was realized using the video record (self-confrontation), and participants filled out questionnaires evaluating their driving characteristics (behavior patterns) and their reaction to each separate situation.

RESULTS

Results stem from the analysis of data from driving data and biomechanical data for two driving situations. The first situation, called “stop” situation, consists in the crossing of a very small village with two intersections. The first intersection does not raise problem but the second one has a vehicle stopped at the stop line and this vehicle jumps the stop when the participant is arriving.
The “stop” situation is delimited by the curvilinear abscissa of the entry of the village and the one of the beginning of the second intersection of the village. The second situation is the “crash” situation presented in the simulation scenario part. The “crash” situation is delimited by the distance between the truck which begins to overtake the tractor and the participant’s vehicle and by the collision. Each section is divided into ten iterations. BCD parameters of each criterion are calculated for each iteration of each section for each driver. The first iteration corresponds to the beginning of the situation and the last one corresponds to the end of the situation, just before the potential collision. Complete results are obtained for 27 participants over 39 due to technical problems and the difficulty to have simultaneously biomechanical, physiological and behavioural data.
Next paragraphs present the results for each criterion.

Force applied on the brake pedal (N)

In both studied situations the brake pedal is not used to have a complete stop of the vehicle. It seems to be used to try to control the situation by a decrease of the speed and an action on the steering wheel. So the values observed are less important than the ones presented in the literature concerning emergency braking (Behr et al., 2011). For the last iteration, just before the crash, average value is 238 N and maximum is 550 N, while Behr et al. observed more than 800 N with results on the driving simulator. Results are presented on Figure 4. The figures indicate the number of participants with a benefit (yellow), a cost (blue) or a deficit (orange) for each iteration. Some participants brake at the entry of the village. These participants try to decrease the vehicle’s speed because it is over the authorized limit.
The reading of Figure 4 underlines that BCD parameters allow the detection of a risky situation from the iteration 8 for the “crash” situation and iteration 9 for the “stop” situation.

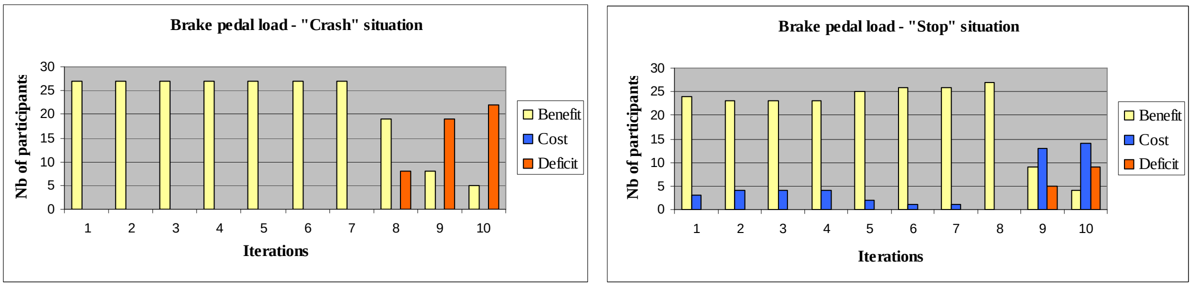

Figure 4 Brake pedal load for "crash" and "stop" situation

A deficit detected for one driver in one iteration was also detected in the following iterations. In other words, the drivers continued to brake until the end of the situation. So, the emergency of the "crash" situation was detected by the behaviour of 8 drivers from the iteration 8, 11 more drivers reacted at the iteration 9 and 3 more drivers reacted at the last iteration just before the crash. 22 participants over 27 allowed the detection of an emergency situation according the brake pedal use. The emergency of the "stop" situation was detected by the behaviour of 5 drivers from the iteration 9 and 4 more drivers at the last iteration. 9 participants over 27 allowed the detection of this situation.

Car speed (km/h)

The results stemming from car speed analysis underline that the speed just before the "crash" situation is generally respected (Figure 5). On the other hand, on the "stop" situation, for the crossing of the village, half of participants did not respect the speed limit. The majority of the participants who did not respect the speed limit did not try to reduce the speed by braking.
During the "crash" situation, all the participants who had a heavy braking also exceeded the speed limit.

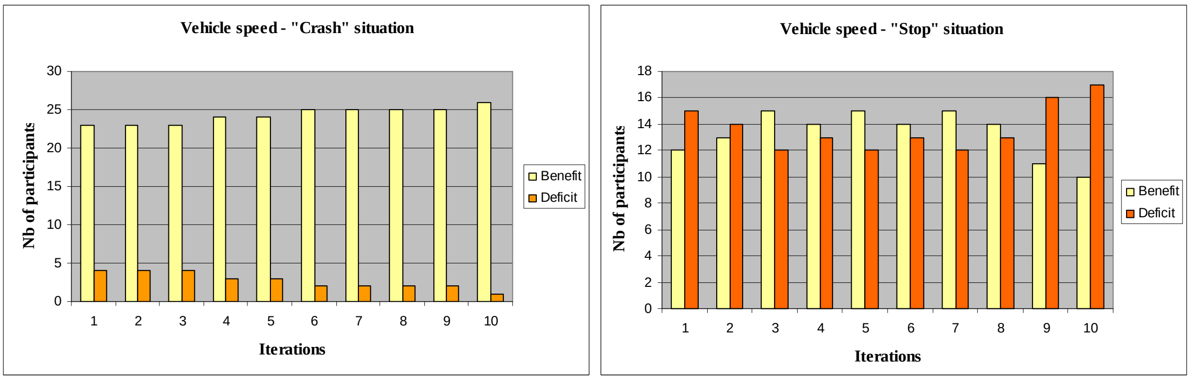

Figure 5 Car speed for "crash" and "stop" situation

Moment applied on the steering wheel (Nm)

This criterion allows knowing whether the participants push or pull the steering wheel. The number of detections is less important than for the brake pedal load but the trend is similar. The detection is more important for the "crash" situation than for the "stop" situation. The BCD parameter of this criterion is mainly benefit for the first 7 (8) iterations of the "crash" ("stop") situation, respectively (Figure 6).
Except for one participant, the drivers who pushed or pulled the steering wheel at one iteration continued the action at the next iteration(s). All participants who pushed or pulled the steering

wheel had also a hard braking on the pedal. On the other hand, all the participants who had a hard braking first did not push or pull the steering wheel.

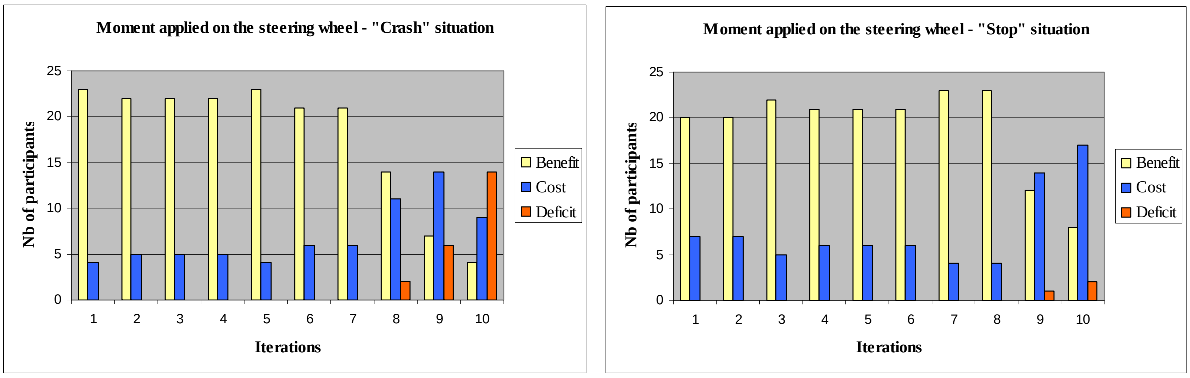

Figure 6 Moment on the steering wheel for “crash” and “stop” situation

Speed of the steering wheel (m/s)

This criterion provides another type of information concerning the use of the steering wheel. Because the participants can push or pull the steering wheel without turning it, it is interesting to look at its movement and in particular its speed. Results underline the same interest as the first two criteria, mainly for the “crash” situation (Figure 7).
All the participants tried to avoid the collision by turning the steering wheel, except two participants on the “stop” situation. The cost on the “crash” situation may be due to the curve of this situation.

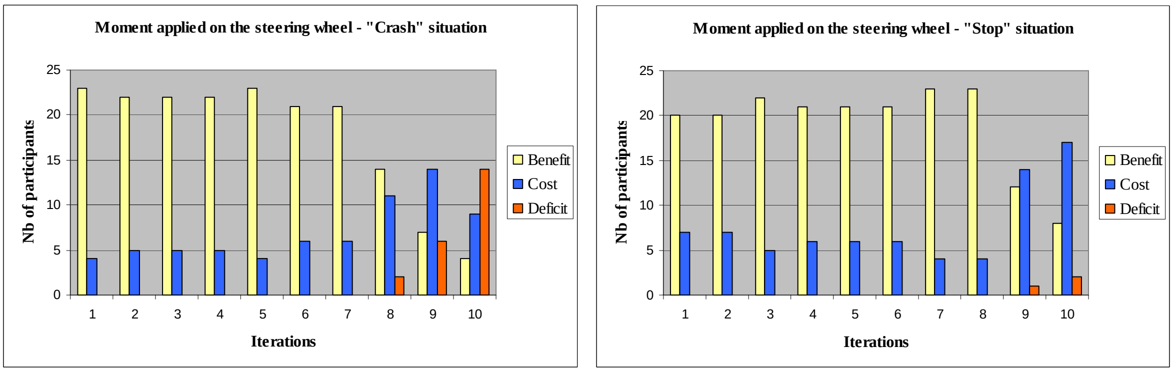

Figure 7 Speed of the steering wheel for “crash” and “stop” situation

Distance from line crossing (m)

Results stemming from the lateral position of the vehicle in the lane were less usable than the previous criteria. Concerning the “crash” situation the detection of a dangerous position is very late, on the last iteration; it is only for 7 participants over 27. Concerning the “stop” situation, the cost increases with the approach to both intersections (first intersection during the iterations 5 and 6; last intersection during the three last iterations).

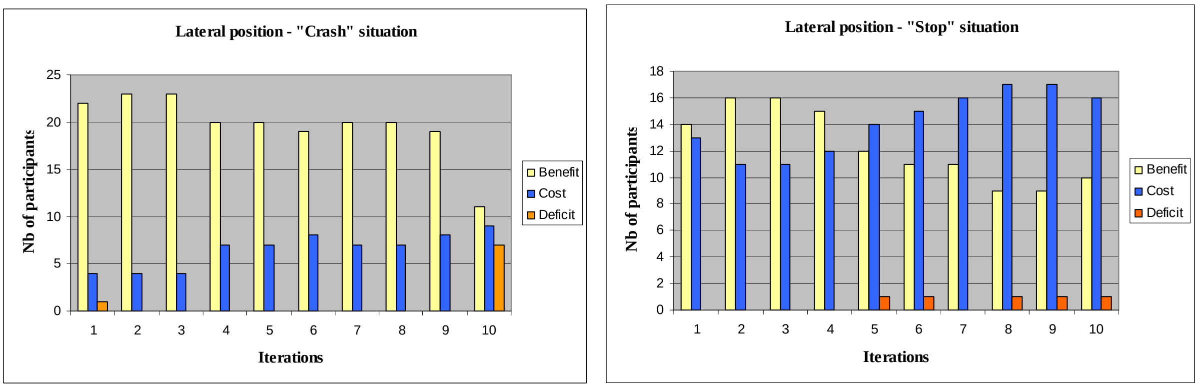

Figure 8 Distant from line crossing for “crash” and “stop” situation

Time to move from accelerator pedal to brake pedal (s)

This criterion could detect emergency situation but for few participants (7 over 27 participants) (Figure 9). The participants who changed the position of their foot very quickly were also on deficit for the brake pedal load and the steering wheel use.

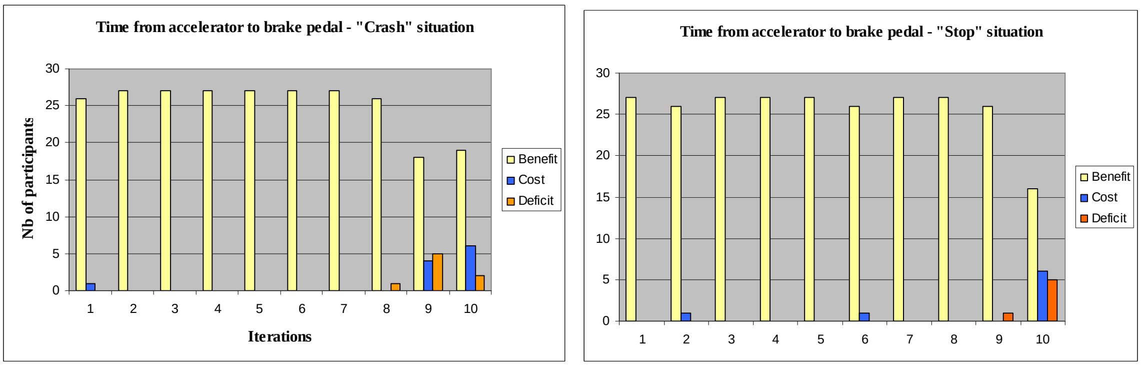

Figure 9 Time from accelerator pedal to brake pedal for “crash” and “stop” situation

Combination of criteria

In order to estimate the behaviour of the 27 participants according to the BCD parameters a score is calculated. The benefit parameter is multiplied by 1, the cost parameter is multiplied by 5 and the deficit parameter by 15. A score is calculated for each section in order to take into account driver’s behaviour. The more important the score of a participant is, the easier the possibility to detect an emergency situation is, and the driver could need to be assisted. Figure 10 presents the scores of each participant and it underlines some risky behaviours. “Stop” situation score is more important than the one of “crash” situation; it is mainly due to speed limit which is often not respected during the village crossing.
A risky behaviour observed for one driver on one situation is not always observed for the second situation. Several explanations can be provided. The degree of danger of both situations may not be evaluated in the same way by participant. “Stop” situation can be controlled and the crash can be avoided but not for the “crash” situation. The speed is also different, so BCD parameters of each situation do not evolved in the same way.

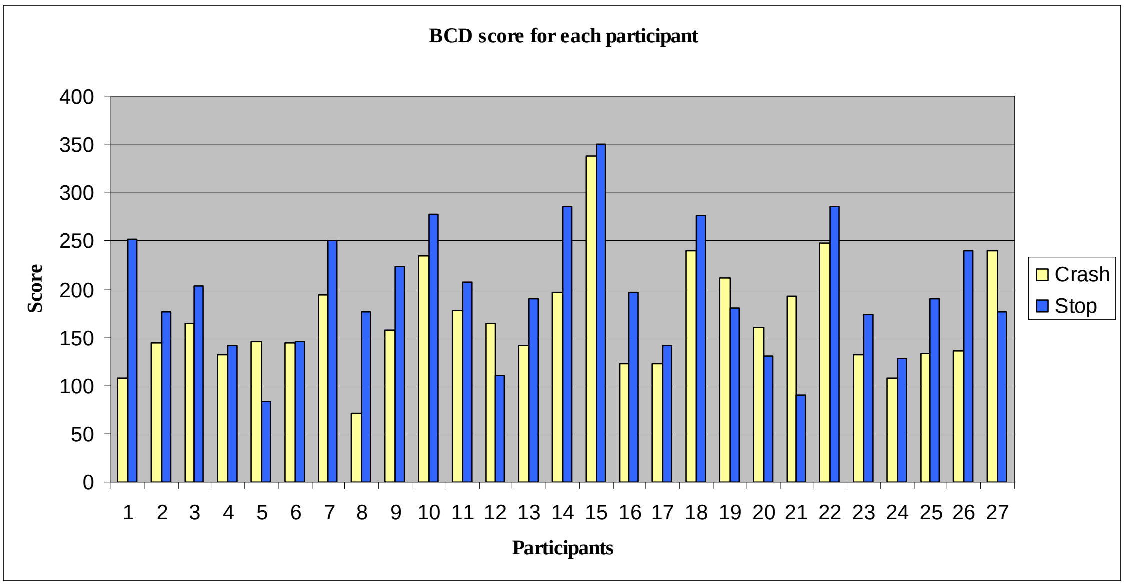

Figure 10 BCD score for each participant for “crash” and “stop” situation

Time to detect one deficit

It is the time of the first detection of one deficit among the criteria except speed limit. Speed limit criterion is not used because when it is not respected it is usually all along the situation. In other words, this criterion is mainly related to driving habit. Figure 11 underlines that for two participants on the “crash” situation and 8 participants on the “stop” situation, it is not possible to detect anything from deficit.

When one deficit is detected, the average time to detect emergency situation is 0.98 s for “crash” situation and 0.83 s for “stop” situation.

A combination of the five criteria may reinforce the validity of the emergency situation detection, but may delay the time of detection.

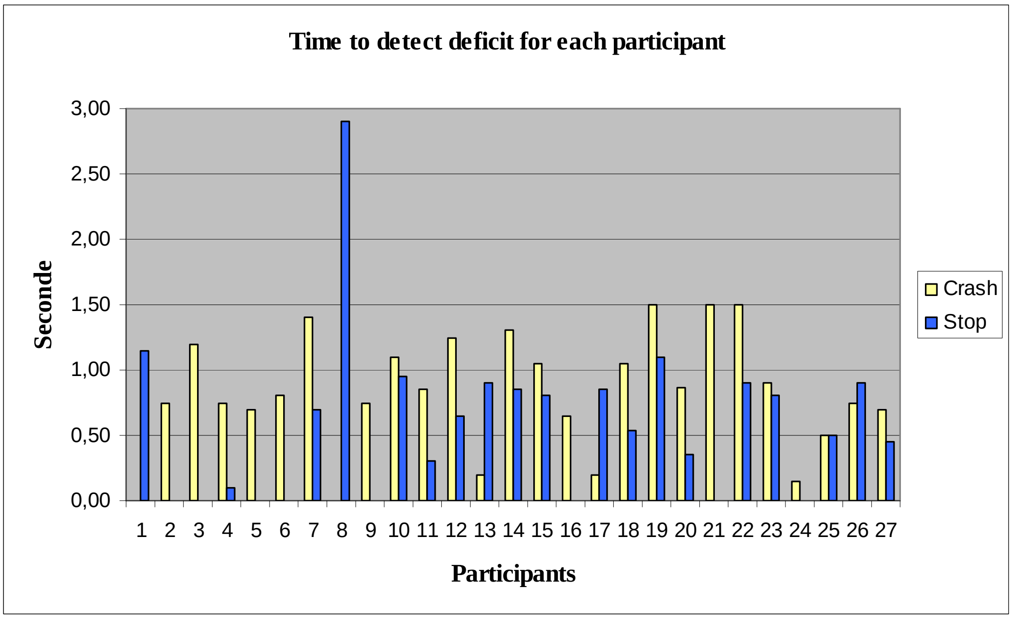

Figure 11 Time from the detection of one deficit to the end of the situation for each participant

CONCLUSION AND PERSPECTIVE

This paper highlighted the interest to use the BCD model to detect emergency situations for an important number of drivers. The brake pedal load, the moment applied on the steering wheel, the steering wheel speed, the lateral position and the time between acceleration and brake pedal appeared to be good criteria and this BCD approach allows reaching a good synthesis of behaviour in order to detect emergency situation. Nevertheless it would be interesting to define thresholds for each criterion for each driver according to what a driver thinks about her/his driving behaviour and on-line or off-line BCD parameters thresholds identification from driving. A cumulative control of BCD parameters could be this time preferable (Pacaux and Vanderhaegen, 2007).

More analysis has to be conducted. In order to know participants' driving habit a score could be calculated according to their answer to some questions. More this score would be important more the declared behaviour would be aggressive, nervous, risky and with little taking account of the traffic. It is also necessary to add the analysis of the driver's behaviour during "normal" driving situation, i.e. situations with no unexpected driving event. For Darby et al. (2009), attitude, behaviour, knowledge and hazard perception are highly correlated with self-reported collisions. Future analysis will verify this result by finding correlation between the declared driving habit and the observed behaviour analyzed with the BCD model during normal driving situation. If correlation is found, it will be able to search threshold for each driver in order to adjust the detection of emergency situation. If no correlation is found, it would be due to an intentional or unintentional wrong answer to questionnaire. However, it would be also due to a lack of familiarity with the driving simulator or experimental vehicle. In this case drivers cannot adopt the same behaviour as with their own vehicle. Another possibility of the lack of correlation would be the heterogeneity of participants' behaviour. In fact, one result of the studies of Behr et al. (2010) is that the behaviour of participants in real vehicle tests appeared much more homogeneous than in a driving simulator, and braking strategy is different.

This approach, with qualitative and quantitative data analysed by BCD model, supposes that drivers accept to provide information concerning their driving habit. However, if drivers want to buy an efficient system to protect them, perhaps they can be prompt to accept. So, embedded systems could perform the detection of emergency situation according to driver behaviour and communicate with other embedded systems dedicated to driving environment analysis such as traffic detection and analysis (radar or other systems able to have information about surrounding traffic). Such fusion of data could lead to trigger safety system.

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REFERENCES

Behr, M., Poumarat, G., Serre, T., Arnoux, P.-J., Thollon, L., Brunet, C. (2010). "Posture and muscular behaviour in emergency braking: an experimental approach". *Accident Analysis and Prevention*, Vol. 42, 797-801.

Darby, P., Murray, W., Raeside, R. (2009). "Applying online driver assessment to help identify, target and reduce occupational road safety risks". *Safety Science*, Vol. 47, 436-442.

De Lange, R., Tandler, J., (2007). "Intelligent safety systems integrating active and passive safety". *Proceedings of the IRCOBI Conference,* Maastricht, The Netherlands, 2007.

European Commission, Directive 1999/98/CE, du 15 décembre 1999, portant adaptation au progrès technique de la directive 96/79/CE du Parlement européen et du Conseil concernant la protection des occupants des véhicules à moteur en cas de collision frontale.

Hault-dubrulle A., Robache F., Pacaux-lemoine M.-P., Morvan H. (2011). "Determination of pre-impact occupant postures and analysis of consequences on injury outcome. Part I: A driving simulator study". *Accident Analysis & Prevention*, Vol. 43, Issue 1, 66-74.

Hault-dubrulle, A., Robache, F., Drazetic, P., Guillemot, H., Morvan, H. (2011). "Determination of pre-impact occupant postures and analysis of consequences on injury outcome. Part II: Biomechanical study", *Accident Analysis & Prevention*, Volume 43, Issue 1, January 2011, 75-81.

Murad, K., Cheok, C., Das, M. (2008). "The Use of Fuzzy Logic Techniques in the Real Time Control of Adaptive Restraint Systems". *Proceedings of the Americas 8th madymo users' meeting*, april 16, 2008.

Pacaux-Lemoine, M.-P. and Vanderhaegen, F. (2007). "BCD model for human state identification". *Proceedings of the 10th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems*, Seoul, Korea, September.

Robache, F., Morvan, H., Polet, P., Pacaux-Lemoine, M.-P., Vanderhaegen, F., (2006). "The BCD model for biomechanical application". *Proceedings of the 25th European Annual Conference on Human Decision Making and Manual Control*, EAM'06. Valenciennes, France, 27-29 september 2006. ValenSciences, PUV : Valenciennes. ISBN 2-905725-87-7

Vanderhaegen, F. (2004). "The Benefit-Cost-Deficit (BCD) model for human analysis and control". *Proceedings of the 9th IFAC/IFORS/IEA symposium on Analysis, Design, and Evaluation of Human-Machine Systems*, Atlanta, GA, USA, 7-9 September 2004.

Vanderhaegen F., Chalmé S., Anceaux F., Millot P. (2006). "Principles of cooperation and competition: application to car driver behavior analysis". *Cognition Technology & Work,* 8(3), 183–192.

Vanderhaegen, F., Polet, P., Zieba, S. (2009). "A reinforced iterative formalism to learn from human errors and uncertainty". *Engineering Applications and Artificial Intelligence*, 22, 654-659.

Vanderhaegen, F., Zieba, S., Enjalbert, S., Polet, P. (2011). "A Benefit/Cost/Deficit (BCD) model for learning from human errors". *Reliability Engineering and System Safety*, vol. 96, 757-766.

Vanderhaegen, F. (2010). "Human-error-based design of barriers and analysis of their uses". Cognition, Technology & Work, 12, 2, 133-142.

Zhang, Z., Polet, P., Vanderhaegen, F. and Millot, P. (2004). “Artificial neural network for violation analysis”. *Reliability Engineering and System Safety*, vol. 84, n°1, pp. 3-18.

Zieba, S., Polet, P., Vanderhaegen, F. (2011). “Using adjustable autonomy and human–machine cooperation to make a human–machine system resilient: Application to a ground robotic system”. *Information Sciences*, 181, 379–397.