

A PARADIGM CHANGE IN ROAD SAFETY EVALUATION: FROM HYPOTHETICO-DEDUCTIVE TESTING TO DESIGNING SAFETY SYSTEMS

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ABSTRACT

The automotive industry is going through immense changes. For the rapidly changing technologies and the forthcoming intelligent vehicles, evaluation of road safety is of renewed importance. The traditional evaluation paradigm is centered on a passive safety paradigm and stabilized evaluation routines. However, safety technology is changing with cars becoming capable of communication with other cars and the infrastructure. This implies a move towards a pro-active approach for avoiding accidents. In this work, we argue that, given these changes, road safety evaluators should be involved with the design of those systems. We defend that that the current trends towards an hypothetico-deductive approach extending the traditional paradigm of safety evaluation is insufficient and there is a need for a more holistic approach: road safety system evaluators need to become co-designers of safety systems, providing inputs to the system designers, while, in turn, they build a new generation of evaluation models and practices. The proposed principles are illustrated with examples on lane keeping assistant system and the analysis of a low-friction system design.

Keywords: road safety, safety evaluation, safety system design, evaluation model design

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1 INTRODUCTION

Road safety is a major concern at the international level. According to the WHO (Peden, 2004),(World Health Organization, 2004), 1.2 million people in the world die each year because of road crashes. Built on a 40 year old practice started in the late 60s, evaluation of road safety seems a well-established, routine practice, with well-known methods and generally accepted norms (Got, 2011). This has led to the creation independent and expert structures like the LAB (Laboratory of Accidentology and Biomechanics) – a laboratory co-owned by Renault and Citroën – where evaluation of safety performance of cars can be carried out independently from the internal processes of the car manufacturer (LAB, 2011).

However, automotive industry is seeing major evolutions: energy crisis, sustainable development challenges, global competition, electrical propulsion, assistive technologies, car to car (C2C) and car to infrastructure (C2I) possibilities. These new technologies, inside or outside the car, is equivalent to a change in the evaluation paradigm. Indeed, methods that exclude driver's behavior and environment are no longer sufficient for proper and accurate evaluation even though the usual methods are still valid at some point.

In design terms, the identity of the object "car" is no longer stable as we are on the frontier of breaking a well-established dominant design – that has not seen major changes for decades. This changes inevitably affects the organization of an entire ecosystem of transportation, including the safety evaluation practices and organizations.

When an object's identity is stable (design completed), its evaluation modalities are also stabilized. The purpose and the intended functionalities of the object are known thus what needs to be evaluated is clear. When the identity becomes subject to change, the evaluation modalities need to be redesigned according to the newly emergent forms. Since automobiles' identity is strongly questioned and subject to evolutions, the classical schemas for the evaluation of its performances (e.g. about safety) need to be reconsidered and redesigned jointly.

The eco-system of road safety evaluation, either not realizing the nature of this shift or lacking adapted theoretical lenses to recognize its properties, tends to adopt a hypothetico-deductive stance for the evaluation of emerging technologies. The efforts are concentrated on *what can be measured* instead of *what does a particular road security issue imply* and how evaluators can help with it (Fricheteau, 2011).

The paper proposes that the hypothetico-deductive stance is inadequate and proposes instead a conceptive perspective where the road safety question is seen as a part of a larger design issue, and evaluation models adapted to specific variants (i.e. technological or experimental) need to be designed using appropriate design approaches.

We propose that actors, such as the LAB, responsible for the evaluation of safety aspects need to carry out additional responsibilities within the new context and to actively participate to the design of road safety systems – providing input and expertise to the system designers (such as the car manufacturers) early on: they need to become **designer of safety evaluation models** and they can no longer hold onto an evaluator position solely. These propositions are fundamentally new for the road safety evaluation field and illustrate the contribution design methods and approaches can have in this domain.

Plan of the paper: In section 2, we review shortly, traditional car safety paradigm and current evolutions in the automotive industry. Section 3 presents current philosophies and approaches to safety evaluation. We argue that the most widely used techniques are black-box approaches and give two examples (for a priori and a posteriori evaluations). In section 4, we present two fundamentally new approaches to extend the role of evaluation expert's role in the car safety eco-system. First method is a functional evaluation approach where evaluators can provide inputs during design of safety system based on the features of different candidate technologies and their match with the safety issue being handled. Second method is the use of a formal design theory in order to map out different road safety scenarios related to a particular safety concern (e.g. road adherence, low friction) and the potential evaluation methods for each. Section 5 concludes with a short discussion.

2 STRONG EVOLUTION OF AUTOMOTIVE INDUSTRY: IMPLIED CHANGES FOR THE EVALUATION OF SAFETY

2.1 Traditional vision of safety: within the confines of a dominant design



Figure 1. Evolution of car's in-depth accident analysis (65km/h) – Driver dead, injured and finally intact (Labrousse et al, 2011).

The car industry provides the archetypical example of what is often called a *dominant design* (Abernathy & Utterback, 1978). Its main features such as the generic architecture is generally accepted as the best possible combination that maximizes the objects utility and purpose. In such situations, an objects identity is stabilized i.e. its functional design, conceptual models and associated business models do not see major changes over several development episodes (Le Masson, et al., 2006).

When languages and parameter spaces for describing an object are stable, design follows a logic of optimization of the current sets of design parameters to achieve maximal performances within the confined description space of the object – including its performance criteria.

One of the key performance criteria for a car is safety of passengers. As figure 1 shows, this has been a major issue where significant progresses have been achieved over the years. Choice and improvement of materials, numerous additional safety systems (airbag, safety belt, etc.) have been introduced without changing the general architecture and disposition of a car.

Following this logic, where design efforts have been extensively focused on the optimization of the existing systems and definitions, the evaluation of road safety of a car has not seen brutal changes. The major criteria to be considered were the number of dead and injured people in the accidents, depending on the existence (or not) of a given safety system among cars involved in an accident (more details on section 3). Note that this procedure is often an *a posteriori* evaluation procedure. With the current interest in intelligent vehicles and assistive technologies, globally, car manufacturers became more interested in developing safety systems that would rather prevent an accident from happening. How to evaluate accidents that have never occurred? – Such is the question that points to significant changes in the current road safety evaluation paradigm, since it is needed to move beyond the passive security paradigm to a more proactive one; Figure 3.

2.2 From isolated cars to communicating cars

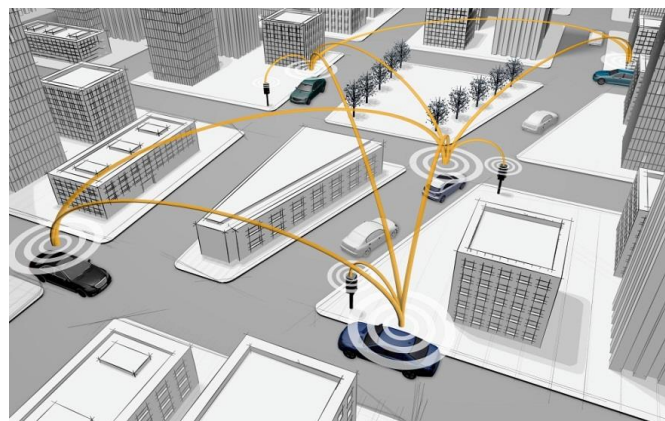


Figure 2. Communicating cars – C2C, car to car and C2I, Car to infrastructure communication

Automotive industry is going through tremendous change. The return of the electrical vehicles (Mock et al, 2009) and the efforts to better integrate the car to the city for sustainability is causing rapid and successive changes in major design parameters. Technical changes imposed by economic and sustainability issues create a favorable environment for embedding more intelligent technologies in cars as well. Years of research in automated or assistive technologies on intelligent transportation systems are being industrialized one by one. The trend will be only accelerated with the upcoming 3rd generation electrical vehicles.

Followed by these technological changes the evaluation models associated with the car need also changing. The expected performances are not the same, for instance, for a thermic engine or an electric one. To give an example, in case of a crash, an issue to be resolved with thermic engine is fire and explosion risks. For an electrical engine, spill out of dangerous chemical substances is one of the main issues (Hervé et al., 2011). While both objects can be classified as cars, significant differences among them imply differences in norms and performance metrics to be used for evaluation purposes.

With C2X (Car to Car or Car to Infrastructure communication; see Figure 2) new and previously unsuspected safety issues arise. For instance, in a setting where cars can handle most of the driving (at least in particular conditions, such as restricted zones for that purpose), despite all the planning power available to the system, unexpected situations can occur (e.g. unauthorized entry to the zone) where neither the driver, nor the car can take appropriate action in time. Current evaluation practices, tailored rather for the optimization of a unique vehicle's performances as explained in section 2.1, are not adapted for the evaluation of a scenario where the infrastructure and vehicles might and will communicate and coordinate. New evaluation models and practices for a setting whom parameters are yet to be decided need to be constructed. Among other things, this implies that in addition to their roles of evaluator (in the traditional sense), structures like the LAB need to become designers of evaluation models (Fricheteau, 2011).

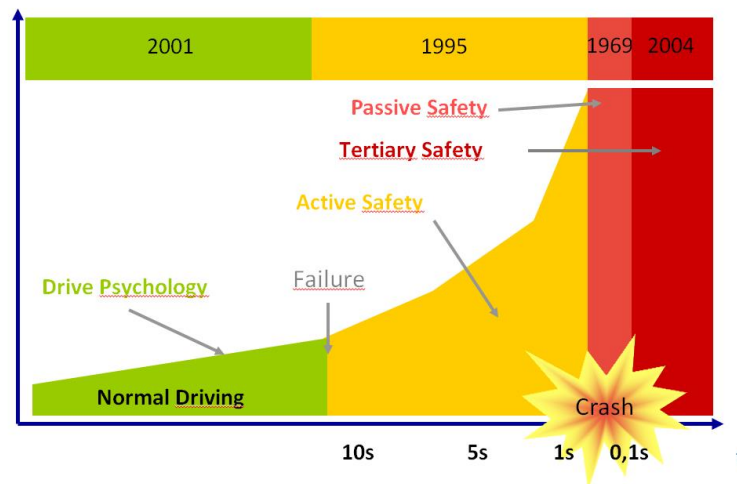


Figure 3. Shift of the foci of road safety systems study over the years.

3 APPROACHES TO SAFETY EVALUATION

3.1 Traditional approaches: Experimental and epidemiologic evaluations

With respect to the safety paradigm presented in section 2.1, a major approach in the evaluation of safety is the classical scientific experimental setting. It consists in conducting a controlled experiment with a well defined experimental plan, defined and isolated variables, devices for measuring and synthesis of results. This process has all the expected advantages of classical scientific methods (controllability, repeatability, etc.). This type of experiences is justified by the need to have accurate information on the driving behaviors and thus for being able to evaluate performances of primary security systems. This practice has limits when it comes to communicating vehicles. In US, recent studies conducted by Michigan University (Michigan University, 2012) involved 25 vehicles within a 50km² surface where collecting data in a controlled environment proved to be difficult. Facing such challenges, another approach called epidemiologic evaluation is often envisaged. Vehicles, driven by drivers specifically chosen (e.g. for their driving style), are equipped with various sorts of data

gathering devices. The aim is to gather data in a realistic and naturalistic setting. This approach has the advantage of gathering enormous quantities of data. The downside is that it is difficult to know how to process all these data and also to what end. For instance, the vehicle can be observed as slowing down, but the reasons for such behavior are multiples and they can be combines: rain, other vehicles stopping, traffic...

This contrast between experimental and naturalistic evaluations points to the real challenges of traditional evaluation methods in road safety. Either, we limit ourselves to a small set of controlled variables and measure mostly their effect *a posteriori* (the accidents have already happened), or, we have an abundance of data, but what needs to be measured or what the evaluation is for is no longer clear.

3.1.2 Black-box evaluation: a priori and a posteriori evaluation

There are two very common ways of evaluating a road safety system; a priori and a posteriori evaluation. A priori evaluation is about judging the benefits of a system before it has been developed. Since the system does not exist, it cannot be evaluated with respect to the situations where it saved lives or failed to do so. Rather, considering the existing databases on accidents, it is determined the ratio of accidents that could have been avoided had the system been installed in the vehicle(s) involved in the accident. Such an analysis can be effectively carried out using a black-box scheme (Wiener, 1948); Figure

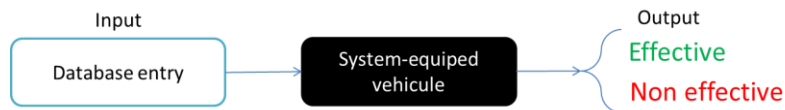


Figure 4. The overall black-box scheme for a priori evaluation (Paget, 2012)

The result of such an analysis is the partitioning of the set of accidents as in Figure 5. For the development team who need to decide whether to launch the design project, the important parameter is the size of the effective part, i.e. the maximal ration of accidents that could have been avoided.

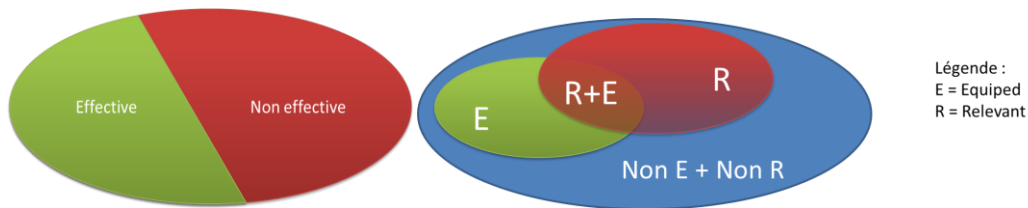


Figure 5. Results of (a) a priori evaluation (b) a posteriori evaluation (Paget, 2012)

A *posteriori* evaluation considers the effect of a safety system introduced into the cars and traffic. Again based on the available databases, the information about the vehicles equipped with a particular safety system and the accidents that are relevant with respect to that system's purpose are retrieved;

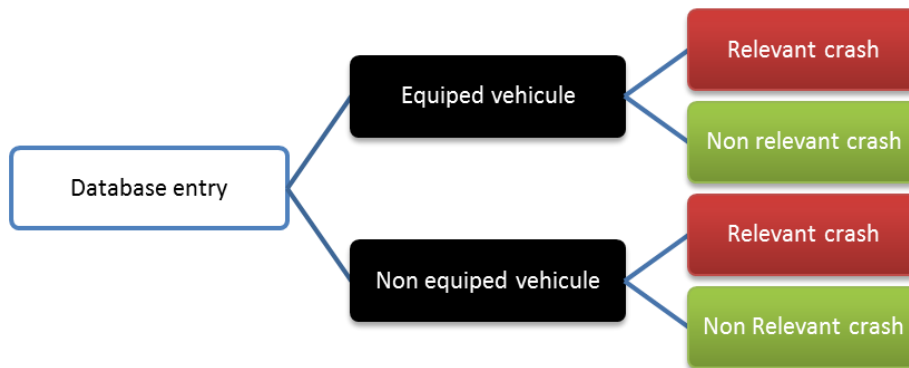


Figure 6. The information compiled for a posteriori evaluation (Paget, 2012)

3.2 Current trend: towards hypothetico-deductive FOT

An approach combining the advantages of the two previous traditions have been used for a European Project, euroFOT (euroFOT, 2012). FOT stands for Field Operational Tests. The objective of the project is to provide a testing approach for road safety in quasi-natural environments given the shift towards C2X systems. Test are being made on a variety subjects such as Adaptive Cruise Control, Blind Spot Monitoring, Curve Speed Warning, to name a few.

For the needs of the platform, a general process has been proposed by FESTA Consortium (FESTA Consortium, 2008) is a step-by-step approach that preconizes mainly a hypothetico-deductive process where a precise research question and hypotheses must be formulated before proceeding with the collect of data and analysis. A fundamental step in this process is the construction of an evaluation model by the analyst for the research question at hand. This construction involves finding appropriate indicators, performance metrics and thus conditions in a significant way which data should be collected to represent to the best of possible the defined dimensions of evaluation. Kircher (Kircher, 2008) has produced a manual for listing some indicators that are, although not exhaustive, are advised to the evaluators for use in euroFOT.

We need to stress immediately that this hypothetico-deductive vision for a given safety evaluation issue is reductionist and dissecting the global safety problem into pieces where the analyst may very well loose from sight the interactions – at which point either the study will be biased or the meaning of the result will be lost.

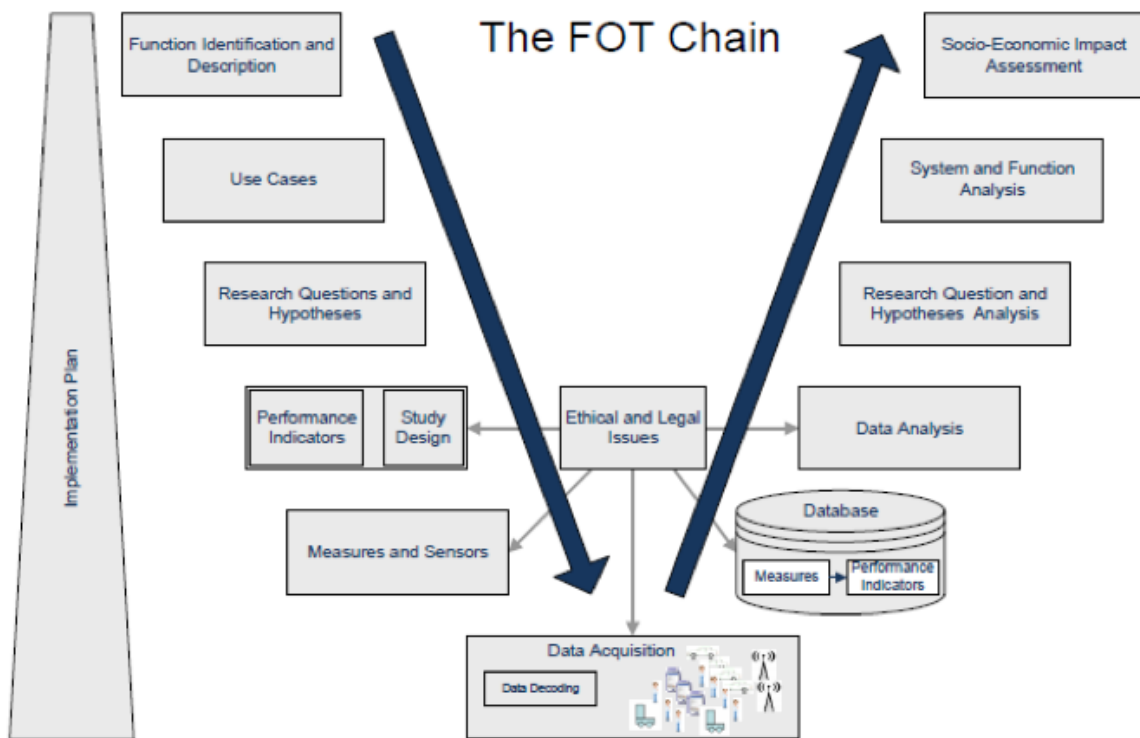


Figure 7. A representation of FOT process

Let us try to see potential problems of this approach with an example proposed by Kircher (Kircher, 2008):

1. **Research Question:** What would be the effects and efficiency of a system warning the driver about a zone with low friction of tires?
2. **Hypotheses:**
 - a) Such a system would increase the average distance between cars when a warning is given
 - b) The average speed will increase when there is no warning
3. **Indicators:** average inter-distance / average speed

There are some fundamental limitations of the implicit reasoning model embedded in this approach. First, as we can see in the example, since the proposed process is disconnected from the global design process of the security system, the research question seems context-free and general – which is an error. What would be the meaning of the collected data if the day of the test it is snowing or there is ice on the test grounds – which would cause drivers to slow down? We can see that, despite the attempt to

move towards the evaluation within a multiple-cars and natural conditions, the limitations of the isolated car evaluation setting is imported, possibly without recognizing it. More significantly, we can see that the analyst needs precise and accurate knowledge about the behavior of drivers *and* possible (and various) driving conditions, in order to come up with relevant hypotheses – which reduce the risk of distorting the phenomena. In order to have such knowledge, the philosophy of an evaluation independent of the design process must be abandoned. It should be acknowledged that the evaluators must now become part of the design process, by becoming designers of safety evaluation models in collaboration with car designers.

4 RE-INSTATING DESIGN CAPABILITIES FOR THE SAFETY EVALUATION UNITS: FROM EVALUATORS TO CO-DESIGNERS OF SAFETY SYSTEMS

Given the previous analysis, we see that it is necessary that road safety evaluators actively participate to the design process in order to give relevant input to system designers but also in order to build appropriate evaluation models for the system being designed is necessary. We shall propose two types of approaches that can be used to this end. These approaches are not meant to replace existing practices, which have their own sphere of validity and relevance. On the contrary, what is targeted is to propose ways to complement existing practices in order to cope with the current transformations in automotive and road safety industries.

4.1 Functional and technological evaluation: The example of lane keeping assistant systems

A first topic about which road safety expert can bring valuable expertise during system design is on the evaluation of **functional and technological requirements during the design**. Consider the example of Lane Keeping Assistant systems (LKA). Such systems are based on the idea of Lane Departure Warning (LDW) that emits a warning to the driver when the vehicle changes the current lane in a seemingly involuntary way. LKA takes corrective action in an automated way to prevent the drifting (Malone 2008). For such a system, the designer might arbitrarily consider a very large number of functions. For the sake of example, let us assume that the car designer plans to introduce the following functions:

- F₁: Functioning during the night
- F₂: Functioning in broad day light

Recent studies in accidentology (Ledon, 2011) show that 38,6% of relevant accidents happen during the night whereas only 0,4% happened in broad daylight. Such information allows evaluating functions of the system being designed and it is of immense value for the system designer for deciding the value and priorities of a security system design project.

As it is most often the case with rapidly evolving product definitions, there are numerous technologies that can provide the same functionality. Once a safety system design team decides a functional requirement list, they need to evaluate which technological solutions to adopt to continue their design. Once again, the safety evaluation expert may provide inputs to the design process. Consider for instance the following table (Ledon, 2011):

Table 1. Properties of different technology for LKA

Technology / Property	Optical	Infra-red	Laser	Radar	GPS
Signal before crossing	Yes	No	Yes	Yes	Yes
Possible extensions	A lot	No	Detect people	Detect people	Already one
Weather restrictions	Bad weather, dust	No	Bad weather	No	No
Range	?	None	Limited : danger	100 m	Infinite
Accuracy	High	High	High	High	Not enough
Speed	High	High	Low	?	High
Need for environment evolution	Low	Low	Low	Huge : reflecting line	Detailed cartography

With such detailed decomposition of a given safety system, it becomes possible for the safety evaluation expert to pinpoint to relevant portions of database or to proceed to specific tests for each of the considered technologies in an *a priori* manner. The relevance of each property is evaluated according the analysis of real car accidents. Thus one can say that such property is necessary or than another is not. Then just make the connection between properties/technologies and technology/safety system. Our evaluation through a safety viewpoint is done.

The hypothesis that all the systems with the same purpose (e.g. systems for LKA) are equivalent can be lifted, in favor of a more accurate analysis. The black-box becomes transparent.

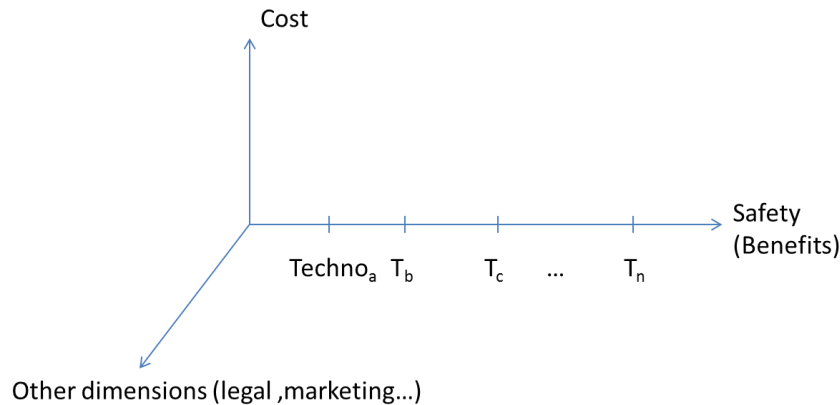


Figure 8. Road safety evaluation expert as a co-designer specialized in safety (Paget, 2012)

At the moment, this type on analysis is not being done in Road Safety evaluation units – more importantly, car or safety system designers do not ask for such inputs. This only shows that, car manufacturers are as much fixated as the road safety evaluation experts on what the role for those latter group is. As depicted in Figure 8, safety evaluator can become a partner in the design process rather than for the end product – on the specific dimension of safety.

4.2 Becoming co-designers for safety systems: the example of avoidance of low-friction

The participation of road safety expert to the design and testing of systems might become more direct and better organized through a better understanding of the overall process and a new type of organization – possibly at the ecosystem level. In paragraph 3.2, we have seen that one of the most significant efforts in today’s ecosystem for improving road safety systems’ evaluation, the euroFOT initiative, suggests essentially a hypothetico-deductive approach. Among many potential difficulties and inaccuracies this approach may cause, or simply delay quick convergence towards viable C2X safety systems, is its ignorance of the hole of the safety issue, rapidly reducing it to a set of hypotheses and data gathering. A safety system is seen as an entity whose purpose is uniquely definable and identifiable, whereas in such a rapidly evolving technological contexts, where norms and regulations have not been stabilized yet this is too big an assumption. As we have seen with the example of low friction warning, **the system taken in isolation from its use, environment and the driver might lead to invalid or questionable assumptions**. In order to provide a rigorous evaluation for a class of objects whose design have not been finalized and whom identity is not stable, a better integration of evaluators with system designers is necessary.

Such integration requires an approach to design that is holistic and provides the possibility to consider multiple potential identities for the system being designed. In the current work, we propose to use C-K theory (Hatchuel & Weil, 2002) as a general tool for mapping a messy design process and as a means for coordinating design efforts. Let us consider again the example of low friction to illustrate how the theory can be used to systematically build both the system and the evaluation models associated with each variant. We are going focus on pedagogical aspects, and not the full sized application, since our aim is to illustrate the approach and the project details are confidential (Paget 2012).

4.2.1 Avoidance of low-friction as a design problem

In order to explore possible meanings of our initial concept C_0 : *Avoid low friction* the first step is to better frame what is friction. As we can see from Figure 9, it is possible to define and explore a variety

of combinations regarding the states of the environment, the vehicle and the driver. Once the details about the environment and the vehicle have been defined, it is possible to consider the driver's reaction (which, currently is not considered in traditional road safety studies). For each unique combination, a different safety system might be required. In case such a system does not exist, its design may be connected to the conceptual description space. Whether it exists or not, the appropriate evaluation model can now be selected or constructed – since the precise conditions for which the system is intended is now defined by *design*.

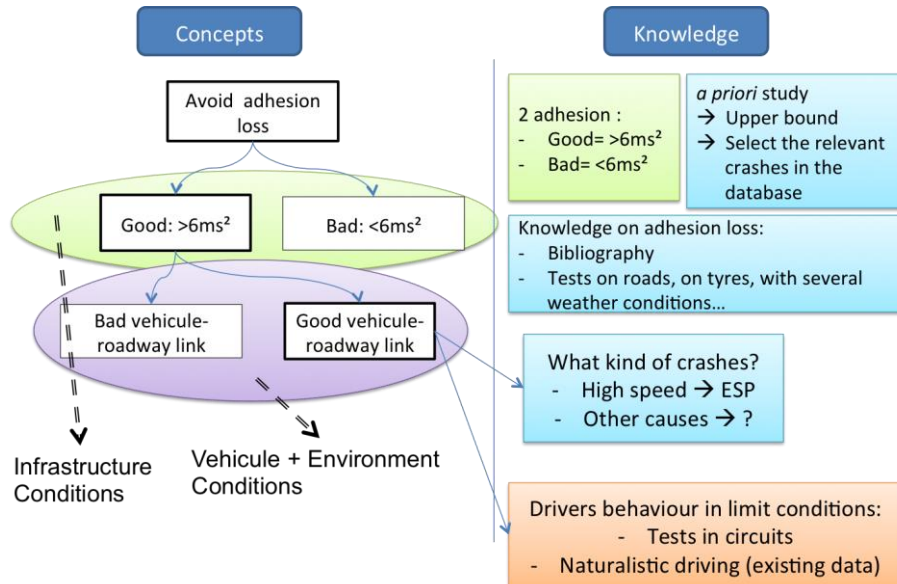


Figure 9. Defining knowledge for friction and low friction for vehicles.

For instance, in Figure 9, a situation where the road allows a high friction ($>6\text{ms}^2$) and the vehicle is equipped with adequate materials (e.g. tires in good conditions) is depicted. In such a case, although the conditions are favorable for a safe driving experience, there are cases where accidents still occur. Normally, such situations are outside the expertise area of the safety system designer – contrary to the safety system evaluation expert. In fact, one such reason for which accidents may occur under those conditions is high speed and the necessity to hit the brakes due to an unforeseen cause. The evaluation experts have a history of test results for similar conditions where ESP (electronic stability program) has been proven to be effective. In addition, relevant cases from the accident databases might be analyzed to determine other possible causes and drivers' behavior in such conditions. Such analyses are likely to be extremely helpful for the system designer as gradually all the possible situations and potential measures will be mapped out. This, in turn will give the possibility to better target the necessary functionalities and technologies. Moreover, the road safety system evaluator can devise better-targeted and precise tests in order to reveal both the design need and the performance of the envisaged solutions.

5 CONCLUSION

The automotive industry is going through immense changes. For the rapidly changing technologies for the forthcoming intelligent vehicles, evaluation of road safety is of renewed importance. In this paper, we have presented and analyzed traditional evaluation paradigm that is more centered on passive safety paradigm and stabilized evaluation routines. We argued that, since safety technology is changing and becoming more based on a pro-active approach, given the current communicating vehicles-infrastructure systems being designed, road safety evaluators should be more involved in the design of those systems. We pointed out that a hypothetico-deductive approach extending the traditional paradigm of safety evaluation will not be sufficient and there is a need for a more holistic approach: road safety system evaluators need to become co-designers of safety systems, providing inputs to the system designers, while, in turn, they build a new generation of evaluation models and practices. The proposed principles are illustrated with examples on lane keeping assistant system and the analysis of a low-friction system design.

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