# THE BCD MODEL FOR BIOMECHANICAL APPLICATION

**F. Robache*, H. Morvan*,**
**P. Polet**, M.-P. Pacaux-Lemoine**, F. Vanderhaegen****
* LAMIH- Human-machine Systems Team
** LAMIH – Biomechanical Team
UVHC – UMR CNRS 8530 – LE MONT HOUY
59313 Valenciennes Cedex 9 – France
email : {frederic.robache; herve.morvan; ppolet;marie-pierre.lemoine ; vanderhaegen}@univ-valenciennes.fr

Abstract

*For years, automotive engineers have been working to improve vehicle safety by using dummies, human corpses and animals to test safety systems. However, in most cases, crash tests do not consider drivers differences, much less their reactions. In reality, no one can make real crash tests with living drivers.*

*Current approach is to simulate crashes using a driving simulator to analyze driver's behaviour, especially before and during a crash incident. A campaign was organized on a static simulator, during which 40 subjects were asked to drive a 50-kilometer runway and finally were exposed to a virtual crash.*

*Some driver pre-crash positions are analysed with numerical simulations, reproducing the situation of a head-on collision at about 50km/h. The results of runs highlight critical situations which could lead to serious injuries.*

*Designers provide their car with protective barriers. These barriers are efficient if some postural condition are respected.*

*This paper describes most particularly how we used a BCD approach to understand why drivers land up in critical position at the time of pre-crash. The goal of this study is to purpose a framework in order to describe and analyse the consequences of a deviated behaviour faced protective barriers such as air bag.*

**Keywords** : Biomechanics, BCD model, Safety, Car driver, Crash

## 1 Introduction

The BCD approach was initially based on indicators that assess the consequences of deviated human behaviours on several criteria. These consequences can be positive or negative. Positive ones are benefits whereas negative ones are acceptable costs when the undesirable events are under control or deficits when they are over control. In other words, a cost is an acceptable negative consequence when the human behaviour is successful and a deficit is an unacceptable consequence when this behaviour leads to a undesirable event such as an accident. Therefore, whatever the deviated human behaviour status (i.e. intentional or unintentional deviations), the corresponding human action occurrence is supposed to be assessable by three distinct consequences on several evaluation criteria (Polet et al, 2002):

- The acceptable costs due to the success of a deviated use or a creation of a defence.
- The expected benefits due to the success of a deviated use or a creation of a defence.
- The unacceptable possible deficit related to the potential occurrence of a hazardous situation, in case of unsuccessful deviated behaviour due to the occurrence of uncontrolled events.

This BCD approach was validated to study particular violations called barrier removals. It was extended in order to explain not only intentional human errors but also non-intentional ones (Vanderhaegen, 2004). This paper aims at using this BCD approach in order to define a biomechanical model of a car driver when facing a crash.

## 2 The BCD approach applied for biomechanical study

This study aims at building a biomechanical model of the car driver facing a crash and to describe human behaviour during the pre-crash situation. The environment of the car driver is composed into two main constraints: the external constraints related to the road traffic, the infrastructure and the road rules, and the internal constraints regarding the possible interactions inside the car, i.e. interactions with doors, seats, pedals, steering wheel, gear stick, etc. (Cf. Figure 1). The modelling consists in taking into account all these constraints and to study the impact of human behaviour considering criteria such as workload (i.e., facility of access, number of actions, time consuming, etc.), safety (i.e. crash), or comfort (i.e., well-being). In order to assess the BCD parameters for these criteria, a reference model is required. For this study, the model related to the optimal efficiency of an air bag when activating is taken, i.e.:

- the position of the hands: they have to be at the so-called 10 past 10 position.
- the position of the head: it has to be in a straight position and to face the air bag by watching the road.
- the position of the body: it has to be in a straight position on the driver's seat.

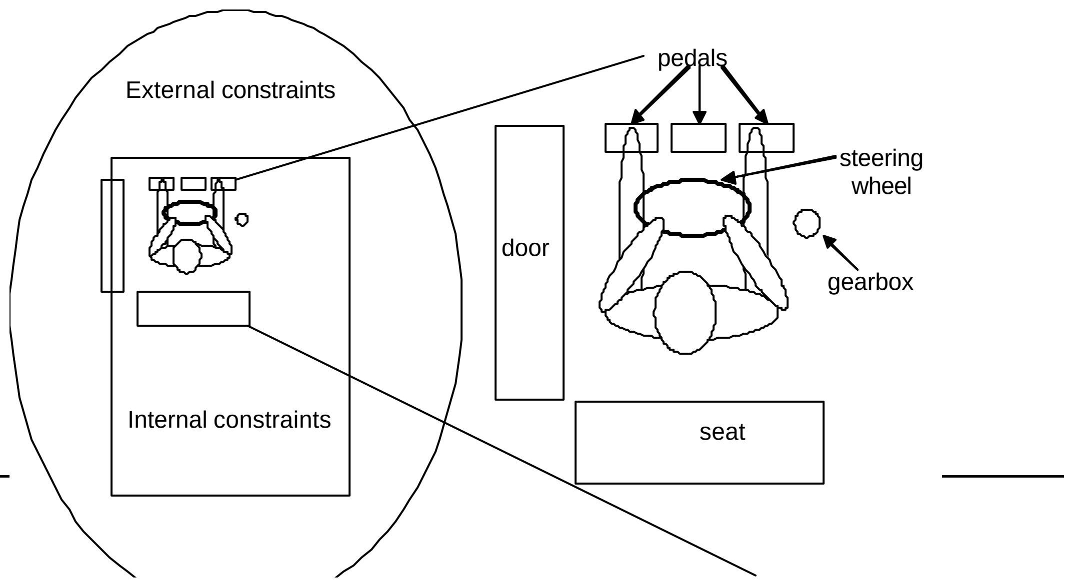

Figure 1. External and internal constraints of a car driver.

Regarding this reference model, benefits, costs and potential deficits can then be assessed in order to describe different human behaviours inside the car and to study the impact of human position when facing a crash and when interacting with barriers that are supposed to protect him from the occurrence or the consequences of hazards. This explanation aims at refining the barrier design or proposing on-board efficient assistant tool in order to reduce risks intuitively taken by the car drivers.

## 3 The experimental protocol

Experiments were made on the driving simulator of the University of Valenciennes by 40 subjects who drove in a realistic scenario of about 50 km including urban areas and motorway sections (Pacaux-Lemoine et al., 2006). In the course of each simulation, an unavoidable crash situation was introduced. A truck pass a tractor, heading straight towards the subject vehicle. The presence of trees along the side of the road coupled with the trucks makes the crash unavoidable, Figure 2.

The recorded data were (1) objective measures related to the driver behaviors (e.g., braking actions, gearbox position, steering wheel position, speed, etc.), (2) driver characteristics such as the driving attitudes, physical data and (3) video and audio data.

a) Pre-crash simulation: a face-to-face collision

b) Impact simulation

Figure 2. Pre-crash and crash simulations

## 4 Preliminary analysis

Four criteria are used to analyse the results concerning consequences of the human behaviour during the pre-crash: the comfort (i.e. feeling of well-being), the facility of access, the number of actions and the safety (i.e. consequences of the air bag activation). In order to compare the observed human behaviour when facing a crash, a virtual air bag was activated applying the physiological and physical data of each driver and considering the crash was not avoided (Hetier et al., 2005). Potential deficit is then identified and the benefits and the costs are determined comparing the observed and referred positions of the hands, the head, the body and the car.

The aim of the BCD approach is to describe and analyse the consequences of a deviated behaviour. The experimental study gives us the behaviour of driver just before the pre-crash and the behaviour at the pre-crash instant. The air-bag is an efficient protection if some conditions are respected. These conditions are usually given by the regulation authorities. For instance, in France, drivers are trained to adopt the 10 past 10 position for hands on the wheel.

### 4.1 Position before pre-crash

The majority of drivers did not respect the recommended « 10 past 10 » hands' position. The table 1 gives examples of positions adopted by drivers.

Table 1 : class of drivers' position before pre-crash.

| **class of driver** | **right hand position** | **left hand position** | **benefit** | **cost** | **potential deficit** |
|---|---|---|---|---|---|
| **class 1** | on the gearstick | ~10 hours on the wheel | comfortable position facilitate the gear shift | reduce the maneuverability of the vehicle | difficulty to avoid an obstacle |
| **class 2** | inside the wheela | t ~6 hours | comfortable position | reduce the maneuverability of the vehicle | difficulty to avoid an obstacle<br><br>potential injuries if the airbag is deployed |
| **class 3** | on the middle of the wheel | on the leg | comfortable position | maneuvrability very low | difficulty to avoid an obstacle<br><br>potential injuries if the airbag is deployed |
| **class 4** | at ~10 minutes | at ~10 hours | | | |

The main class is the first one. Drivers of these class adopted a comfortable position. At this moment they drove during 30 minutes (20 minutes on highway). The maneuvrability is reduced with this position of hands. But this cost is not so high because they drove on a main road (not in town).
For the second and third class of drivers, the situation is more complex : the maneuvrability is high reduced and these position may lead to injuries (at hands and arms) if the airbag is deployed.

Only one driver adopted the recommended position (class 4).

## 4.2 Behaviours at pre-crash

Regarding the head movement of head drivers we observe that 80% driver moved their head on backward. This movement reduce the efficiency of the airbag. The head, in this case arrive on the airbag in late. It is difficult to explain formally this behaviour, which is more a « reflex » than a thought behaviour. The benefit for driver is certainly to avoid damage due to the crash and to protect their head.
60% of drivers leant them self their body in the right. The behaviour, also reduce the efficiency of the air bag protection. The benefit is certainly to have the feeling to protect them self from damage of the wind shield.

The majority of drivers of first class put they right hand on the wheel quickly. But some drivers lead their left hand on the right side of the wheel. This behaviour may lea some injuries at the face if the air bag is deployed.
Some drivers of second and third classes arrived in problematic situation. Some of them had their hand blocked inside the wheel. If the air bag is deployed at this instant, their hand may be injured.

## 4.3 behaviours before and during pre-crash

This preliminary analysis highlights some difficulties to make a barrier such as the air bag efficient. This barrier is efficient only if condition of use are respected. These conditions concern positions during normal driving and at the crash instant. The study shows how drivers deviate they hands position from recommended ones. These deviations may lead to dangerous situation at the crash instant.
Two ways are possible to avoid these situation. The first one concerns the protective barriers design. Designers may enlarge the acceptable positions set in order to take into account effective driver's position. But this way is not so easy to take. The second way is to find another means in order to avoid dangerous positions of drivers.
An analysis in depth of drivers behaviour have to be done in order to evaluate formally why they adopt some dangerous positions. The BCD approach can be a tool for this analysis.

## 5 Conclusion and perspectives

This study has developed a framework for a biomechanical model using the BCD approach. This framework is useful to build a database describing the human behaviour facing a particular event such as a crash and to support the car designer when specifying safety barriers.

Usually a barrier is design to protect the human operator. The efficiency of the barrier is guaranteed by the respect of some conditions of use. This study highlights this problem.

In order to avoid miss-use of barriers some another barriers have to be place. Barriers have to be the center of the global design of the system. Some equipment may be designed in order to oblige the drive to adopt the correct behaviour. For instance some safety belt may be deigned in order to avoid the driver lean on right side in case of crash. But these new barriers have to be accepted by drivers. Else, these barriers may be "crossed" or inhibited.

## 6 Acknowledgements

The present research work has been supported by Science and Technology for Safety in Transportation, the European Community, the Délégation Régionale à la Recherche et à la Technologie, the Ministère Délégué à l'Enseignement Supérieur et à la Recherche, the Région Nord Pas de Calais and the Centre National de la Recherche Scientifique : the authors gratefully acknowledge the support of these institutions.

## 7 References

Hetier, H., Robache, F., Autuori, B., Wang, X., Morvan, H. (2005). Experimental investigation and modeling of driver's frontal pre-crash postural anticipation. SAE 2005 Transactions Journal of Passengers Cars – Mechanical Systems, Paper No 2005-01-2684.

Polet, P., Vanderhaegen, F., Wieringa, P.,(2002). Theory of safety related violation of system barriers. Cognition Technology & Work, 4, 3, 171-179.

Vanderhaegen, F. (2004). The Benefit-Cost-Deficit (BCD) model for human error analysis and control. 9th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design and Evaluation of Man-Machine Systems, 7-9 September 2004, Atlanta, USA.

Pacaux-Lemoine, M.-P., Morvan, H., Robache, F., Drazetic, P. (2006). Towards an attempt to understand the transition period from active to passive safety. IFAC2006 – Helsinki, Finland