Road Safety Data, Collection, Transfer and Analysis

DaCoTA D5.4
Determination of a general evaluation model Preliminary report

Please refer to this report as follows: Hermitte T., Fricheteau R. (2011) Determination of a general evaluation model, Deliverable D5.4 of the EC FP7 project DaCoTA.

Grant agreement No TREN / FP7 / TR / 233659 /"DaCoTA"
Theme: Sustainable Surface Transport: Collaborative project
Project Coordinator:
Professor Pete Thomas, Vehicle Safety Research Centre, ESRI
Loughborough University, Ashby Road, Loughborough, LE11 3TU, UK

Project Start date: 01/01/2010 **Duration 30 months**

Organisation name of lead contractor for this deliverable: GIE RE PR			
Report Author(s): Thierry Hermitte and Romain Fricheteau – GIE RE PR			
Due date of deliverable	**30/11/2011**	**Submission date:**	**03/11/2011**

Project co-funded by the European Commission within the Seventh Framework Programme	
Dissemination Level (delete as appropriate)	
PU	**Public**

Project co-financed by the European Commission Directorate General for Mobility and Transport

TABLE OF CONTENTS

GLOSSARY

Concept: They represent class of knowledge that are frequently use in evaluations. For instance, the concept “stakeholder” is one of them. This useful entity aims to describe people that are connected to an evaluation

Constructivist: epistemological paradigm which considers the relative and evolving knowledge. It exists only for a particular context and for a given observer (depending on experience and knowledge)

Epistemology: the branch of philosophy of science which is defined as "study the establishment of valid knowledge" [Le Moigne, 1999]

ESC: Electronic control system stability, also known as: ESP (Electronic Stability Program), DSC (Dynamic Stability Control), VSA (Vehicle Stability Assist), VSC (Vehicle Stability Control) or other

Evaluation: activity whose goal is to build, with tools and methods, value judgments and / or measure system’s performance. We differentiate the assessment of the evaluation. Evaluation refers to the activity that brings together all the steps to achieve. While the assessment made reference to the operational part (application of the method).

Evaluator: one that supports the design and implementation of the assessment activity

Indicator: definable mathematical object that informs on the performance of a safety strategy according to specific issues

Knowledge: information is taken in a context that is interpreted by a human based on their beliefs and experience. It is used by the knowing subject to the achievement of its business. Finally, it is created and evolves by learning, for identification or construction

LAB: Laboratory of Accidentology and Biomechanics, PSA Peugeot-Citroën Renault

Meta-model or conceptual model: The construction of an evaluation activity model comes to develop a meta-model (as defined in systemic) or a conceptual model (as defined in knowledge engineering). Both are a set of knowledge on the domain and the reasoning (the know-how - tasks and methods)

Model: intelligible representations of perceived reality with which we are led to think and communicate

Paradigm: used to define a model of thinking to scientific disciplines such as evaluation and modeling of knowledge

Positivist: epistemological paradigm which considers the absolute nature, stable and deterministic knowledge. Context modeling and the observer / modeler are not taken into account

Safety Strategy: Describes the coordination of safety actions implemented in order to achieve a specific goal. Among the road safety actions, we distinguish the safety measures (regulations, training, etc.) and technological safety systems

Stakeholder: person or group of persons related to the issues of road safety and / or assessments

Systemic: general theory of knowledge modeling-based methodologies and practices in the objective is the study of complex systems considered

UML: Unified Modeling Language

EXECUTIVE SUMMARY

In the context of road safety, evaluations are performed in order to provide knowledge on the safety strategies' performances. This type of knowledge is needed by the stakeholders who are involved in the management of the road safety system. It allows them to control the activities they perform. For instance, national governments need information about the abilities of a new speed regulation to save people or to reduce injuries. Such results, which are provided by evaluations, help them to validate the strategy (a posteriori) or to decide its implementation (a priori). According to this statement, evaluation activity is one part of the safety improvement process. In this report, a model of the evaluation activity is presented. It aims to guide evaluators in the achievement of evaluations.

In order to improve the evaluators' monitoring on their activity and to perform relevant evaluations, we identify some issues that need to be handled. The current issues on evaluation activity concern its objectives, the indicators, the tools/methods and the unpredictable changes.

Firstly, it is difficult for evaluators to identify what are the stakeholders' expectations concerning evaluation. Their diversity implies diversity in their needs; they do not all want the same things. Some of them focus on the economic side, other on the public health or technological sides. We notice that for evaluators (who design and perform evaluations) this is quite a major issue because we have not found method or tools that could help them in identifying needs.

Secondly, the major media used in evaluation to deliver the results is the "indicator". It is a mathematical object that gives factual information. Related to the first point, the conception of indicators is dependent of the expressed needs. Therefore, according to issues in identifying needs, evaluators have difficulties to offer relevant indicators. They mainly used indicators that they are in the habit to use and that they are able to calculate. Moreover, we do not identify methods/tools that allow designing new indicators.

Thirdly, evaluation is an activity that needs to be formalized in order to guide the evaluators' work. We only identify some operational methods and tools but we do not know how they were build and if they are relevant according to the needs. We do not find a general evaluation model that could handle its definition, its realization, its valorization and its evolution.

Finally, the road system is a complex system that is usually represented by the triptych: vehicle, user and environment. One can understand its complexity by the unpredictable behavior of each of its component. For the evaluators, who need to understand what they evaluate, complexity is an obstacle. They cannot foresee all the unpredictable changes that could affect performances of a safety strategy. For instance, the implementation of a system that automatically regulates speed of the vehicle could lead to the appearance of new driver behavior that could be dangerous. The drivers can take advantage of it to perform other task like phoning or reading. Complexity also implies a dynamic vision of the evaluation activity; it is not always the same. Evaluation activity evolves according to the changes of its context. However, how evaluators can make evolve evaluations?

Following these observations, we developed a framework of the evaluation activity. This report introduces the representation of this framework through a systemic paradigm. Various functional and descriptive models are proposed. Evaluators used them as guidelines in order to model knowledge on study case and to design evaluations. Our general framework takes into account the various viewpoints of stakeholders and evaluators. It allows performing evaluations that are (1) relevant for all the various stakeholders and that (2) aim to assess performances according to various viewpoints (aggregation of various performances from road safety fields – accidentology, economy, biomechanics, etc.).

1. INTRODUCTION

1.1. DaCoTa project

The overall objective of DaCoTA is to help develop knowledge-based road safety policies in European countries by continuing to develop the European Road Safety Observatory (ERSO) and providing methods allowing using ERSO data for policy development and implementation.

Road safety has been increasing in motorized countries now for 30 years and this increase shows that political willingness and efficient countermeasures can actually produce positive results. The last two decades have seen a promising increase in e-safety systems directly linked to technological progress. These systems are complementary to traditional safety countermeasures (regulation, education, enforcement, advertising and information campaigns, car crashworthiness, infrastructure improvements, etc.).

eSafety is often regarded from a very limited viewpoint that concerns only stand-alone car technologies. It is however, actually embracing much more: road infrastructure safety, traffic, car-to-car communication, also car-to-infrastructure or user-to-user communication or any kind of countermeasures linked with the availability of new technology.

Relevance of potential responses by technology to traffic safety problems has been studied for years and especially by EU-funded projects, noticeably the TRACE, eIMPACT and PreVal projects (FP6) that aimed at estimating the safety and/or the social and economic benefits of a selection of safety systems. These projects have made some encouraging improvements with regard to methodologies and have (or are still on the way to) produced results that deserve to be reported in an observatory. These projects, however, haven't covered the research field. There is indeed still a need for studies concerning the benefits of technologies:

- Because the research projects (TRACE, eIMPACT and PREVAL) have (or will have) studied only a small set of on-market or close to market applications and that there is a permanent launch of new applications in or out of European projects. These new applications, ideas or close to market products, still have to be properly evaluated.
- Because most of the projects have studied so-called '*generic applications'* only whereas it appears that the safety benefits depend much on the parameters of the applications (e.g. the deployment threshold of an ESP). Sensitivity studies (what safety benefits at which parameter value?) deserve to be undertaken, searching for the best parameter values, i.e those with the most potential safety benefits.
- Because the evaluation studies focus mainly on the safety benefits and scarcely on the other types of benefits.
- Because it is still difficult to assess the benefits of technologies at the EU27 level as most studies can only use data which is available in a limited number of countries.

Apart from recommendations for a *relevant structure* for a diagnosis of the safety problem and the evaluation of the safety benefits of counter measures, as well as for methods and results to be integrated in ERSO, we also expect:

- An update of the explanatory accident causation model following the work done in TRACE and SafetyNet. The ones that have been used up to now (based on the basics of etiology, epidemiology, psychology, ergonomics or systemic) will probably reach their limits very soon and there is a need for a new theoretical framework to make improvements in accident and injury prevention.
- Following this theoretical accident causation model, a well matched statistical analysis model will be developed that allows the quantitative assessment of whether

the technology based applications are addressing the real users' needs revealed by the causation analysis

- The theoretical models for the accident causation analysis and their empirical validation are considered to be the fundamental plinth upon which the relevant data to be incorporated in the Observatory and the associated data analysis methods are determined.
- The expansion of *benefits* figures, which are currently available in a few countries only, to a much greater part of Europe 27, with the necessary explanation of discrepancies between regions.
- The analysis of the interactions between technology-based applications and prioritization of the most promising package of applications as far as safety is concerned (what is the best package of applications that is saving the most numerous road users? Especially, what is the best mixture between passive and active/preventive applications)

The purpose of this report is to define a general model for evaluating the safety benefits and other benefits of safety functions. It is, of course, not intended to effectively include measures of "other" benefits. Rather, the idea is to outline such a general model for evaluation in order to demonstrate that safety benefits are in fact only a (small) part of the universe of all impacts of safety policies based on technological solutions. The general model can thus help in locating safety benefit analysis properly among all possible forms of impact analysis. Under the conceptual framework outlined above it will be possible to identify systematically the data and methods which are relevant for the assessment of the impacts of existing and new technologies on traffic and vehicle safety.

1.2. Evaluation activity for road safety management

The WHO[1] estimates that 1.2 million people die in road accidents each year and about 20 to 50 million are injured (2004 figures) [Peden, 2004]. Even if a marked improvement is noticed in some developed countries, the WHO predicted in 2004 a worldwide increase of 65% of deaths and injuries between 2000 and 2020 if nothing new is done. This rise will mainly concern developing countries where the vehicle equipment rate is growing (a rise of more than 80% of deaths and injuries is expected in these countries). An updated estimation reports that in 2030 road crash deaths and injuries are projected to be the 5th largest cause of healthy life years lost by the total population (compared with the 9th largest cause in 2004).

In light of this expected evolution, some of the stakeholders are working to develop countermeasures in order to reduce and/or to avoid crashes. Stakeholders are people or organizations related to the road system. All of them have their own role and their own capabilities. Some of them are active, which means that they implement changes to the road system (those who develop countermeasures). Others are passive, which means that they are only parts of the system – they are the drivers for example. The following list presents some of the existing stakeholders: research laboratories, national governments, motorway companies, car manufacturers, insurance companies, universities, road users, car parts manufacturers, etc. They all are parts of a network.

We define a countermeasure as a strategy that aims to contribute to the improvement of road safety. It could be an action like policy and regulation or a technological system like airbag and communication systems. It can also be a mix of both. A huge amount of possibilities exist. This is due to diversity of the problems to solve and the domains that are connected to road safety. A countermeasure needs to be considered according to a context.

---

[1] WHO : World Health Organization

Without it, it is not possible to understand its functioning, its limits, its performances, etc. In the rest of this report we mainly use the term “safety strategy” because it is more appropriate to the definition we propose.

Those who develop the safety strategies perform their activity according to visions that describe ways to consider road safety issues and ways to collaborate (Safe System and Vision Zero for instance). In the following figure, the safe system is presented [OECD, 2008]. It describes the major areas to improve road safety. They concern the enforcement of road rules, the improvement of the understanding of crashes and risks, education and formation, and the admission to road system. The operational results of these areas concern the speeds, the vehicles, the roads and roadsides, and the prevention of crashes. Each of these actions has to be done according to the central statement of the safe system: human body has tolerance to physical force. Related to these areas, the safe system suggests that certain stakeholders have to be engaged in some areas and therefore there are opportunities to share responsibility and knowledge. For instance, local government and road authority share their knowledge in the area of “safe roads”.

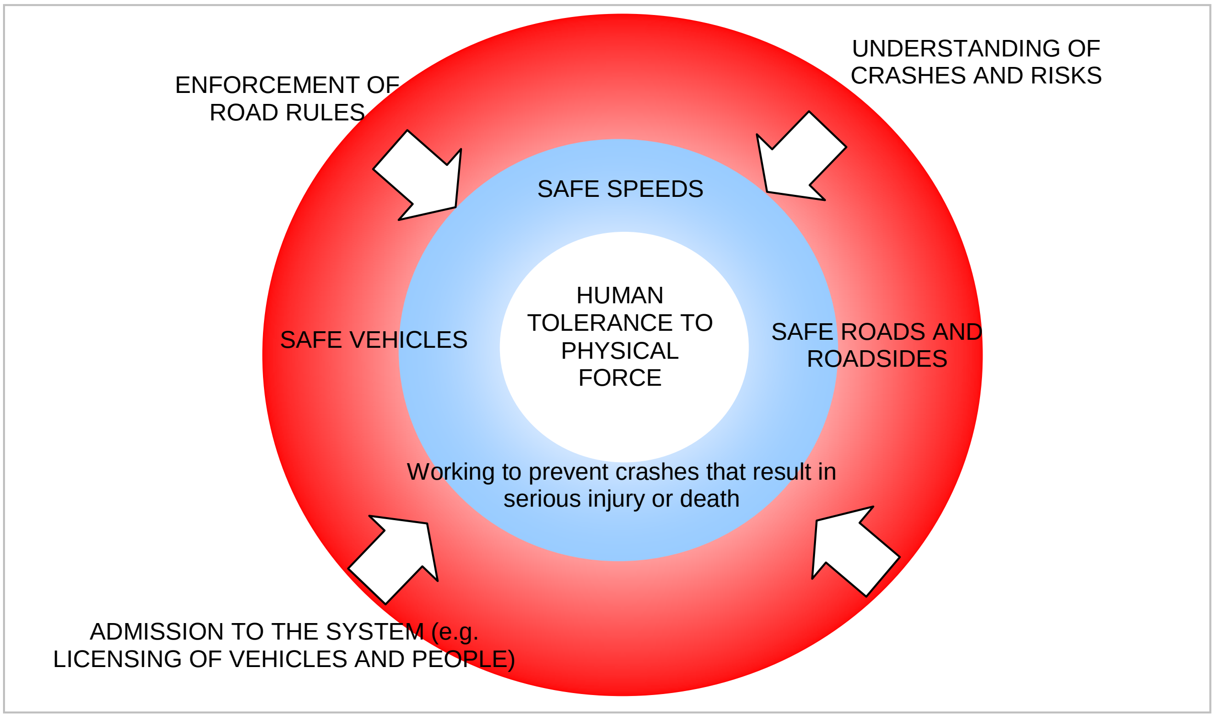

Figure 1 - Model of the "Safe System" [Newton, 2008]

In the “Vision Zero”, which is a thinking framework that is a declination of the safe system, the protection of the users comes first. Mobility is only a side of safety; it is no longer the main concept. The goal is to build a road system that is more tolerant with regard to users' mistakes and where all the stakeholders collaborate and have a part of responsibility concerning road safety.

Nevertheless, these frameworks raise some complex matters. Firstly, cooperation is needed but the operational solutions to perform it are not obvious. One knows that sharing knowledge depends on the cultural context and the level of understanding. For instance, is it possible to share accidentological knowledge between countries that don't have the same typology of crashes or the same value system? And if it possible, are there some limits? This matter mainly concerns transfer of knowledge between developed countries (where safety figures were improved) and the developing countries (where safety situation will get worse). Secondly, facing the various possibilities of countermeasures, what is it still possible to improve? What are the good solutions to develop? And, how ensure that all solutions work well together? We will see that these questions are partly handled by making evaluations.

According to these two frameworks, one can say that the improvement of road safety implies diversity of stakeholders in terms of abilities and knowledge, and diversity in countermeasures. This statement is central to our work on the evaluation activity. Evaluators have to be aware of this and they have to be able to integrate it into their works.

Evaluation activity is directly related to this context. It aims to provide information relevant to the various issues in road safety. One assumes that it is an activity integrated in the continuous improvement of road safety. The following figure describes this. We present the policy cycle and the PDCA wheel of Deming. The first diagram is related to the improvement of policies and the second refers to research area on quality (in industrial companies). Those two diagrams detail the macroscopique goal of the evaluation activity. Evaluation activity is performed in order to help stakeholders in their activities by assessing, a priori or a posteriori, the results of their actions. Results of evaluation are used in order to improve activities; evaluation activity is part of a continuous improvement process.

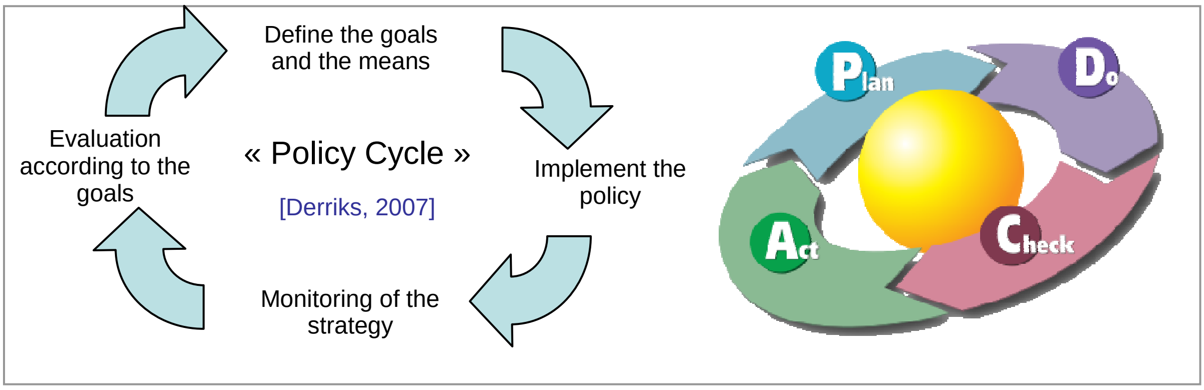

Figure 2 - Schemes of continuous improvement: the Policy Cycle and the Deming Wheel (Plan Do Check Act - PDCA)

Results of evaluations are information on the performance of the evaluated safety strategies according to specific viewpoint and a particular context. These results are mainly formalized in terms of indicator. It is a mathematical and calculable object that provides factual information on the performance of evaluated strategy. For instance, indicators based on the number of fatal accidents or/and on the number of injured accidents are used. These indicators refer to public viewpoint but other viewpoints are also used. These are for instance the economic or the technological viewpoints. For each of them, some indicators exist.

According to these various statements on evaluation activity, some issues are brought out. Evaluations is an activity performed by evaluators for reasons and according to an understanding of the monitored safety strategy in a changing context. Are we sure that the current evaluation practices are able to fullfill these goals? This question is motivated by the need to better control evaluation activity and to be abble to provide the most relevant results. In order to answer it, we focus on four points (those used to define evaluation activity). They concern the indicators, the multidisciplinarity of the stakeholders, the tools/methods used to perform evaluations and the complexity. We detail them in the part 2.

2. THE ADDRESSED PROBLEM - ISSUES ON EVALUATION ACTIVITY AND LIMITS OF THE CURRENT PRACTICES

In this chapter, we question whether the current evaluation approaches are capable of fulfilling all the expectations. To do this, we focus on the following points (these four questions are detailed thereafter):

- Are evaluation indicators capable of providing knowledge for all the various expectations?
- Can the evaluators understand all the questions that come from the stakeholders?
- Are the methods/tools good enough in resolving evaluation problems?
- Finally, how the possible unpredictable changes on the road system are handled by evaluators?

Objective of this section is to detail some of these major issues. Some assertions of this section seem exaggerated or over simplify (Manichean). However, this allows highlighting issues that justify the need to propose a new general evaluation model. These criticisms come from a study of the current evaluation practices through a state of the art, interviews of evaluators and workshops with stakeholders.

2.1. Reflection on indicators

As said before, an indicator is a calculable object that has a mathematical definition. It is considered as the main media because it is used for delivering evaluation results to the stakeholders. It is calculated according to a context and for specific goal(s). Therefore, an indicator has to go with justifications about its definition and its calculation. The indicator value is as important as the conditions for obtaining it. This allows preventing all errors of misuses. This concerns for example the temporal limits of use, the calculation limits (on the tools and/or the data), the assumptions of the evaluation, etc.

Even if the indicators currently in use are usable and relevant, we need to consider some possible issues. They concern their structure, their use, their selection and their design (calculation issues are tackled in following section). We are looking to formalize definitions and tools that will enhance the design and the use of indicators.

We start by providing two indicators that are used in evaluating a safety strategy. They are parts of indicator categories that are the most common - they are related to public health and economic viewpoints.

- Reduction in the number of deaths or injuries
- Ratio cost – benefit (monetary value of deaths/injuries and the implementing cost of the safety strategy)

Firstly, these two indicators focus on safety strategy's performances by assessing its efficacy and its efficiency (see Figure 3). However, we assume that according to the wheel of handling a general management of road safety, other dimensions are needed. We added the two following dimensions: effectiveness and coherence. For instance, when a public government has to validate a safety strategy, its performance has to integrate the efficacy in reaching a goal but also the coherence of the economic means and the objectives, as well as the match between the observed and the expected results. The contribution of this proposition is to broaden the definition of the indicators. It guides evaluators to attempt to be the more relevant.

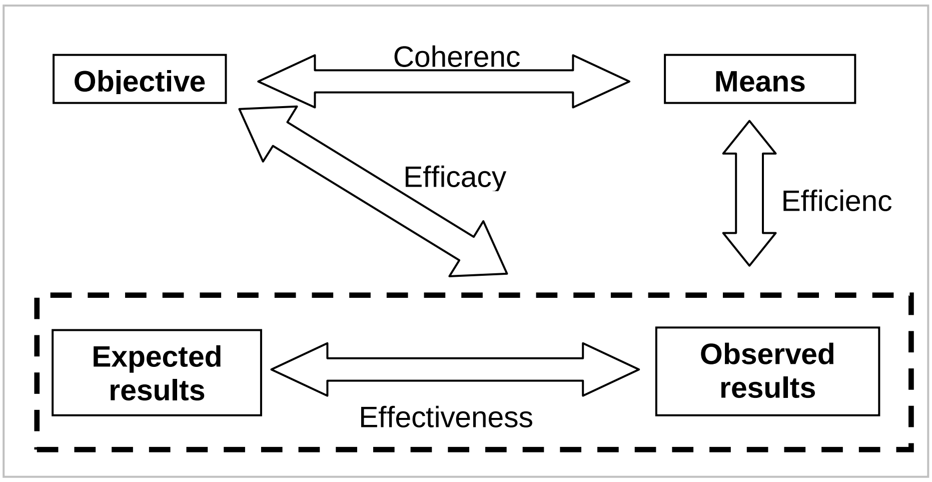

Figure 3 - The performance square

Secondly, the same thought can be made on the viewpoints. Evaluators cannot limit their activity to the economic and public health viewpoints. They have to consider those connected to the juridical viewpoint, the environmental viewpoint, the technological viewpoint, etc. All of them are related to the general road safety vision; safety issues have to be handled by the collaboration of all the various stakeholders in the context of a sustainable development. Therefore, the performance of a safety strategy is multidimensional. For instance, since Global Warming issues have become central, indicator on the environmental performance is quite relevant.

Thirdly, one has to think about issues on the reliability of the calculated indicators. We assume that the available data and the calculation tools could be one of the causes of mistakes. For instance, the representativeness, the coding errors or the misuses of statistical tools are the usual issues that could affect reliability of the indicators. Evaluators may not know these limits or some have been forgotten or simplified. Challenges are to identify those limits and to integrate them in the practices of evaluation.

We summarize this section on indicators by providing a list of questions:

- **Who is the recipient of the evaluation results? How take into account diversity of stakeholders?**
- **Do the evaluators ask the good questions?**
- **Do the evaluators answer to stakeholders' questions?**
- **Are the results relevant to expressed demands?**
- **Are the indicators good considering demands/expectations?**
- **What is the reliability of the results?**
- **How perform multidisciplinary evaluations?**

In our model, we propose models and knowledge that allow handling these issues. These are for instance, a generic mathematical description of indicator and rating system (stakeholders mark the relevance of the proposed indicators).

2.2. Reflection on multidisciplinary

Multidisciplinary is an issue both for the stakeholders and the evaluators. It has an impact on the evaluation needs (related to the stakeholders) and the ways to perform evaluations (related to evaluators and some stakeholders).

Firstly, stakeholders have evaluation needs that are connected to their activity and their discipline. For instance, there are mechanical engineer, politicians, road users, insurers, public decision-maker, etc. Each of them could have some specific evaluation needs. However, evaluators usually provide the same indicators to them. Therefore, we assume that sometimes, stakeholders cannot use the results because they are not completely adapted to their needs. The two main raisons for this are the inability of evaluators to identify the needs, or the inability of the stakeholders to formalize them. The following figure illustrates this statement. It is not about evaluation activity, but it depicts the same issue. Each person has his own interpretation of a swing; the risk is that the result does not correspond to the expectations of the user. This risk is the same concerning evaluation. The challenge related to this issue is for the evaluator to be able to fully describe each of the real stakeholders' needs, to differentiate them and to not change their meaning.

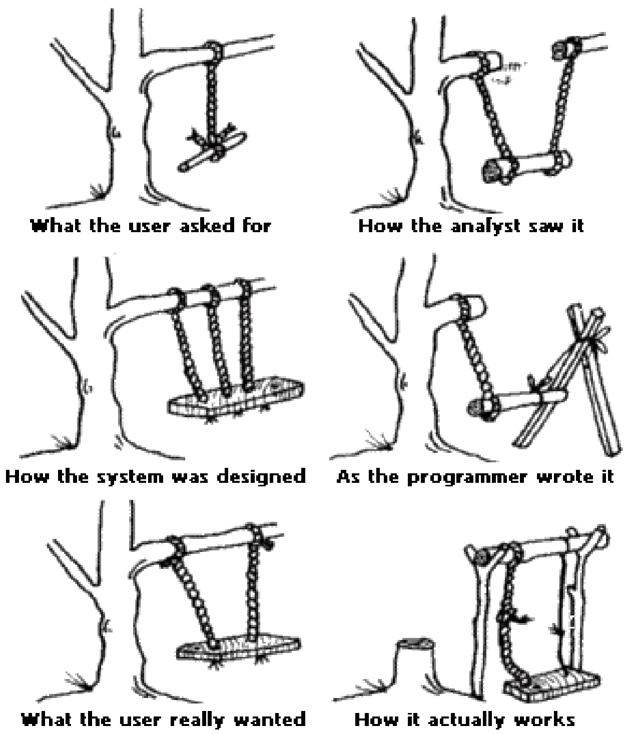

Figure 4 - Various interpretation of a swing

Secondly, each evaluation depends on evaluators' abilities and position. That is why results can be variable for one same question. Their skills/abilities influence the way they perform evaluations. We assume that evaluation activity does not follow an absolute and deterministic model. Indeed, the continuous changes in the evaluation context imply to consider a constructive approach of evaluation activity. This means that evaluation methods and indicators need to be design or redesign if new expectations or behavior appear. However, do evaluator posses such skills? If not, how can we handle a constructive evaluation approach that will suitable for all evaluators?

Thirdly, multidisciplinary evaluations are not enough used. There are not enough interactions between evaluators from various fields (or viewpoints). For instance, collaboration between accidentologists and biomechanicians is unusual and there is no method to enable this. This disconnection between fields goes against the objective of constructing a general management of road safety. A general vision requires mixing evaluators' viewpoints.

We can identify a list of questions that highlight the difficulties concerning multidisciplinary:

- **How to identify the various needs concerning evaluations?**
- **How to ensure that needs are well understand by evaluators?**
- **What is the compromise between ethics and scientific field (if a compromise is needed/recommended)?**
- **What is the evaluator's positioning according to the road safety management?**
- **What is the impact of evaluation on the innovative approach in countermeasures?**
- **How to develop collaboration between evaluators from various domains?**

In order to facilitate the formalization of evaluation questions, we propose lists of generic questions. They are examples of questions that are mainly asked by stakeholders. We also propose a process that guides evaluators step by step in the identification of the relevant elements that constitute an evaluation question (see also the following section).

2.3. Reflection on methods and process

This topic aims to apprehend issues that concern functional and structural aspects of evaluation. It is to inquire if the evaluation practices are effective regarding expectations. We focus on the following main thought: evaluations are mainly performed routinely without considering the needs for novelty.

In order to perform evaluations, evaluators use institutional knowledge and their creative abilities. Institutional knowledge refers to the knowledge that is shared by evaluators. It depends on the field of the evaluator (accidentology, biomechanics, ergonomics, etc.) and his experience. For instance, they share indicators or assessment methods that are widely used. Regarding creativity, we notice that there is no will to expand it. However, it is needed to cover the permanent changes of the case study (road system, safety measures, needs, etc.). Therefore, evaluators tend to reuse what they can do without sufficiently considering changes in the road system. Thereby, the outcomes of evaluation are often the same because of the failure to use a design approach. Evaluators work routinely without considering changes in the evaluation context.

One way to shed further light the previous issues is to highlight the lacks of methods and tools. We have no found formalized methods or tools that help to perform certain stages of evaluation activity. Indeed, there are no methods to formalize stakeholders' expectations, to design indicators and methods, to perform assessment[2], and to provide/exploit/capitalize the results. The following points illustrate this statement:

- **Identification of the target**: Any activity involves objectives to be reached; they are used to decide what have and should be done. Nevertheless, in the case of the evaluation activity in road safety, stakeholders' needs are not well expressed. We already develop this issue in the previous parts. Define the needs is a major step in order to produce relevant evaluation results.

[2] We differentiate the assessment of the evaluation. We consider that the evaluation refers to the activity that brings together all the steps to achieve. While the assessment made reference to the operational part (application of the method).

- **Misuse of existing indicators**: the used indicators are always a sub-set of the existing ones. Evaluators use those they know. The risk is that indicators could be not suitable to the treated study case. Indeed, even if some indicators are mostly relevant for many cases, it is important to not forget their meaning and their target. Evaluation activity is not restricted to the use of the well-known indicator. We explain this issue by the lack of design methods and the lack of formalized objectives (see the previous point). Evaluators do not have enough information to justify and to perform design of new indicators when it is needed.
- **The tools**: Evaluators, who are experts, insert the limits from the tools and the data directly in the step of the selection of the indicators. For instance, some data on the exposure are not available. Therefore, evaluators, who know that, identify an indicator that does not use it. It allows them to provide a usable indicator but not necessarily the most relevant one. We assume that evaluators should firstly design (or choose) the indicator according to the needs and then take into account the limits. There would be a decoupling between the constraints from the needs and the operational constraints. This way of thinking leads to an iterative process where indicators are designed and adapted according to the needs and constraints. The other benefit of this approach is to be able to identify some evaluation issues. When evaluators are confronted to operational constraints, they can identify areas for improvement in the data collecting, the models and methods for example. This type of information is crucial in order to enhance the evaluation practices.
- **Reuse and sharing**: capitalization of all data on the evaluation study cases is essential in order to assist the future evaluations. For instance, the stored data concern the description of the stakeholders' needs, the indicators, the assessment methods, the results, the limits, etc. Currently, there is no process that allows such storage. Capitalization is mainly based on the expertise of the evaluators and scientific reports. However, this does not allow easily finding relevant information according to a specific need; this is not a standard for capitalization. More over, what happened when an expert retires? We also assume that capitalization allows sharing knowledge.

To conclude this section, we summarize a list of questions that highlight the difficulties concerning practices and methods:

- **Which approach to use to go beyond the current practices?**
- **Do we use the relevant tools and methods?**
- **How to model the existing evaluation methods?**
- **How to build the evaluation methods?**
- **Do evaluators assess what they plan to do?**
- **How to handle the constraints in the achievement of evaluations?**
- **How to perform the transmission of the results to the stakeholders?**
- **How to develop the capitalization of indicators and methods?**
- **How can we store all information on evaluation study cases?**
- **How can we access to the data on the previous study cases?**

In our general model, we seek to propose a description of the evaluation activity that enhances thoughts on ways to improve evaluations. For instance, it is to help evaluators to formalize the evaluation questions and to find new relevant indicators.

2.4. Reflection on the complexity of the evaluation activity and the road system

Complexity is about the unpredictable behavior of systems. This characteristic, which is based on processes of adaptation and emergence, is defined in scientific area. We report some of those areas with their corresponding vocabulary on complexity:

- Physics: non-linear interactions, instability, irreversibility
- Mathematics: incompleteness, undecidability, random sequences
- Biology: loops, conditional reactions, exchange of information

We handle the question of the complexity in the road safety and in the evaluation activity.

Road system evolves because of the changes of its elements. There are some new vehicles, some new countermeasures, some new driver behavior, etc. For instance, drivers can adapt their behaviors to the introduction of a new safety system. The risk is that evaluators may not be able to foresee all changes because of their partial unpredictability. They cannot fully understand a safety measure (description, operation, interaction, misuse, etc.). For instance, can they anticipate interaction between the ESC and a hypothetical system that will automatically warn the drivers of a low grip? Therefore, there are (or will be) some impacts/effects on the road system that they cannot foresee. Performances of a safety measure may be unexpected, counterproductive or incompletely assessed.

These statements imply a need to consider an evolutionary practice of the evaluation activity. However, this is something rather difficult because of the lack of models. Evaluation activity evolves according to changes in road system, stakeholders, countermeasures, etc. Therefore, evaluators needs to be aware of these modifications and they need to be able to handle them. However, it cannot be reach by the existing evaluation approaches, they are not sufficient to deal with novelty.

Thinking on complexity is a difficult challenge. The difficulty could be linked to our limited understanding of the phenomena but it could also be linked to the intrinsic complexity of the studied system. In both case, evaluators are faced to the challenge of evaluate unpredictable systems. Are there any tools to help them? If so, what could they be?

We have identified a list of questions that highlight difficulties concerning changes of the evaluation activity:

- **How to anticipate future evaluation demands?**
- **How to anticipate changes in the road system?**
- **How to evolve our evaluation indicators and methods according to changes?**

We decided to handle these issues by adopting a thinking paradigm that is adapted to complexity; this is the constructivism paradigm. It provides knowledge and tools that allow constructing complex models.

2.5. Synthesis

In this chapter we analyzed the evaluation activity through four main issues (see Figure 5). The aim was to answer our general question: are the current evaluation practices relevant according to the expectations?

Current evaluation practices are not sufficient for meeting the expectations related to road safety management. Firstly, evaluators work routinely without well-formalized processes and methods. Secondly, the performance of the evaluated system is only assessed according to a few set of dimensions. Thirdly, positioning of the evaluators is not clear. Finally, there are no methods to handle complexity of the road system. All these limitations constitute the basis of our general thought on evaluation activity. We aim to propose a new framework in order to deal with them.

Some relevant scientific fields were used according to these limitations (see the following figure). They have been selected because they provide answer to our questions. We focus on the evaluation activity, the knowledge modeling and the design theories. The first field allows seeking some usable theories and knowledge on evaluation activity. There are theories in other domain that could be applied to the road safety. We mainly seek in the education, economic or design domains. The second field aims to provide knowledge on the way to model an activity. As we are looking to craft a new model of evaluation, we need to understand what the best way to model is. The major reflection is about the use of the existing models and the experts' knowledge. Finally, the last field concerns the design theories. It is relevant as we want to propose a constructive model of evaluation activity. We aim to propose models and tools that can be used to design indicators and evaluation methods.

All of these fields bring the knowledge needed to construct a new evaluation method. In the following chapter, we detailed the approach to model evaluation activity. Theories on the design activity are used in the chapter 4.

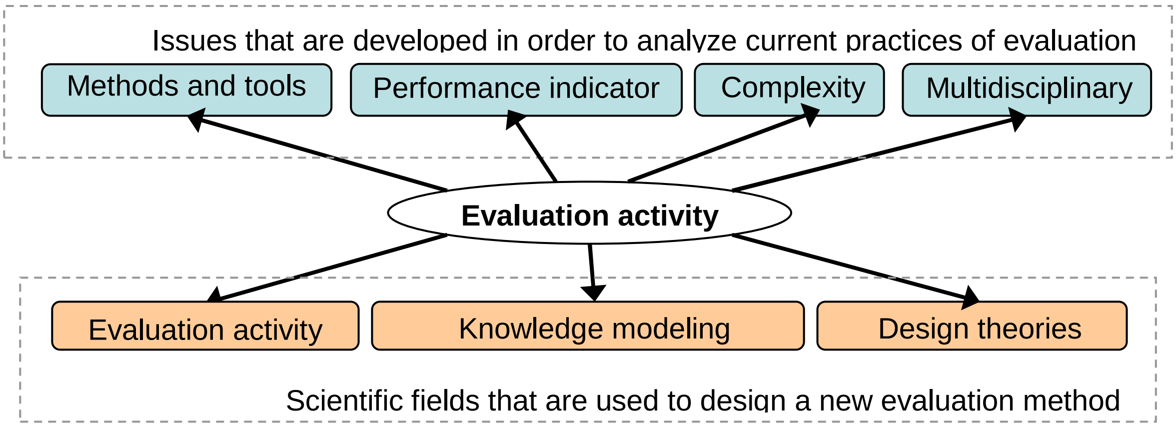

Figure 5 - issues on evaluation activity and the relevant research fields

3. A NEW FRAMEWORK OF THE EVALUATION ACTIVITY

3.1. State of the art on the needed theories

We present the knowledge we used to design the model of the evaluation activity. The first section aims to present general knowledge on the evaluation activity. It is focus on the five steps model. It provides a macroscopic definition of the evaluation activity that we used as a generic pattern. The second section is about the systemic paradigm. It provides knowledge to handle modelling complexity in order to understand the road system and the evaluation. In the last section, we describe knowledge on the design theories.

3.1.1. The Five Steps model of the evaluation activity

The five steps model (see the following figure) is the most macroscopic representation of the evaluation activity. It provides the steps that evaluators always have to execute during evaluations (not restricted to road safety).

It is a synthesis of knowledge on evaluation that comes from road safety and other fields like engineering design, education, and economics. We identified definitions according to the state of the art, interviews with experts and workshops with stakeholders. Therefore, we assume that this representation is not completely relevant for all the areas. However, it is enough generic in order to be adapted to the needs. It describes all the activities to be performed, but evaluators can only execute some of them according to their evaluation context.

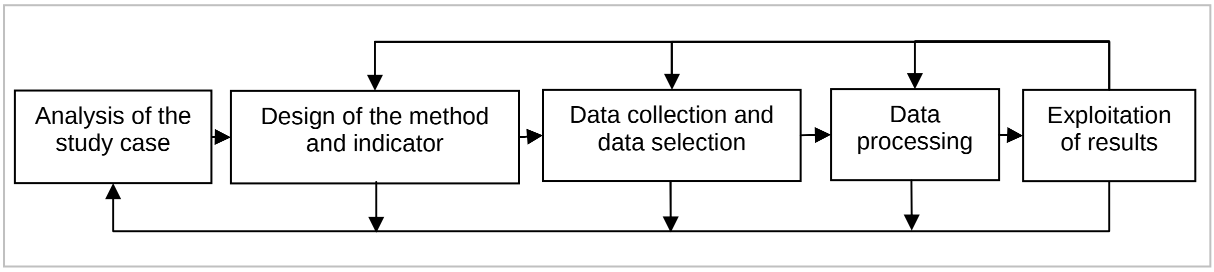

Figure 6 - General model of the evaluation activity – The five steps model

This model aims to propose a definition of the evaluation activity that can be used by the evaluators. It is based on a central sequential process (composed by activities) and on feedback loops. These latter are used in order to allow asking for more knowledge on the evaluation case or to redo some steps when results are not validated.

We consider two types of activities. The first type is about the activities that focus on the upstream of the evaluation activity. They are the “analysis of the study case” and the “design of the methods and indicators”. The second type concerns the operational activities. They are the “data collection”, the “data processing” and the exploitation of the results”. We detail them in the following points:

- “**Analyze of the evaluation case**”: ”: formalization of the evaluation case provides goals and contextual knowledge used by the evaluators to design and execute evaluations. Knowledge on the study case is significant to achieve an evaluation. For instance, this is knowledge on evaluation problems, on the evaluated safety strategy, on the context and on the stakeholders. The evaluators design and adapt their behavior in order to reach goals that they identify during this first step. This step is taken by the evaluators in relation to the stakeholder. The stakeholder expresses (but not automatically) his needs concerning the evaluation, his activity, his assumptions and hiss understanding of the evaluated safety strategy.

- "**Design of the evaluation method and indicator**": this second step is about the design of the indicators and the evaluation methods. It focuses on the selection or/and the construction of the relevant indicators and methods that are used to answer to the declared problem(s). We speak of a design step because of the need to evaluate things that are in constant evolution. Evaluators can reuse methods and indicators that already exist, but sometimes they have to propose new ones.
- "**Data collecting and data selection**", "**data processing**" and "**exploitation of results**" focus on the execution of the methods that were designed earlier (step N°2). These streps are geared to finding the relevant data, to process them and to exploit the results.

We have not considered all the steps of this model; instead we decide to focus on the first steps of the evaluation activity. This decision results from certain observations (which will be detailed below), as well as the constraints of our research work and its context.

We noticed that the first steps of the evaluation activity are those that most need to be enhanced by providing new models. From now on, most of the studies concerning evaluation concern the last three activities. Accident data collecting and statistical methods are the most common fields of research in evaluation. They are as significant as the two first one in the achievement of evaluations. However, we notice a large lack in the formalization in the two first steps while they directly influence the achievement of the three others. This is what explains our decision to focus our research on them. The following points presented some of the main issues on these two steps that we identified:

- As shown previously, it is difficult for evaluators to model knowledge on the study case. Firstly, this inability comes from lacks in the formalization of stakeholders' needs. Evaluators do not have access to this information or/and stakeholders cannot clearly express their needs. Secondly, there is an issue concerning the communication between people from various areas (see the figure on the swing). How can evaluators be sure they are not distorting what they hear? Thirdly, some of the objects/systems to be modeled are complex. Therefore, they are not obvious to model. This is the case for the road safety (see previous section on complexity). In order to overcome these limitations, evaluators need a detailed process that describes the knowledge that must be modeled and the way to do so.
- Concerning the design of the indicators and the methods, we firstly assume that evaluators mainly use their habit to do so. The risk is that the results may not be adapted to the needs. Firstly, this is because the evaluations are not performed according to the needs but mostly according to the operational constraints (availability of the data and the tools). Secondly, there may be not enough tools adapted to the evaluation in the area of road safety. There is a need for tools that will fit the use of indicators and methods with the study cases. This concerns the reuse and the enhancement of the design of new indicators and methods (construction step).

In conclusion, the five steps model provides a general representation of the evaluation activity. We decided to focus on issues that concern the two first steps. According to them, we need definitions and tools that will be used by evaluators in order to improve the evaluation activity. In the next section we detail knowledge that is relevant to model such definitions and tools.

3.1.2. The modelling activity

Modeling activity aims to construct models that depict behavior and structure of systems. For instance, models could be used in a prescriptive way, i.e. to predict future behavior of systems; evaluators have to identify all the possible effects of the introduction of a new safety strategy. It also describes the way to perform an activity such as evaluation.

In this section, we focus on the theories that can be used to deal with issues on the modelling of the evaluation activity and the road system. These issues are about the complexity and the formalization of processes.

Firstly, some theoretical knowledge on epistemology is provided. Designing of models is performing according to a paradigm. It provides some "*rules*" for buildng models. This is a way for seeing the world. In the classical paradigm of modeling, knowledge is absolute and shapes deterministic models of the systems' behavior. Modelers have access to the reality and they are able to build a general model of it. However, this paradigm is not suitable for modeling complex systems. Complexity characterizes the possibility (or chance) of emergence of some new and unexpected behavior. For instance, the introduction of an automatic speed regulator surely implies the emergence of new driving behavior. Due to absolute and deterministic vision of the classical paradigm, this change would not be modeling in a prescriptive way. This change will only be modeled if it appears.

Thereby, there is a need for another modeling paradigm that handles the complexity of road system. It will not replace the classical paradigm; it will be complementary. In our research, we use the systemic paradigm. In France, Le Moigne [Le Moigne, 1999] has formalized and enhanced this paradigm under the concept of "*the general system*". He followed the research of Von Bertalanffy [Von Bertalanffy, 1973] and he was inspired by Morin [Morin, 2005] and Simon [Simon, 1996].

Systemic paradigm was developed in order to provide answer to the limits of the classical modeling paradigm. It proposes a relative vision of the modeling activity when systems are dynamics objects. The general formulation of this paradigm is based on four axes: "***a system is something that exists (ontological viewpoint), that operates (functional viewpoint), that evolves (genetical viewpoint) in a dynamic context by following some goals (teleological viewpoint)***". The major differences with classical paradigm are on the genetical and the teleological axes. Complex changes of the systems can be understood by taking account these two axes. Complex systems change its behavior according to the modifications of their context in order to achieve their intrinsic goals[3]. In this paradigm, modelers are no longer external of the modeled reality; they directly interact with it. Each modeler has his own representation of the world. Thus, models are relative to the modelers.

Modeling activity does not only consider systems or objects, it also concerns activities. This epistemological reflection on modeling activity is usable for evaluation activity. We used the systemic paradigm to design a model of the evaluation activity. This allows modeling the emergence of new indicators or methods. Evaluation is constructed gradually according to the evaluation context and the evaluators' capabilities.

Depending on the complexity of the system to model, we use either systemic or the classical paradigm. They are complementary and the aim is to use them according to the modeling needs.

---

[3] A system acts in order to reach specific goal(s). For instance, a driver acts in order to move to one point to another according to its context (road infrastructure and other road users) and its preferences. The behaviors of the driver are related to its intrinsic knowledge and the context in which he evolves.

Secondly, we focus on knowledge from the knowledge engineering. This scientific field provides the concepts, methods and tools for acquiring and using knowledge. Three modelling approaches are proposed. There is an approach based on the expertise (or bottom-up approach led by the data). There is one on the reuse of existing knowledge (top-down approach or model driven). And the last is a mix of the two others. Our approach is mixed because we use both theoretical knowledge (on evaluation activity and the systemic approach) and expert knowledge of the evaluators. This positioning has led us to conduct workshops on the evaluation activity with stakeholders in automotive safety and other areas.

3.1.3. The design theories

According to the identified issues on design of the methods and the indicators, we have looked for knowledge on this activity. An evaluation has to be done with the aim to propose indicators and methods that are relevant to the expectations and the needs. The continuous changes of these latter leads evaluators to propose new indicators and assessment methods. Nevertheless, we did not identify processes or approaches that allow handling such needs.

From the analysis of the existing theories and the needs we identified the following issues:

- The designed indicators and methods have to be adapted to the evaluation problem(s). Therefore, the design activity has to be linked to the modelling of the evaluations study case. Evaluator performing the design needs to be aware of the expectations. The issue is that we do not have a method yet that allows expressing the expectations.
- Finding theory(s)/process(s) that are adapted to the current evaluators' activity. Indeed, it is impossible to impose new tasks on them if they are not adapted to their activity. This has to be an evolution of their job and not a radical change. For instance, the selected theory has to be understandable, usable and adapted to time constraints.

One has to consider design in terms of problem solving and/or creative processes. Indeed, this activity can be described as a methodological process [Pahl, 1996] and [Gorti, 1998] or as a cognitive process [Lawson, 2003]. The first one considers design as a deterministic and linear process that begins at the specification level and goes to the desired result. The design is then fully described in terms of tasks. The second one considers design as a human cognitive activity. There are no deterministic processes. Design is an activity performed by persons according to their creative behaviour and theories.

We decided that the two viewpoints on design are considered together in our approach to the design of indicators. This solution allows proposing solutions that are adapted to the constraints. The deterministic approach is easy to understand and it is useful when evaluators do not have a lot of time. In contrast, the creative approach is more complex to use because of the specific skills needed and it often needs more time to be performed.

3.2. A systemic framework of the evaluation activity in road safety – Focus on the analyze and design steps

In this section, we present our framework. Its goal is to provide to the evaluators, a guide for performing evaluations. We do not seek a deterministic model because of the incapacity to be exhaustive and the irrelevance compared to our expectations. Our approach is to set a general framework that helps evaluators. It will push them to achieve relevant evaluations according to the concerns presented in Chapter 2.

The following points describe the aims of our framework:

- Firstly, it helps to model knowledge on stakeholders, safety action and context.

- Secondly, it provides models that guide evaluators in designing indicators. This second step uses knowledge that comes from the modelling step. Added to this, performing the design implies the construction of new knowledge or new knowledge is needed. Therefore, there are back loops between these two steps.
- Finally, evaluators' capabilities are significant for evaluation, they are not considered as operators, i.e. people that perform a model that already exist. They use their creative behavior and their expertise to design and to perform evaluations.

We report this approach in the Figure 7.

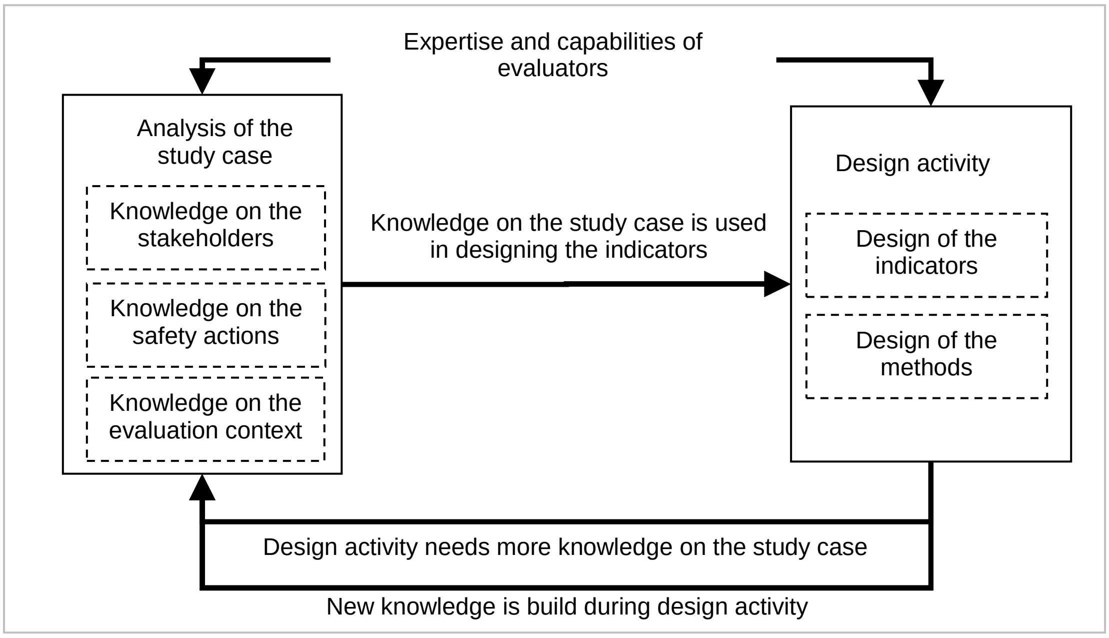

Figure 7 - Objectives of the proposition to frame the two first steps of the evaluation activity

In the section 3.2.1, all the concepts that are relevant for performing an evaluation are described. This is the structural (ontological) presentation. In the section 3.2.2, we present the actions that evaluators have to do in order to fulfill evaluation goals. This is the functional presentation.

3.2.1. The structural model of evaluation activity – The relevant concepts

In order to perform evaluation activity, evaluators use **concepts**. They represent a class of knowledge that is frequently used in evaluations. For instance, the concept "*stakeholder*" is one of them. This useful entity aims to describe people that are connected to an evaluation.

To identify these concepts we studied the evaluation practices and conducted interviews with evaluators. We firstly selected those concepts which are relevant. Then, we defined them (by specifying their attributes). Finally, we validate them through some examples.

The UML language is used to represent the concepts (the class diagram – see Figure 8). It allows describing concepts by the definition of their attributes and the connections between them.

The attributes are information that evaluators need in order to model the concept. For instance, a "*safety strategy*" is characterized by a name, goal(s), human means, financial means, etc.

The connections describe external links that exist between two concepts. It could be association, aggregation, or composition[4]. For instance, aggregation is used to describe an "*evaluation problem*". A problem can be composed of one or many other problem(s). This possibility of decomposition allows searching simpler problems when evaluators face to an unsolvable one.

The following figure depicts all the concepts we identified. Associated with activities, they are all used in order to perform evaluations. We detail them in the Chapter 4.

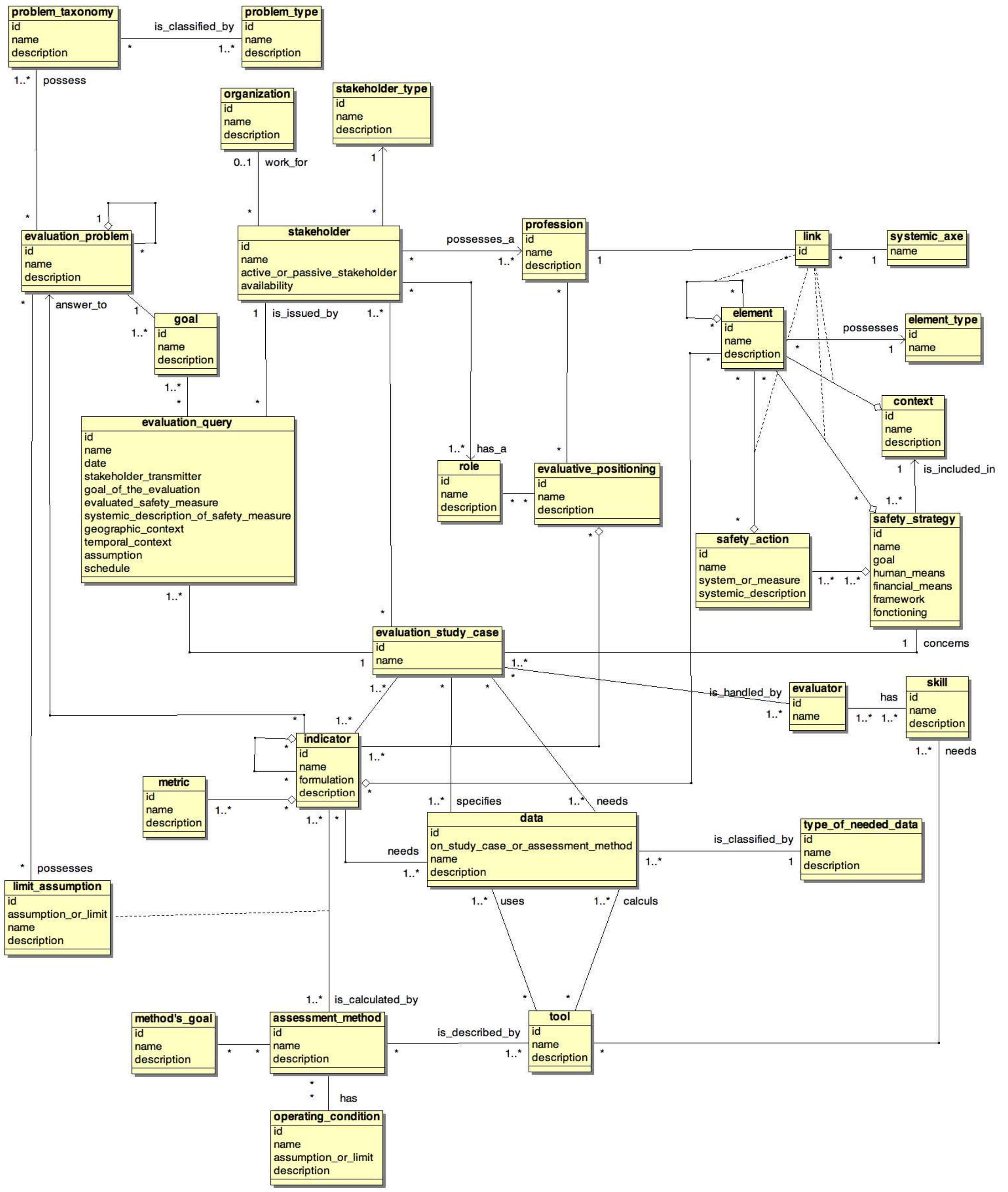

Figure 8 - Class diagram of the relevant concepts for the evaluation activity in road safety.

---

[4] A composition link is close to an aggregation but it is stronger. In a composition, the destruction of the container implies the destruction of every instance. For example, the destruction of the car involves the destruction of its parts.

3.2.2. Functional description of evaluation activity – Activities to perform

The macroscopic model of the evaluation activity (see the five steps model) is decomposed in a more detail model (see Figure 9).

For each of the five steps, their goals are expressed in a use case diagram. This diagram aims to present a graphical overview of the functions to be performed during evaluations in terms of actors, their goals (the use cases), and any links between those use cases.

This new intermediate level of representation of the evaluation activity is detailed below in association with the class diagram (see Chapter 4).

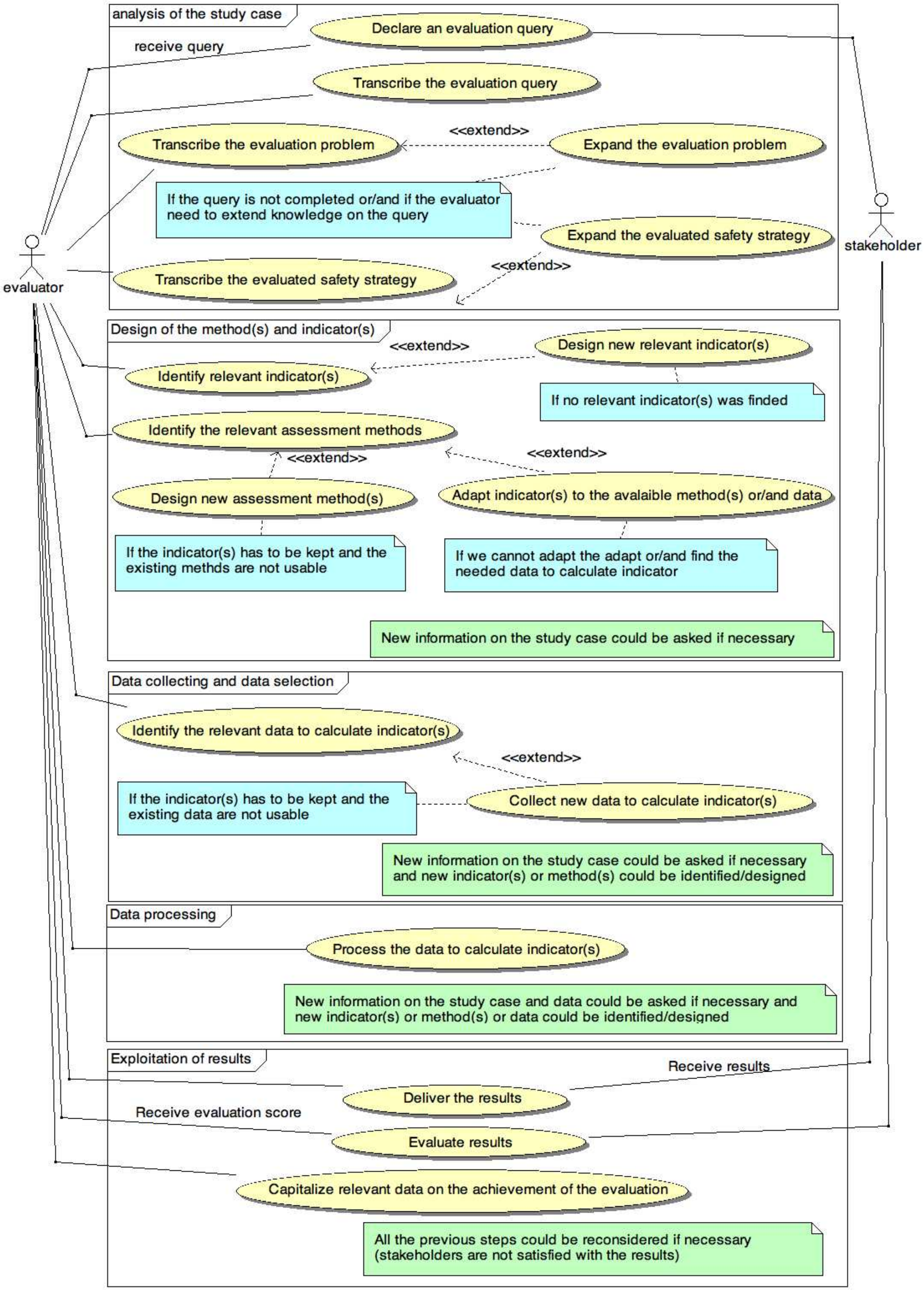

Figure 9 - Use case diagram of the evaluation activity

In order to make operational this functional description, tool and patterns were designed. The tool is a prototype of database (see Figure 10). It is used to fill in forms with information from evaluations. This is for instance the data on the evaluation study case (stakeholders, problems, evaluated safety strategy, etc.). The patterns are generic descriptions that are used to facilitate modelling activity. For instance, we use the Haddon's matrix in order to model a safety strategy (see Table 1). We have also done this work for the description of the evaluation problems and some indicators.

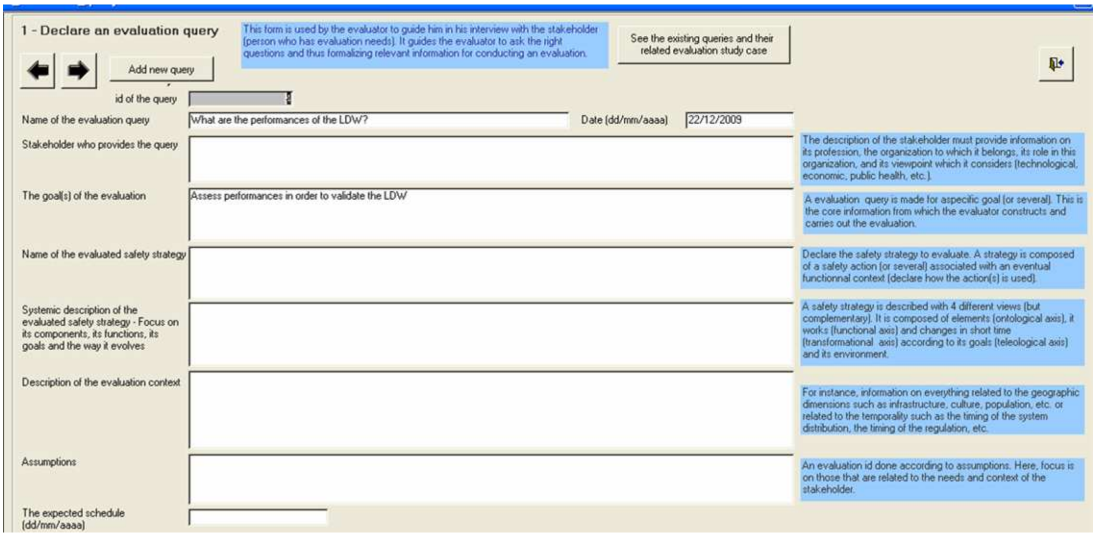

Figure 10 - Print screen of the tool used to perform evaluations (prototype on ACCESS)

<table>
<tr><th></th><th>Primary safety (before the crash)</th><th>Secondary safety (during the crash)</th><th>Tertiary safety (after the crash)</th></tr>
<tr><td>Vehicle</td><td>ESC</td><td></td><td rowspan="2">In-vehicle emergency call system "eCall”</td></tr>
<tr><td>Infrastructure</td><td></td><td></td></tr>
<tr><td>Road user</td><td></td><td>Seat belt</td><td></td></tr>
</table>

Table 1 - Haddon's matrix with examples [Haddon Jr, 1972]

4. DETAILED DESCRIPTION OF THE MODEL

Aim of this chapter is to describe knowledge (definitions) that will be directly usable by evaluators to perform evaluations. As we said before, all the five steps are represented, but only the two first ones are modeled.

For each of the use cases (see Figure 9), we detail the goal, we present the relevant concepts and we expound the tasks to be performed.

4.1. Analysis step of the evaluation study case

In this step, we focus on the way to improve formalization of information on the study case. This implies using guide/forms that push evaluators to search the needed information.

This step is focus on the main following issues:

- What is the relevant information on an evaluation study case?
- Is there any way to consider various stakeholders in a same evaluation study case?
- How can we improve the understanding of the evaluated safety strategy?
- How can evaluators express the evaluation problem they have to handle?

We deal with these issues by providing structural and functional models that allow modeling information on the problem and the safety strategy. It also allows giving the possibility to separate the various stakeholders and their viewpoints (each of them could have specific query).

We designed this step in relation with the following ones. Evaluators formalize relevant information in order to use it to construct indicators and to accomplish the assessment.

4.1.1. Declare an evaluation query

4.1.1.1. Goals

We noticed that evaluators have difficulties in identifying stakeholders' needs. We propose that the evaluators use a questionnaire in order to interact with the stakeholders for the identification of all the relevant information on the study case. Information is about the context, the requirements, the safety measure, the work of the stakeholder, etc. By using this questionnaire, evaluators are able to better understand the stakeholders' needs and their context.

4.1.1.2. The relevant concepts

The major concept for this step is the "*evaluation query*". It regroups all the information that an evaluator should ask from the stakeholder. The evaluation query is about the stakeholder, the goal of the evaluation, the strategy to evaluate, and the context. The most relevant attributes of this concept are those on the evaluation goal and the evaluated safety strategy. For instance, if we consider a stakeholder who wants to evaluate the complete deployment of the "lane departure warning" on all the vehicles (the safety strategy) according to its economic and health objectives (evaluation goal). This information is part of the basis to perform evaluation.

4.1.1.3. Functional description

The following figure express activities that evaluators should perform to model the study case. This figure is based on the structural definition presented before. Evaluator uses the proposed form (questionnaire) in order to seek information on the studied case from the stakeholder.

The major issue in this step is the potential lack in the provided information. If the stakeholder is available, this could be handled. Whichever the case, an evaluation query could not be fully complete. This implies the need to consider activities in order to further develop some parts of the evaluation query.

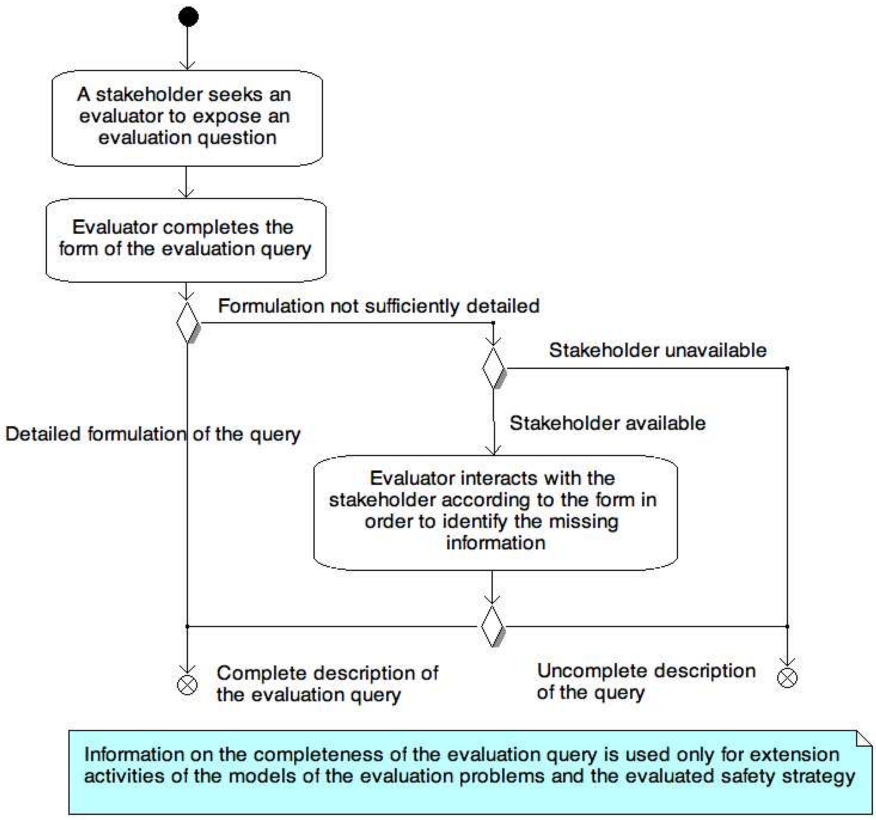

Figure 11 - Activities to perform in order to formalize an evaluation query

4.1.2. Transcribe the evaluation query

4.1.2.1. Goals

At this stage, the structure of the evaluation query is not usable. We need to identify and classify knowledge in order to use them in the following steps of the evaluation. The transcription of the evaluation query aims to adapt the information from the query to the general structural model. For instance, we use information on the stakeholder in order to construct the corresponding concept.

4.1.2.2. The relevant concepts

This step is focus on the following concepts:

- The "*evaluation study case*": it is used in order to make possible the capitalization of evaluations.
- The "*evaluator*" and his "skills": one or more evaluators perform an evaluation according to their skills (mainly used for the operational stages of the assessment).
- The "*stakeholder*": characterization of this concept allows evaluators to better understand the people who ask the evaluation question. The more the evaluators understand the stakeholders, the more they can produce relevant results for them. Therefore, a stakeholder is described by his own intrinsic attributes (name, positioning

according to road safety (maker or user), and availability) and by some external concepts (its role according to the evaluation, his profession, his organization (firm) and his type). All this information allows constructing models of the stakeholder (and its context) that is behind the evaluation query.

- The “*evaluative positioning*” describes the generic viewpoints that are used to lead the evaluations. For instance, the “*public health*” positioning orientates to define the performance of a safety system in relation with the number of saved lives or avoided injuries. Another positioning may lead to another way of defining the performance. The evaluative positionings are linked to the stakeholders (linked to the “*profession*” and the “*role*”) in order to consider their evaluative interest (sensitivity). Finally, the evaluative positioning is described by basic indicators (see Figure 12).
- The “*goal*” is used to describe the aim of the stakeholder in the evaluation study case (it will be used for constructing the evaluation problem that evaluators have to solve).

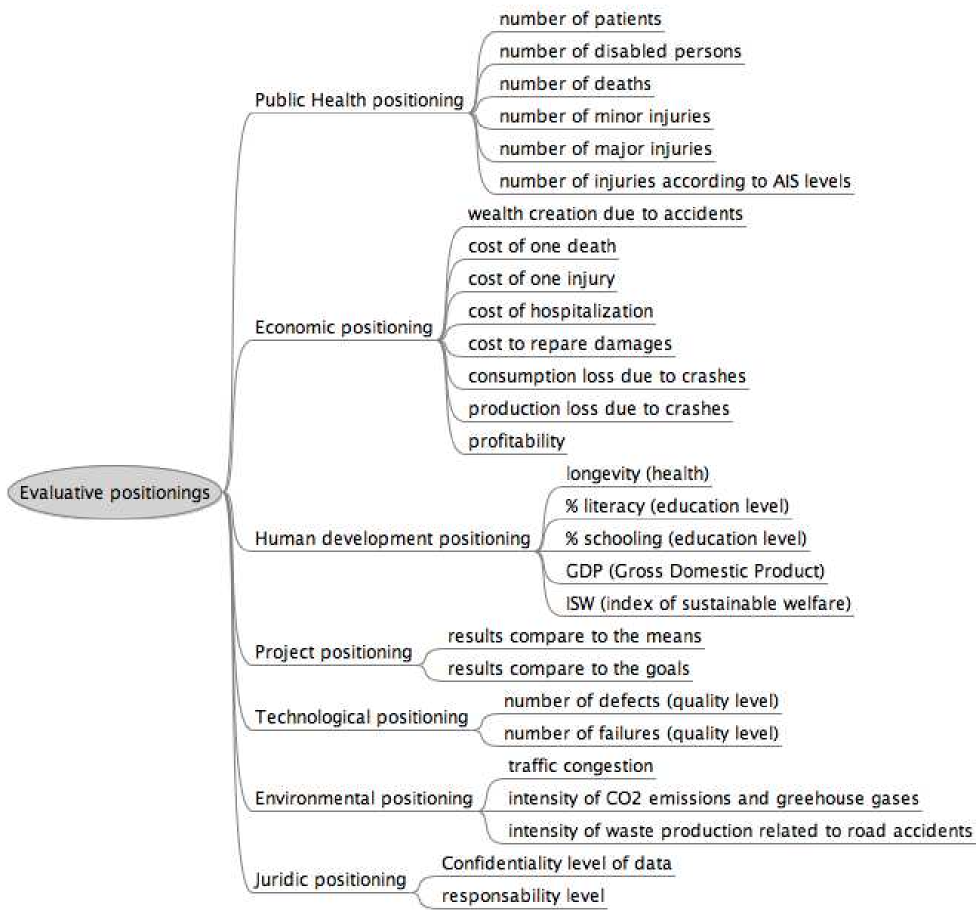

Figure 12 - List of the evaluative positioning and their corresponding basic indicators

4.1.2.3. Functional description

The transcription of the evaluation query is described by the Figure 13. This simple step only focuses on declarations. There is no particular issue.

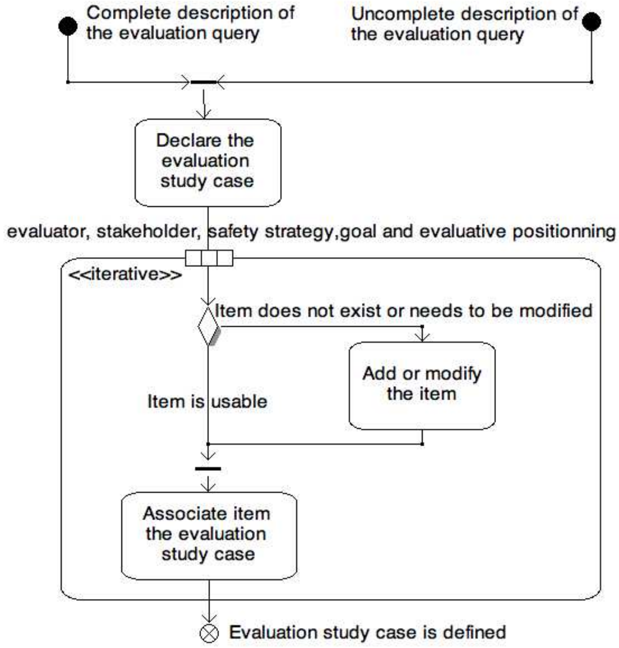

Figure 13 - Activities to perform in order to declare and to specify an evaluation study case

4.1.3. Transcribe the evaluation problem

4.1.3.1. Goals

An evaluation is done to solve a specific problem. However, we notice some shortcomings in its formalization. The aim of this step is to guide the evaluator so as to correctly perform this.

When a stakeholder requests an evaluation, it does not formulate an evaluation problem; he only describes its needs (the goal). Evaluators have to understand those needs and then construct an evaluation problem. The resolution of this problem will provide information that fulfills the needs. For instance the need "*identify the most promising safety systems in order allocate the research funds*" could be linked to the evaluation problem "*how classify the safety systems?*". In this sub-section, knowledge is provided so as to help in the formalization of the evaluation problems.

4.1.3.2. The relevant concepts

This step is focused on the following concepts:

- The "*evaluation problem*" describes what has to be handled through the design and the execution of evaluation. Its resolution allows replying the stakeholders' needs. It is a recursive concept. Indeed, a problem can be divided in sub-problems (they are other evaluation problems). Its formalization depends on certain limits and assumptions, which come from the stakeholders and they affect the carrying out of the evaluation.
- The "*problem taxonomy*" and the "*problem type*". Those two concepts have a dual-purpose: they guide evaluators in the characterization of the problem and they facilitate the reuse of the processed evaluation study cases (attributes that help to identify similar cases). The following table presents some of the types and the taxonomies we identified.

	Selection	Validation	Comparison	Classification	Measurement	Decision	Optimization
Selection of a safety strategy among a sets of possibilities	■		■				
Safety strategy selection (no comparison with alternatives)	■						
Selecting a subset of safety actions systems from another subset	■		■				
Validate/verify a safety action in relation to expectations, assumptions, beliefs, etc…		■					
Decide on the dissemination / extension of the use of a safety system						■	
Work to optimize / improve the safety strategy with respect to a characteristic or relative to a set of characteristics. It can also include finding the best settings or the best package of safety systems							■
Construct a scale/rating tool (need to determine the appropriate tests rating)					■		
Determine what remains to be done to improve road safety						■	
determine whether one can remove an item from a safety strategy with specific constraints						■	
determine if a safety strategy may be replaced by another						■	
Position or establish a comparison with a competitor			■				
Construct a list of the safety strategy according to a given priority				■			

Table 2 - List of the taxonomies (lines), the types (columns) and their corresponding associations

4.1.3.3. Functional description

Evaluators define evaluation problems according to the stakeholders' needs. The aim is to formulate a problem so as to provide knowledge that is usable for fulfilling the expressed needs. This task can only be done by the evaluators (an evaluation calls for some specific skills). Following this, evaluators characterize the problem (see Figure 14).

In some cases, when the evaluators can not find solutions (calculable indicators) to the original problem, it is possible to decompose that problem in sub-problems. The aim is to identify some new problem for which evaluators are able to find good solution(s). Keeping in mind the elements from the initial problem and the blockade points, evaluators identify new needs that will be used to construct the sub-problem.

The Figure 15 is focused on the way to construct or to expand the evaluation problem. This proposition is related to our will to identify problems that are not expressed but relevant for stakeholders. To do this, three approaches are proposed. The first one is based on previous evaluations. Evaluators seek evaluation study cases that are similar and for which the problem characterization could be shared. The second is based on the analysis of the safety strategy. New issues could identify according to the current/future outcomes of the strategy. Finally, the third one relies on the addition of new stakeholders.

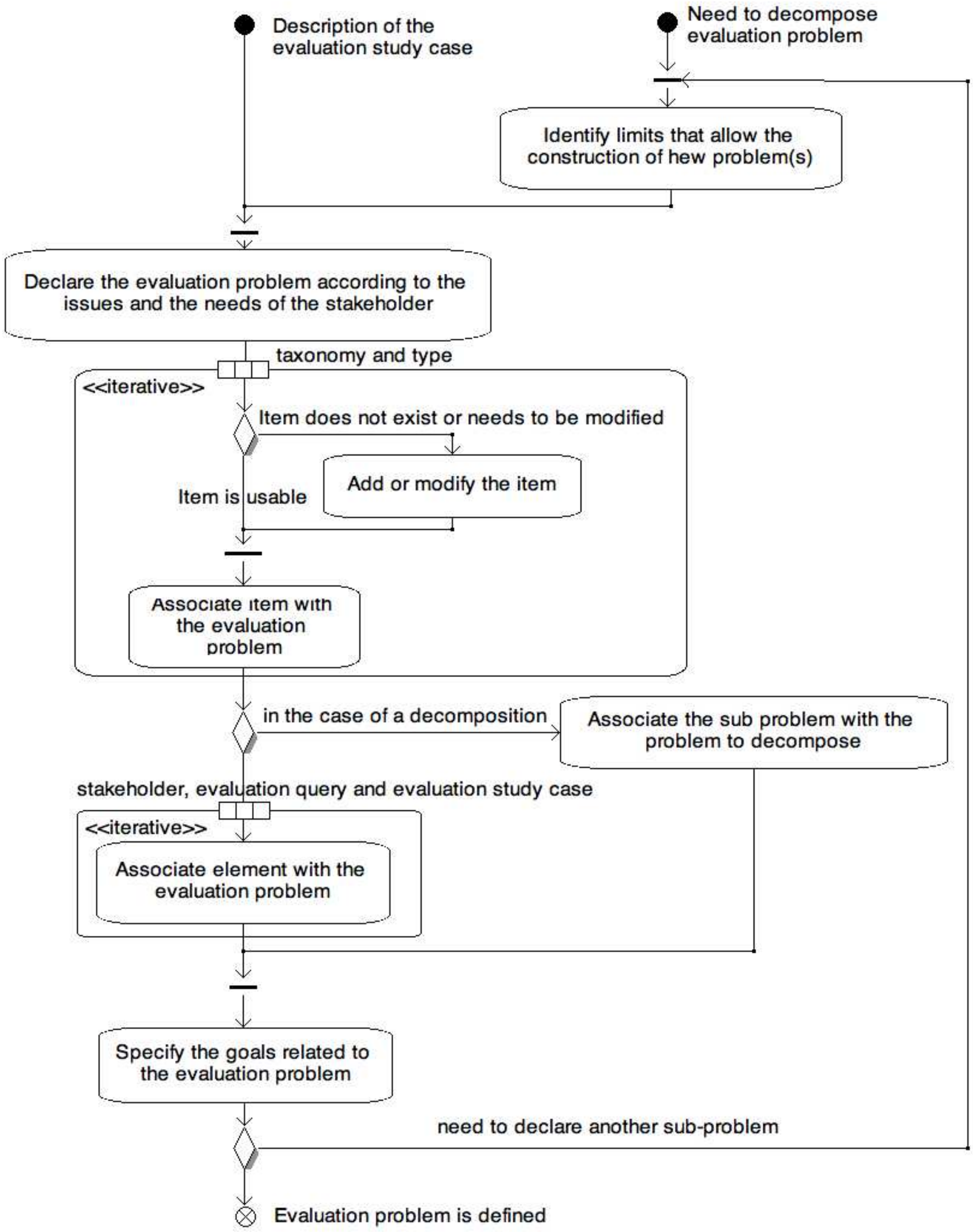

Figure 14 - Definition of evaluation problem

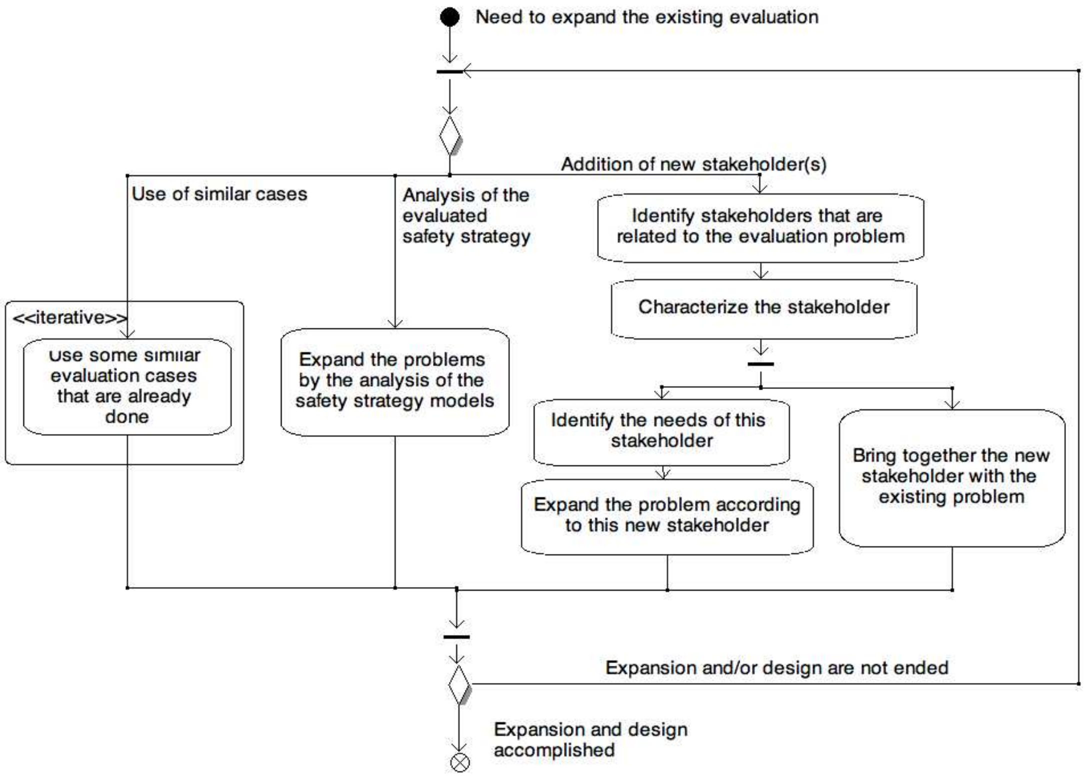

Figure 15 - Construction and expansion of the evaluation problem

4.1.4. Transcribe the evaluated safety strategy

4.1.4.1. Goals

We have already noticed the difficulty to deal with the complexity of the evaluated safety strategy (unpredictable behavior). In order to handle this issue, we propose a meta-model that allows modeling a safety strategy according to the systemic viewpoint (four axes). This model does not provide an absolute way to manage complexity; it only gives some guidelines that push evaluators to consider all the dimensions of a system. A safety strategy exists (one can define it), it works and evolves in a changing context according to its goals. This way of thinking allows considering a general vision of a strategy in relation with its context.

4.1.4.2. The relevant concepts

The relevant concepts for this stage are:

- "*Safety strategy*" describes the implementation of safety actions in order to reach a specific goal (in some case, it could be limited to a single safety action). Safety action(s) is (are) considered in an operational context. It is possible to have the same safety actions in various safety strategies. Actions are absolute but the strategies are context depending.
- "*Safety action*" is the structural element that composes the safety strategy. It could be a safety technological system (seat belt, airbag, ESC, etc.) or a safety policy (regulation, training, etc.). We use the Haddon matrix to characterize it.
- "*Context*" gives information on the items that surround the safety strategy and impact its functioning. For instance, it is about the target population, the economic considerations, the infrastructure, etc. We assume that the consideration of the context is significant in evaluation's achievement.

In order to describe all these three concepts (safety strategy, safety action and context), two further concepts are added: the "*element*" and the "*link*". They are basic pieces that allow constructing systemic models.

"Element" describes the systemic aspects (ontological, functional, transformational and teleological) of the modeled systems. For instance, a "speed sensor" is an element used to describe the ontological aspect of the ESC according to the engineering viewpoint. Each element is characterized by a type (see the Table 3).

Component	Element used to describe an ontology (structural description)
Model	Statement, with a logical value[5], used to describe the operation, the alteration, or the goal of an element or combination of elements. That such functional model used to describe a technological system.
Modeling concept	Abstract idea without a logical value[6]. It stands a real phenomenon and is used by other elements such as models. Example of the concept of "*break*" in the sequential model used for understanding the accidents
Characteristic	Attribute that characterizes all modeled elements. For instance, the component velocity sensor is characterized by a price, a result (an estimated value of speed), operating resources, an operating nominal voltage, etc..

Table 3 - List of the element types

"*Link*": concept used to characterize the interactions between elements and between elements and safety strategies / actions and context. Characterization of links includes the choice of the systemic axis and the choice of the modeling viewpoint (transcribed by the profession).

4.1.4.3. Functional description

The proposed modeling structure of the safety strategy aims to guide evaluators to handle a general vision (they have to consider the four systemic axes). Evaluators firstly declare the safety action and the context (this step is independent of the modeling viewpoint). Then they construct models by using the concepts "element" and "link". This step is details in the following figure:

[5] A statement with a logical value implies that one can say if the statement is true or false.

[6] One cannot say if a statement is true or false if it does not have a logical value.

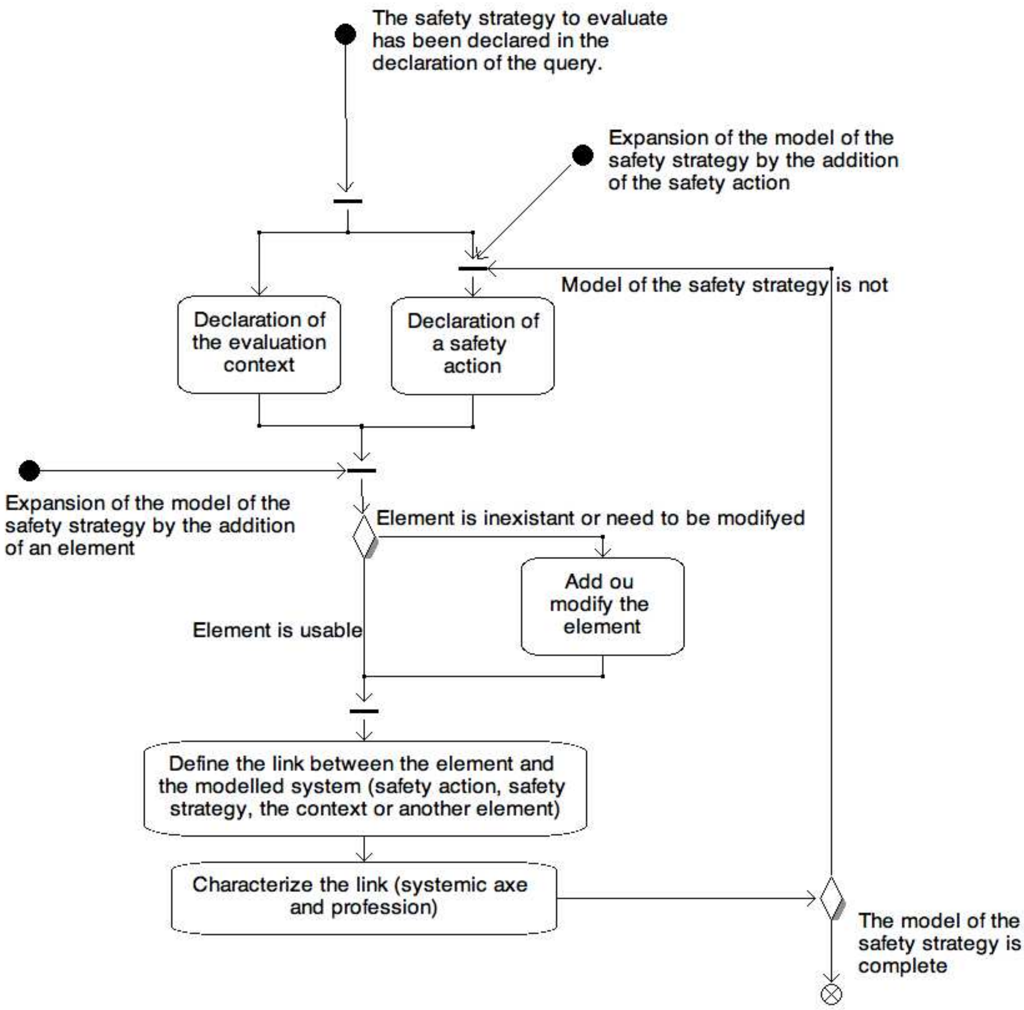

Figure 16 - Establishment of models of the safety strategy, the context and safety action

4.2. “Design” of the indicators

According to the significance of indicators, their selection and their design are sensitive steps. Evaluators have to use their expertise, information on previous evaluations and description of the study cases in order to find/construct the relevant indicators. We propose three processes that could be complementary: one selection method and two design methods. Before presenting these methods, we start by our description of the indicator.

4.2.1. Definition of the indicator

Firstly, an indicator has a mathematical formulation that is based on a composition of different elements (metric, basic indicator and attribute). The choices done by the evaluators during its construction is justified by the assumptions and constraints of the evaluation case.

Secondly, an indicator is used to measure objectively the performance of a safety strategy with the aim of helping the recipient to carry out his business. This performance can be defined along several dimensions. For example it is possible to seek an overall performance of a strategy by considering the combination of performance in public health and economic performance. We recall that an indicator has a purpose with respect to a stakeholder (the recipient of the value of the indicator). Its use allows the implementation of activities such as decision making, design, optimization, etc.

Thirdly, the calculation of the indicators requires tools, methods and data. The usability of an indicator directly depends on the existence or availability of these three elements. Nevertheless, we believe that the generation of incalculable indicators allows identifying research perspective on operational tools. This is for example the need to develop new methods of data collection (collecting new data, changes in measurement tools or use existing tools in other areas).

Finally, an indicator is an object that may have to evolve over time. This reflects the evolution of evaluation cases: a strategy that changes and / or expectations of stakeholders that change and / or valuation issues that change. Our definition of the indicator implies that such changes lead to its revision.

In the following sub-sections, we detail the structural definition of an indicator according to the other proposed models (see previous sections).

4.2.1.1. The metric

The first relevant element for the construction of the indicators is the “metric”. It is used to define the different possibilities of existing measures. We define this concept as follows:

M = set of metrics or measures such as number, percentage, distance, speed, strength, temperature, pressure, cost, etc.

M = {*m* is a metric}

Metrics are basic building blocks that have no meaning when taken individually. For instance, metrics "speed" has no meaning. It is necessary to combine it with another element. However, the term "bike speed" has a meaning in the context of evaluation.

4.2.1.2. Basic/elementary indicators

We propose a recursive definition of indicators. It is possible to describe an indicator with the composition of other indicators. This definition implies existence of low-level indicators that are used to build others. These are the basic indicators. Their characteristics are to be irreducible, to be valid and be related to an evaluative positioning (see below).

To use these basic indicators, we attach them to one or more evaluative positioning. These are the various domains linked to road safety, such as public health, technology, economy, politics and ecology.

The significance of this association is the creation of a link between stakeholders and the basic indicators. Indeed, a stakeholder has at least one positioning. Therefore, evaluators can identify the basic indicators relevant to a specific stakeholder. This task gives him some of the knowledge needful to design comprehensive indicators.

We synthesize this proposed structure in the following figure (see also the Figure 12):

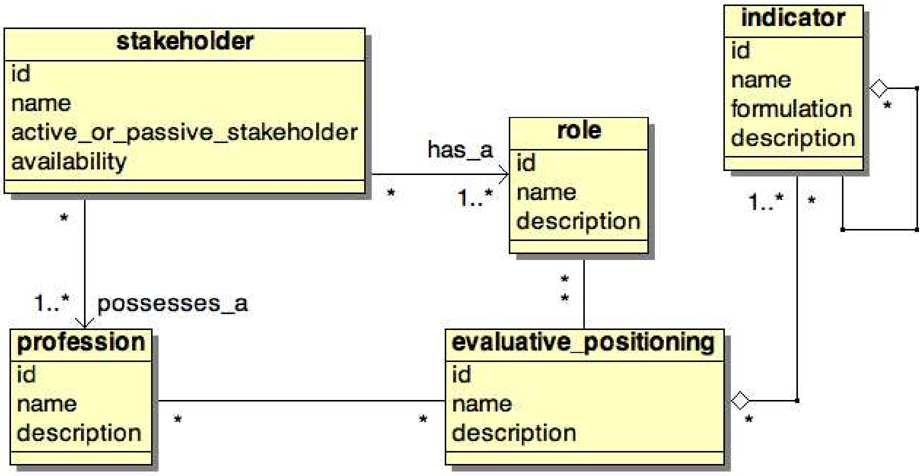

Figure 17 - Class diagram of the stakeholder

Two approaches were used to identify basic indicators. The first one is to find basic indicators that already exist through analysis of practices in road safety. This work has allowed the construction of a list of basic indicators. It was also helpful to build a conceptual model (see previous figures).

The second approach is to use the structure of the conceptual model to generate basic indicators. This means using the metrics and the elements that describe evaluated safety action and its context. This allows offering basic indicators by combining metrics and descriptive elements (example of "speed bike" - it can be considered a basic indicator).

We define basic indicators and modeling elements as follows:

Elt = all elements that are parts of the models of safety actions and their context.

Elt = {*elt is a modeling component*}

Ie = set of basic indicators that consist of metric and element. They are classified according to the evaluative positioning. This set is included in the set I (set of indicators).

$$Ie = \{ie_1, ie_2, Ie_3, \ldots, ie_n\} = \{\exists\ elt \in Elt, \exists\ m \in M, ie = f(elt, m)\}$$

$$Ie \subset I$$

The following figure synthetisizes these definitions. It represents the various concepts related to the indicator.

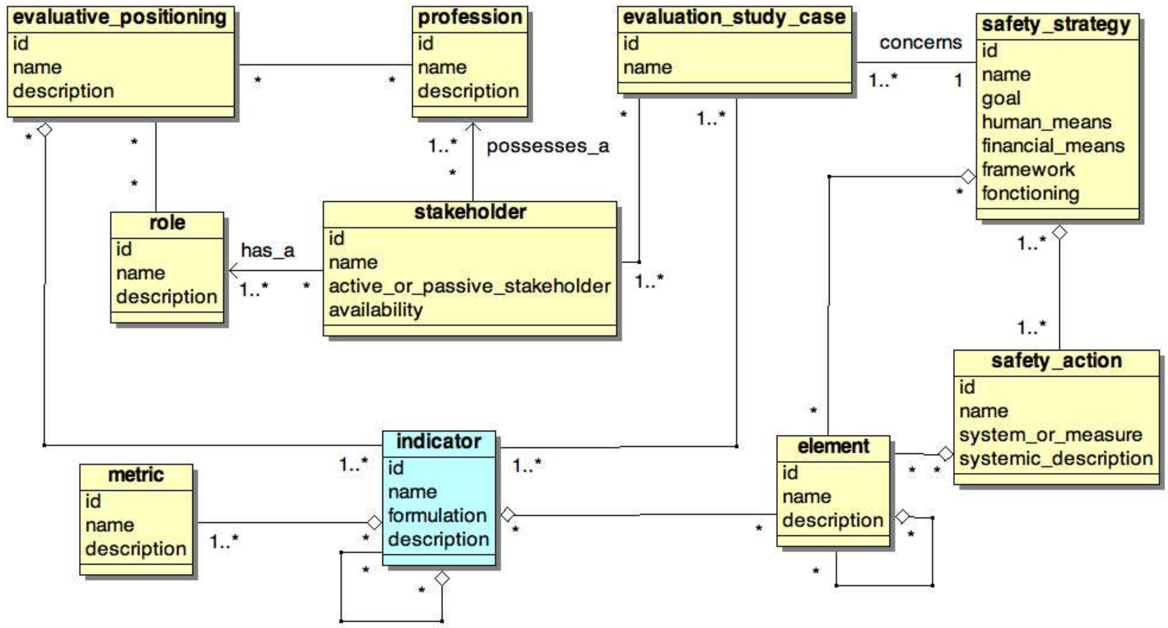

Figure 18 - Class diagram with all concepts connected to indicator

Indicators are objects made of modeling elements, basic indicators and / or indicators. The presence of a basic indicator in each indicator allows the integration of at least one metric in the definition.

This definition is an extension of the definition of basic indicators. This latter provides basis to define indicators.

We propose the following definition:

I= set of objects which are composed of modeling element(s), basic indicator(s) and other(s) indicator(s). These components are organized according to the composition rules.

We summarize the definition using the following expression:

$$I = \{i_1, i_2, i_3, \ldots, i_n\} = \{\exists\, elt \in Elt, \exists\, ie \in IE, \exists\, I \in I, i = f(elt, ie, i)\}$$

$$\text{With } Ie \subset I$$

We illustrate this definition by the following example of indicator:

$$I1 = (\text{fatalities in 2010} - \text{fatalities in 2009}) / (\sum \text{cost of safety actions})$$

"*i1*" is an indicator that provides information on the relationship between the saved lives over a year and the overall cost of the various strategies implemented during this year. "Number of fatalities" is a basic indicator that we consider according to years. He might be associated with a country, a class of people, etc. Regarding costs, we combine the basic indicator "cost" to all safety actions.

4.2.2. Selection of the relevant indicators

4.2.3. Goals

The selection requires an existing set of indicators in which evaluators chose the relevant one(s). A relevant indicator provides knowledge that is used to answer the formalized problem of the study case. Nevertheless, how can evaluators decide which indicators can be used?

4.2.3.1. Functional description

We propose a solution that uses the structure of our model. A case study is decomposed in various items. Some of them are normalized, i.e. lists of types or taxonomies exist. Therefore, depending on previous study cases, there are links between the existing indicators and the present study case. Evaluators can use these connections in order to find similar study case and reuse indicators.

To use this method, substantial lists of indicators and study cases are needed. This condition is not fulfilled because of the lack of previous study cases (performed according to our model).

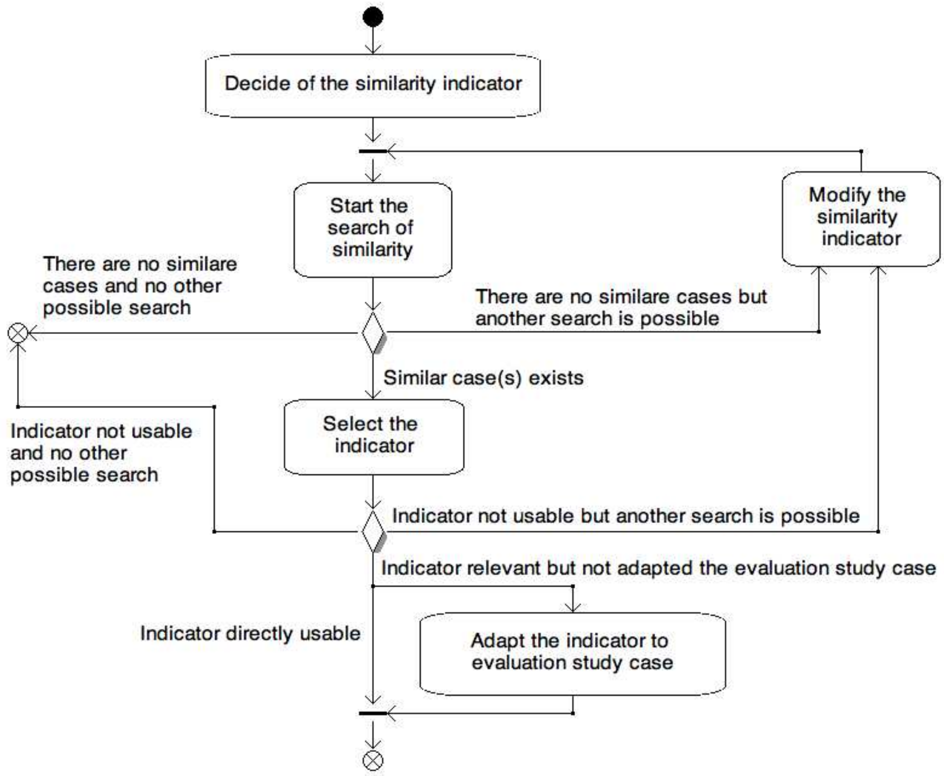

Figure 19 - Selection of the relevant indicator(s) according to similarity

4.2.4. Creative approach to design indicators

4.2.4.1. Goals

Our first method used to design new indicators is based on a creative approach. It aims to organize thinking by using existing knowledge in order to construct new propositions of indicators.

This method aims to create new **concepts of indicator** according to current knowledge. Concepts of indicator are propositions that do not have a logical status, one cannot say if the concepts are true or not. Firstly, they are generated by the exploration of the existing knowledge or with the addition of new knowledge. Secondly, the aim is to extend the set of concepts (extension or specialization). Finally, evaluators seek to validate them in order to make them indicators (not concepts).

This method is based on the C-K theory developed by [Hatchuel, 2003].

4.2.4.2. Functional description

The concepts and knowledge are grouped in their respective spaces: the concepts space (C) and the knowledge space (K). The Figure 20 describes the four operations that are parts of the design reasoning.

- **K to C**: creation of concepts from the knowledge space, it is the rise of the concepts. Any design reasoning must begin with the formulation of a concept (innovative proposal without logical status) from the proposals K,
- **C to K**: this is the end of the design reasoning. The design is complete when the evaluator know that the properties of the concept has a logical status, then the concept is transformed into knowledge,
- **C to C**: rules of partition and inclusion in the set theory,
- **K to K**: logic rules that allow the proper expansion of the knowledge space (inference or experimentation).

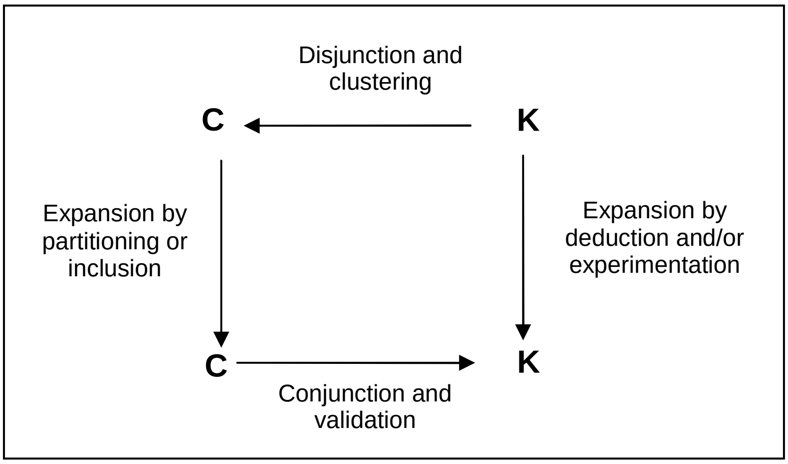

Figure 20 - The design square [Hatchuel, 2003]

The Figure 21 illustrates this design reasoning. We develop a simple example on the selection of a safety strategy. The aim is to generate an indicator that will answer to the following evaluation problem: "*how to select the strategy to put in place?*". Following this problem formulation, the knowledge on evaluation (see the basic indicators for example) and the design approach, a concept of indicator is proposed: "*an indicator that allows deciding the selection of a strategy*". The activation of knowledge on the evaluative positioning leads to the construction of new evaluative indicators. Utilization of knowledge on the context is used to construct a complete indicator. This latter has still to be subject to validation.

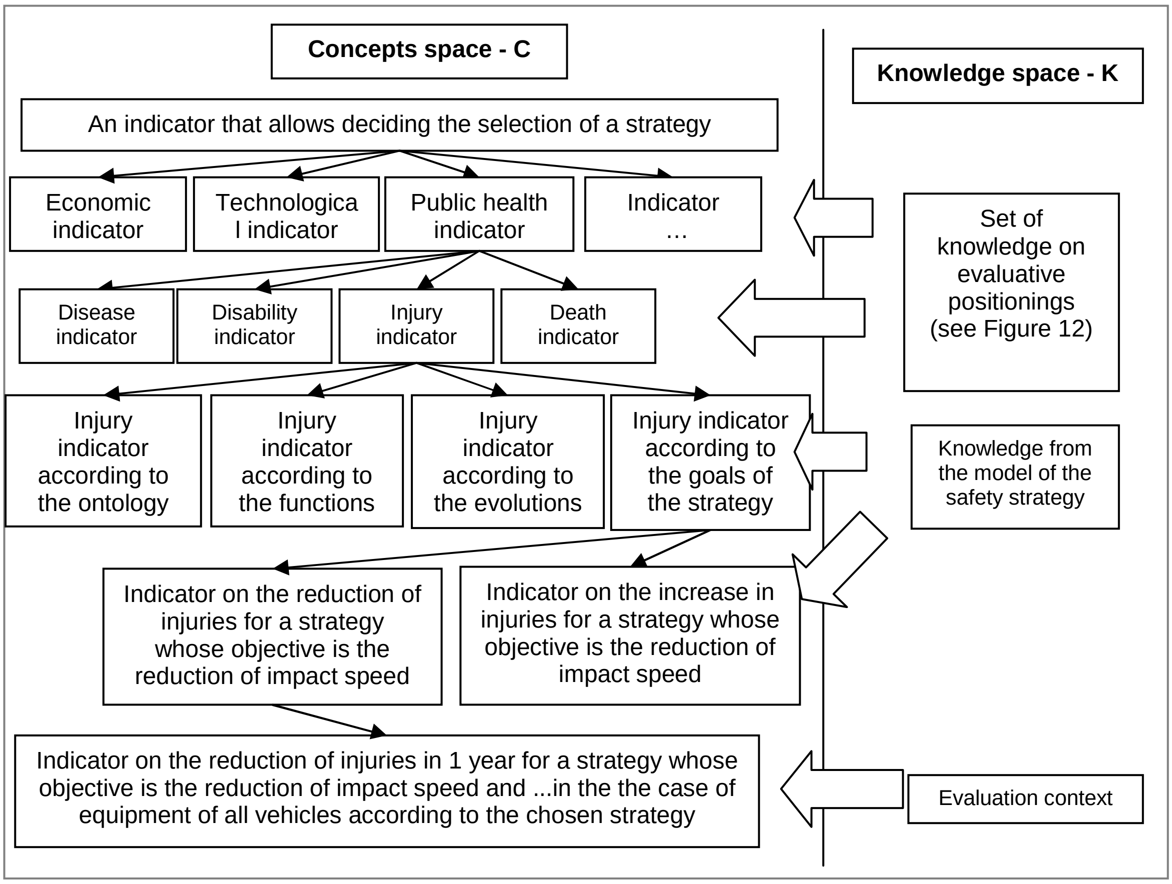

Figure 21 - example of the generation of an indicator from the creative approach

4.2.5. Automatic approach

4.2.5.1. Goals

The creative approach requires specific abilities from evaluators and time to be performed. Therefore, it may happen that this approach is not be applicable. Another method easier to implement might be needed.

We develop a method that “automatically” combines knowledge (items from the structural-model) in order to create indicators. This method uses a structural definition of indicator, some composing rules and items that describe the study case.

4.2.5.2. Functional description

We use a compositional grammar to generate proposals. It aims at structuring the different components used to set the indicators.

The grammar is composed of operators which are expressed in a mathematical and literal formalism. The following table provides the expressions:

Expression	Formulation	Examples
Linked to	i_1 / i_2	Fatalities/engineering cost to develop a safety measure
Amplified by	$i_1 * i_2$	Performance of a system * percentage of road properly delimited
Limited by	$i_1 - i_2$	Performance of safety measure 1 - Performance of safety measure 2
Concatenated with	$i_1 + i_2$	Performance in reducing fatalities + performance to reduce injuries
Associated with	i_1elt_1	Maintenance cost of the airbag

Table 4 - List of the operators and examples of utilization

Our proposal for the generation of indicators is based on the definitions we have given so far. The principle is to generate indicators based on the available knowledge. These components are those related to an evaluation case, they are obtained by modeling (activity performed by the evaluator). The construction of indicators is therefore based on the use of different operators and existing databases (see Figure 22).

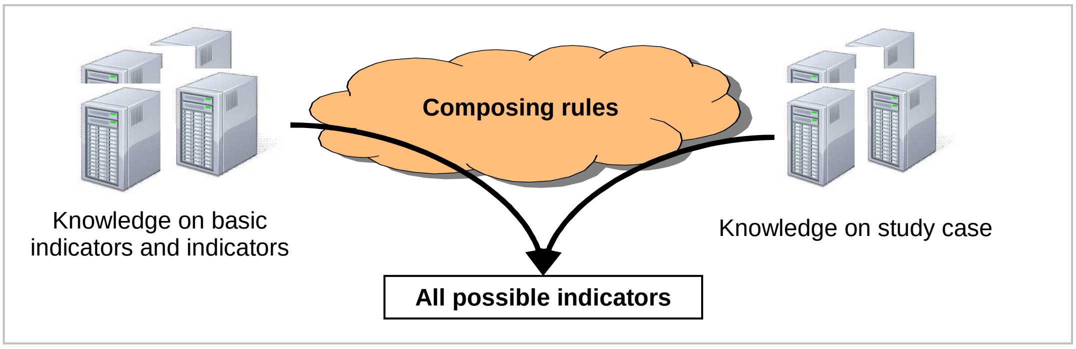

Figure 22 - Representation of the construction of the building

In addition to the compositional grammar, we propose a grammar that allows indicators to evolve. It is based on potential changes to some elements of context. For instance, we use the following concepts: add/remove, enlarge-exalt/degrade and bind/unbind. The objective here is to force the evaluators to conduct a reflection on the indicators so as to anticipate changes in the environment.

Let us consider a project to build a new hospital in a given geographic area in order to illustrate this approach. To be approved by the funders, the project leader has to provide evidences at the first stage of the needs for the local authorities and policy makers.

Apart from daily in-house and at-work accidents, roads and their related infrastructure are one of the main locations of accidents. The project leader has to gather those evidences from professionals. The general practice is to push a request to experts in accidentology to get some knowledge that will support the project.

To be more specific, the project leader would expect indicators that show the need to have in this geographic area a health operator so as to save the maximum of injured persons. In the reality, this is a naive expectation. Experts in accidentology have to understand the reason of the request so that to adapt to it and generate more significant indicators. The question is how?

To generate the indicators, we first provide a description of a hospital. We consider the following elements (components, operating models, etc.). Evaluators seek to model knowledge on the case study according to the concepts we proposed.

- Staff: the number, type of staff, qualification, specialty, organization,
- Characteristics of the hospital: hospital size, number of beds, equipment used, the budget
- The location - the environment: work area, type and number of cases to care, access to hospital (road density, traffic density)

According to the context and the question, we decided to select the public health positioning (see figure with the basic indicators). We are now able to generate indicators: we have a list of basic indicators and items on the case study.

We firstly consider the performance of the structure according to the number of crashes and the available equipments. We propose six indicators that we are going to review (see the table below). They are built with data on the study case (characteristics of the hospital) and basic indicators.

i_1 = (No. of crashes per day) / (No. of hospital beds)	i_2 = (No. of crashes per week) / (No. of hospital beds)	i_3 = (No. of crashes per month) / (No. of hospital beds)
i_4 = (No. of crashes per day) / (staff No.)	i_5 = (No. of crashes per week) / (staff No.)	iI_6 = (No. of crashes per month) / (staff No.)

Table 5 - List of possible indicators to evaluate hospital's performance

In the table, columns express variation on the assessment of crashes (per day, per week and per month) and lines express variation on type of equipment that we review.

At first glance, it is more relevant to consider accident per day because of the use (occupation) of the equipment and available staff. Regarding the hospital beds and staff, we consider that they are both relevant to our question. However, number of crashes is not enough relevant for hospital. It does not inform on the number of injured people. An accident may lead to various levels of injury (including dead or no injury). We have to look for indicators that are more precise.

Therefore, we secondly consider performance of the hospital according to the accident types (in terms of injury level and types) and the capabilities of the hospital. For instance, we focus on crashes that causing fractures of bones. Two relevant proposals are selected (see table below):

i_7 =(number of injuries with bone fractures per day) / (staff number in trauma service)
I_8 = (number of injuries with bone fractures per day) / (number of beds in trauma service)

Table 6 - The two relevant indicators

5. WORK TO BE DONE

In this part, we focus on the selection/design of the assessment methods (they are used to calculate indicators). A draft proposition is proposed according to the needs. However, some developments are still needed. They concern the validation or the improvement of the proposition and above all the modeling of the assessment methods (according to the ontological structure).

5.1. "Selection/Design" of the assessment methods

The constructed models are of two kinds: the structural models and the functional models. The first ones are class diagrams in which all the relevant concepts are detailed. Evaluators rely on these concepts in order to identify and to model all the relevant information to perform evaluations. The second sort of models refers to the activities that evaluators should perform.

We constructed models only for the first step (analysis of the study case) and for one part of the second step (design of indicators). Now, the aim is to round out these models by providing assessment method(s).

The step "*selection/design of the assessment methods*" aims to select/construct assessment[7] methods that will be used to calculate indicators. An assessment method is firstly described by its "goal(s)". It inquires on why the method is used. Secondly, the "tool(s)" describe the structural aspects of a method. This is for example the logistic regression. It is seen as the basic elements of the assessment methods. Finally, the tools have to be organized in order for them to become a method.

This is a significant step because of the interaction between designers and makers (people involved in the evaluation activity). It connects analysis/design and the operational steps. The consequences of this connection are the occurrences of new issues that come from the will for calculating indicators. One must be able to find the appropriate method. However, it may be possible that it does not exist or that the necessary data are not available. In both cases, solutions are needed.

This way of performing evaluation differs from the usual process. Indeed, limits, assumptions or constraints on data and methods are not taken in account from the beginning of the evaluation. In our model, we seek first to provide the relevant indicators according to the stakeholders' needs. Then, we seek the method to calculate them. The operational issues do not interfere with the design steps.

Three processes are needed in order to perform this step: a process to select relevant methods, a process to design new assessment method and a process to redesign/adapt the indicators (drafts solutions are proposed – see below).

5.1.1. Identify the relevant assessment method(s)

5.1.1.1. Goals

The first model is related to the selection of the methods for calculating indicators. Evaluators seek the methods that are directly usable. The selection is done depending on

---

[7] We use the terms "assessment" and not "evaluation". The latter refers to the whole process: design, realization, and validation, while "assessment" refers to the computational aspects of the evaluation.

parameters such as the available data, the evaluators' abilities, the assumptions, the limits, etc (see Figure 23).

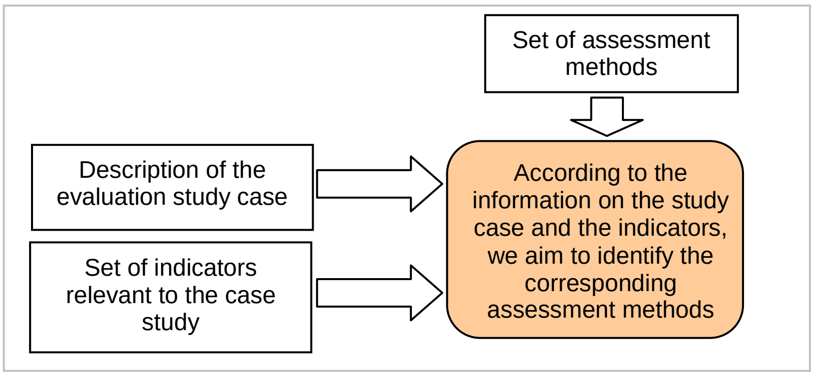

Figure 23 - Selection of the assessment methods

Currently this step is done according to the expertise of evaluators. This could mean that they only used methods they master (but which are not necessarily the most effective). One way to explain this issue is the lack of decision three. Evaluators do not have assistance for finding the relevant methods. Therefore, we seek a way to formalize this step by providing a tool that will help the decisions. It will also be used to justify and to capitalize actions (keep in memories the linked between a study case and an assessment method). We propose a draft model to handle this issue in the following point.

5.1.1.2. The draft propositions

The Figure 24 is an example that presents a structuring diagram of an assessment method. Various tools describe the "assessment method 1". In this figure, various sorts of data are represented; they are the used and the calculated data. Depending on the described tools, data could be both of these sorts (CD4 = UD6).

The major idea of this figure is to present the way we model an assessment method. This description can be understood at two levels: a generic level and a detailed level. That means, we can used it to described the assessment method (generic viewpoint[8]) and to described an evaluation study case (operational/detailed viewpoint). For the moment, we focus on the generic viewpoint.

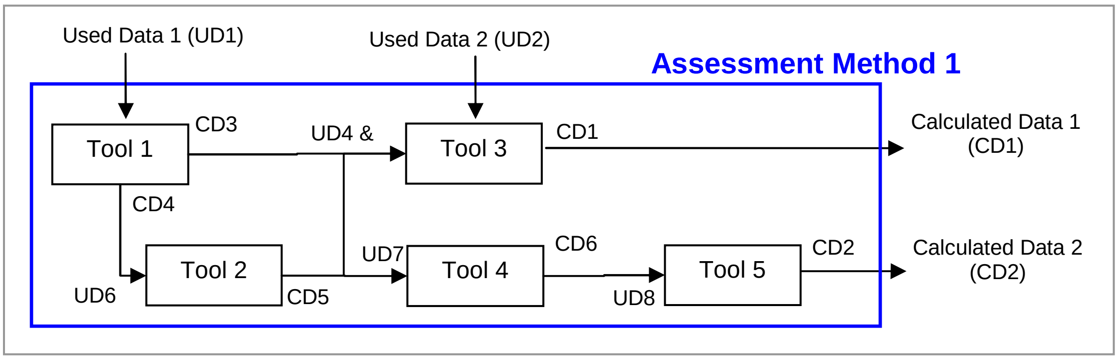

Figure 24 - Description of an evaluation method

The selection of the relevant assessment method implies the ability to link the needs with the opportunities. We propose a solution that linked the description of the study case, the indicators and the assessment methods. To do this, we use the notion of "data". The

---

[8] We need to find a generic description of some of the concepts we use (data, methods' goals, tools, etc.). This allows providing characterizations that are reusable and that facilitate the identification and the selection of the relevant information.

evaluators can describe the needed data for calculating indicators and we know, by experience, the data that the methods provide. Therefore, it is possible to identify the relevant method thanks to the possible similitude between the needed and the resulting data. We summarize the proposition in the Figure 25.

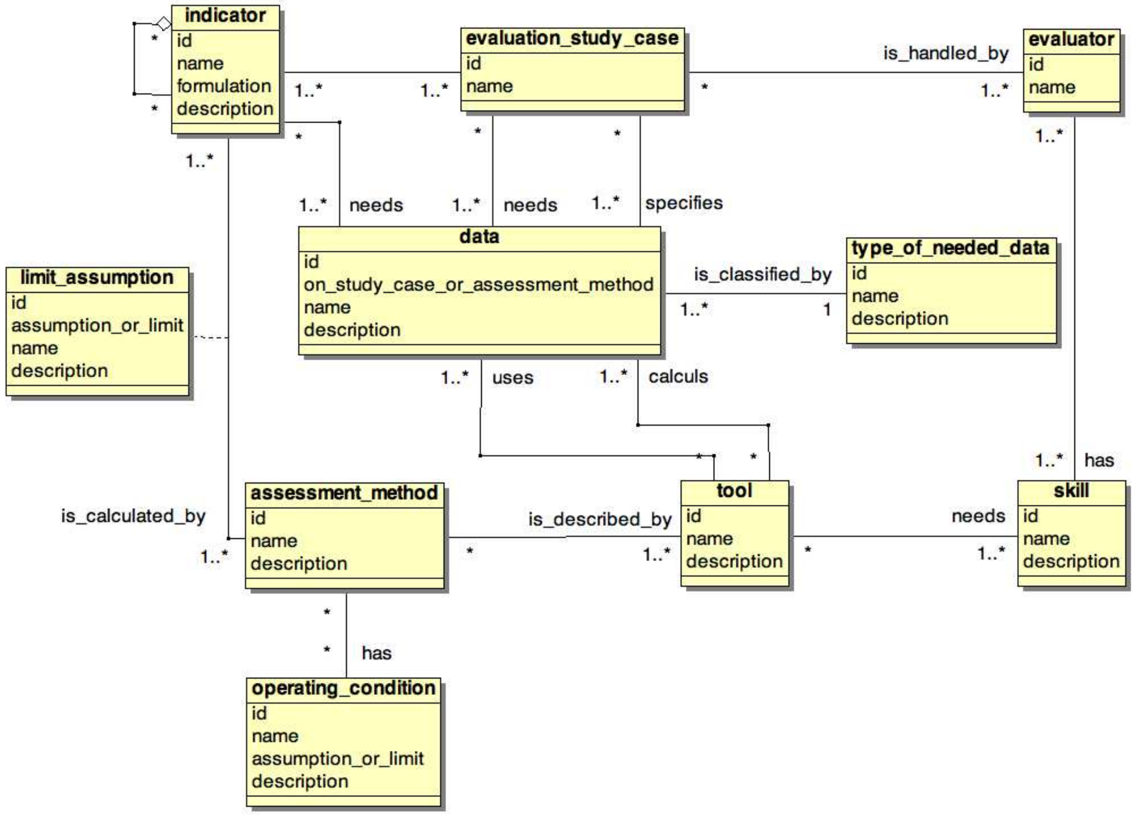

Figure 25 - Description of the data and relations with other concepts

5.1.2. Design of new assessment methods

In the case of no relevant methods were found and if the indicators cannot be changed, reflection on new methods is needed. This work has to be done according to the identified issues. Therefore, a contextual approach is needed. For the moment, we have not formalized a model to perform such an activity. Further work has to be done in this direction.

5.1.3. Adapt/redesign indicator(s) to the available method and/or data

Sometimes, relevant indicators cannot be measured because of the lacks of tools or/and data. Solutions have to be found. One solution is to redesign or to adapt the indicators. This has to be done according to the available data/tools and the study case. However, even if an alternative is found, evaluators have to keep in mind the identified prospects for improvement. The second one is to expand knowledge (data and/or tools). This implies having time and resources.

6. CONCLUSION

6.1. Synthesis

The result of our research is a theoretical framework of the evaluation activity that aims to guide evaluators. This proposal is based on the expertise and capabilities of evaluators as well as on tools for modeling and design. To build such a framework, we used knowledge on the systemic paradigm and on the evaluation activity (the five steps model).

We focused on the description of the analysis phases of the evaluation study case and the design of indicators (first part of the design step). This choice is motivated by the fact that the need for models and methods is more important for the early stages of the evaluation activity. The other steps, that are operational, are already the subject of numerous studies (establishment of a European road safety observatory or the development of statistical tools).

The first phase aims to model the evaluation study case. The models to construct are those on the stakeholders and their expectations, on the safety strategy and on the evaluation context. To achieve this goal, we developed two approaches. The first is used to model the evaluation problems (in terms of formalization and construction) (see Figure 26). The second allows the modeling of evaluated safety strategy in interaction with an evaluation context (see Figure 27).

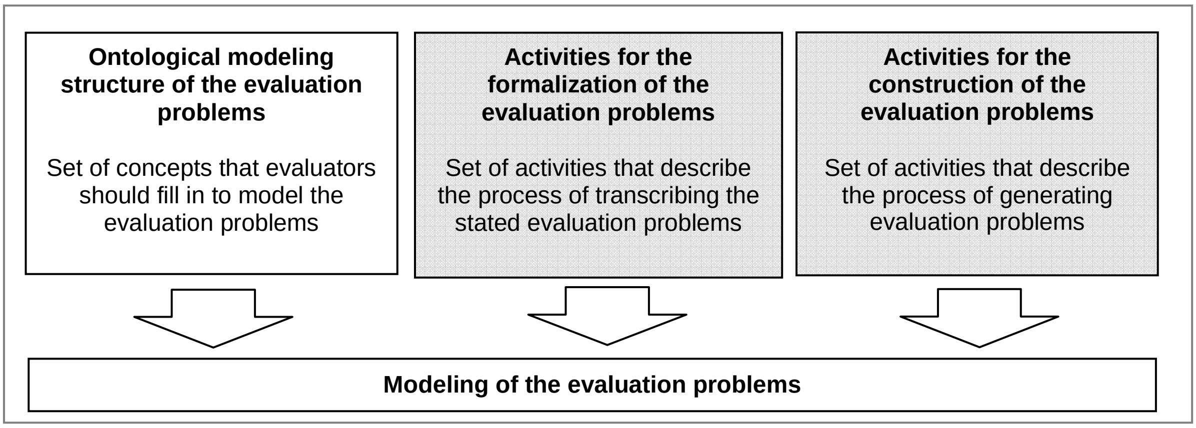

Figure 26 - Summary of proposals for modeling evaluation problems

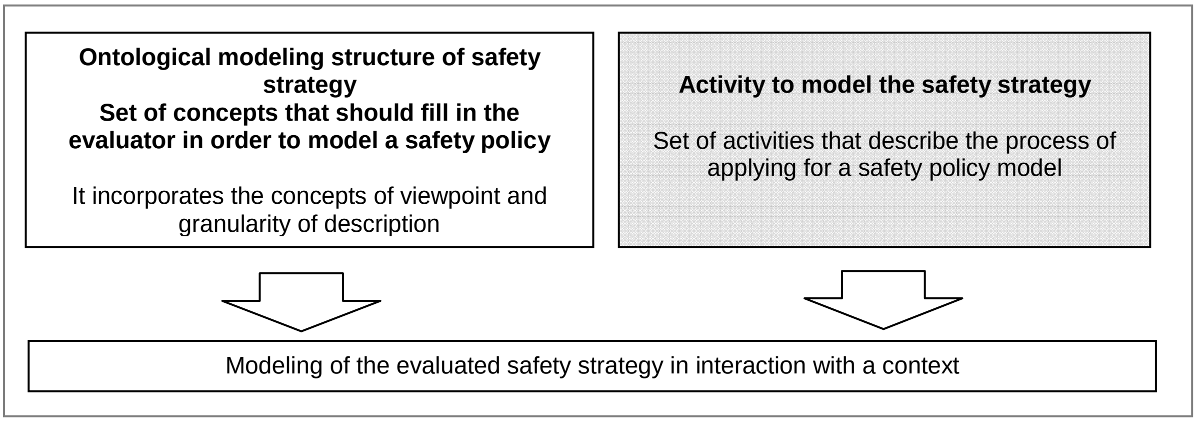

Figure 27 - Summary of proposals for modeling safety strategies

The second step (from the model of five steps of the evaluation) that we discussed in our research is the generation of indicators. Its objective is to identify or develop indicators relevant to the case evaluation. Knowledge formalized in the first phase are used. They specify the problems that indicators should answer and the knowledge used to build or identify indicators.

The first piece of work we have done on the indicators is a working definition. An indicator is a computable digital object consisting of elements, which provides information on the performance objective of a security strategy.

We then worked to formalize approaches to generate them, three are proposed. The first is to identify similar cases and evaluation and reuse of existing indicators. The case description makes possible the evaluation of indicators by similarity search. We can calculate the distance between each case assessment and determine those who are closest in terms of issues or stakeholders, for example. A stage adaptation may be necessary when certain elements of the case different assessment. The second is to use the indicator framework for automatically generating proposals for indicators by combining items describing the case studies (model elements) or basic indicators. This approach, which quickly generates a large number of possibilities, a task involves the selection of relevant indicators. In the latter approach, the assessor uses a theory of creativity to build new indicators is the theory CK. Its aim is to encourage evaluators to use all the knowledge on evaluation to propose new indicators. It is based on the use of existing knowledge but also to manage the acquisition of new knowledge. Gradually, while the evaluator performs his job, he acquires new knowledge that can be directly used in the design of indicators.

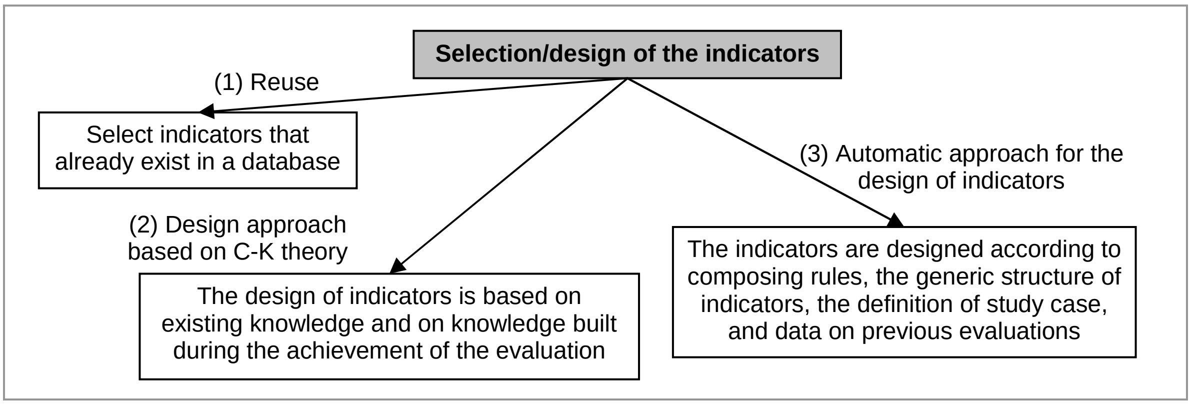

Figure 28 - Synthesis of approaches and sub-approaches used to generate indicators

The general framework of the assessment activity that we propose is for evaluators. Its purpose is to guide them in designing and conducting evaluations. This framework describes the elements to consider and the activities to be performed. However, realization of an evaluation requires creative skills from the evaluators.the pProper use of this framework therefore requires that the evaluators have sufficient knowledge to understand its functioning. This is not only a deterministic method that is sufficient to apply. This approach pushes the evaluator to formalize the right knowledge and ask the right questions.

6.2. Perspectives

In addition to this report, we plan to write another one on an example in order to illustrate all the theoretical models.

Further development is needed in order to complete the proposed framework. This is the case for the three other steps of the five steps model that we did not model yet: data collecting and data selection, data processing and exploitation of the evaluation results. The major issues for the two first ones are well known. However, this is not the case for the third one. This last step consists in providing evaluation's results to the stakeholders and in observing their reactions (to see if the provided results allow them to perform their activity). The issues are:

- Which results should be presented to the stakeholders? Evaluators cannot provide all information on the case study; they have to select the most relevant one. Currently, we do not have tools to perform such a task; it is only based on evaluators' skills.
- How can we evaluate the relevance of the providing results? Evaluation of the results is necessary because of feedback loops (see the five steps model) and the capitalization (in order to retain the relevance of indicators according to study cases). However, we do not have methods to perform this task.

REFERENCES

H. Derriks and P. Mak (2007) *Irtad special report, underreporting of road traffic casualties*, IRTAD, The Hague, Netherlands.

J. Le Moigne (1999) *La modélisation des systèmes complexes*, Dunod, Paris.

M. Peden, A. Hyder, R. Scurfield, D. Mohan, E. Jarawen, D. Sleet and C. Mathers (2004) *World report on road traffic injury prevention*, World Health Organization Geneva.

OECD (2008), *The safe system approach*, "*Towards zero. Ambitious road safety targets and the safe system approach*", pp.107-132, OECD Publishing.

J. Newton (2008) *Road safety–partnership program. Shared responsibility*, Office of Road Safety, Western Australia.

L. Von Bertalanffy (1973) *General system theory*, George Braziller New York.

E. Morin (2005) *Introduction à la pensée complexe*, Editions du Seuils, Points essais.

H. Simon (1996) *The sciences of the artificial*, The MIT Press.

G. Pahl, W. Beitz and K. Wallace (1996) *Engineering design: A systematic approach*, Springer, London.

S. Gorti, A. Gupta, G. Kim, R. Sriram and A. Wong (1998) *An object-oriented representation for product and design processes*, Computer Aided Design, Vol.30(7), pp.489-502.

B. Lawson, M. Bassanino, M. Phiri and J. Worthington (2003) *Intentions, practices and aspirations: Understanding learning in design*, Design Studies, Vol.24(4), pp.327-339.

W. Haddon Jr (1972) *A logical framework for categorizing highway safety phenomena and activity*, The Journal of Trauma, Vol.12(3), pp.193.

A. Hatchuel and B. Weil (2003), *A new approach of innovative design: An introduction to ck theory*, International Conference on Engineering Design - ICED 03, Citeseer, Stockholm, Sweden.