A decision-aiding tool for the choice of road pavements and surfacing

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Abstract We describe the process which led to the specification of a multi-criteria decision model and its implementation into a decision-aiding tool for choosing appropriate road pavements and surfacing in road works in the Southern part of Belgium. The tool was intended to support field engineers managing road works in making good decisions. We report on the elaboration process of the underlying model in a working group involving experts in road works as well as in multi-criteria decision methods and led by the general manager of the Ministry of Equipment and Transport. In the conclusion, we analyze the main difficulties, weaknesses, and strengths of the project.

1. Introduction

This is the story of an intervention in the development process of a decision-aiding tool for the Public Service of Wallonia - Mobility & Infrastructure, formerly called the Ministry of Equipment and Transport (MET). This administration is responsible for the management of the road network in Wallonia, the French speaking, Southern part of Belgium, a region covering 55% of the Belgian territory. The tool was intended to help the engineers managing road works in Wallonia to make the best possible choice of road pavement and surfacing. We first outline the historical and institutional context of the intervention. Then we describe how the model underlying the evaluation of the different possible road pavements and surfacings and their adequacy to different types of road works (RW) was elaborated and validated. This model was implemented as a software tool aiming to facilitate decision and proposed to the end users (i.e., the field engineers responsible for road works). We discuss all along the issues raised in the course of the intervention. Finally, we look back on the entire process and highlight some difficulties encountered in the intervention and some issues that remain open.

1.1. Context of the intervention

A large variety of road pavements and surfacing (RPS) are in use in Wallonia and the choice of a RPS for each road works (RW) was made by the engineer in charge of managing it. The project of building a software tool for improving the choice of an appropriate RPS in RW in Wallonia was launched at the initiative of the general manager of the MET in 2003. A working group was set up,

- headed by the MET general manager (GM),
- assisted by two economic attachés (in charge of writing calls for tenders for public procurement),
- including four Regional Managers (RM) and four Engineers Directors (ED) responsible for the supervision of RW in Wallonia's sub-regions,
- an engineer from the Belgian Road Research Center (BRRC) who is a co-author of this chapter (OP), joined at a certain point in the process, by the two other authors (AF, MP), who are experts in decision-aiding methods.

The task of this working group was to elaborate a decision-aiding tool to be used by the Field Engineers (FE) responsible for RW in Wallonia in order to assist them in choosing the most appropriate RPS.

1.2. The working group

The GM led all meetings of the working group. Not all 14 members of the group attended each group meeting. The GM, the four RMs and the four EDs had an extended practical experience of RW and a good knowledge of the properties of road pavements and surfacing. They had the expertise to assess the adequacy of a RPS to a RW. They were also well aware of the concrete problems met by the Field Engineers (FE) managing RW. Each FE operates in a sub-region of Wallonia and hierarchically answers to the RM or the ED supervising this sub-region. The working group occasionally called upon external expertise, namely that of a member of the Belgian Road Research Center and that of two experts in concrete road pavements from FEBELCEM (Federation of the Belgian Cement Industry). It is important to note that the four RMs and the four EDs hierarchically answer to the GM. The Field Engineers in turn answer to an RM or an ED and, ultimately, to the GM.

The Belgian Road Research Center (BRRC) is a research center associated with the road construction sector in Belgium (both the road construction industry and the public sector in charge of road management and planning). This research center develops and disseminates its expertise on all aspects of road construction. For instance, in relation with the present case, the BBRC had developed tools for dimensioning roads, i.e., what is the required thickness of the road pavement for a given intensity of the traffic). One co-author, OP, a construction engineer, was working for the BRRC. At the same time, OP was pursuing a degree-granting programme (with staggered hours) at the Mons Faculty of Engineering, Belgium. In this programme, he attended a course on multiple criteria decision methods and proposed to write his master thesis on the topic of the choice of RPS aided by multi-criteria analysis. He managed to generate interest for this approach from the direction of the BRRC and from the direction of the MET. He thus joined the working group. In his master thesis, OP reports on the activity of the working group, up to the development of a decision model based on an additive value function and the validation of this model on a dozen of cases corresponding to real RW in the Walloon region.

Initially, the authors AF and MP acted remotely as OP's master thesis advisors. When it came to the model's development phase, they integrated the working group and took an active part in the interactions within the group. After the thesis was defended, a contract was signed between the Mons Faculty of Engineering and the MET in order to implement the model into a software tool, with a user-friendly interface. During this phase, the model was further refined and amended. The intention of the MET management was to ask the FEs managing road works to use this software when deciding which RPS should be chosen. The software interface was designed to enable the user to compare the pros and cons of the top ranked RPSs.

1.3. Goal of the management of the MET

The initial goal of the GM with this working group was to determine the best option for the choice of a RPS in each of the various RW contexts that may appear in the Walloon Region and to impose strong guidelines regarding this choice to the FEs managing RW (who are supervised by the RMs or EDs).

The authors argued in favor of a less prescriptive perspective. Our main reasons were twofold. First, considering the future software tool as a decision aid rather than as a norm, would facilitate acceptance by the end-users. Second, no model is perfect. So there might be cases in which the solution recommended by the model might not be the best option, for reasons not taken into account in the model, but of which the RW manager might be aware.

It was finally accepted that the FEs should use the system in all cases but could derogate from the system recommended solution, in which case they should justify their choice explicitly to their superiors.

2. Highlights of the modeling phase

Initially, only five different types of RPSs were considered. Later, when it came to the evaluation of these five alternatives with respect to the various criteria, it appeared that the evaluation of these alternatives on some of the criteria substantially depended on the exact specification of the upper layer ("wearing course ") of the road surfacing. It was the case, e.g., for the "noise" criterion. The road noise level may be much higher with some wearing courses than with others.

It was thus decided to consider a more detailed list of alternatives composed of 22 combinations of the five basic types of RPS with different wearing courses that can be used with each of them (Appendix A).

Initially, eleven items were retained as having an impact on the choice of a RPS. These are: 1) heavy truck traffic, 2) disturbances due to works; 3) discomfort to users due to maintenance; 4) ride comfort; 5) safety; 6) insertion of inlets (sewer openings, gulleys, inlet cover, manhole cover, etc.); 7) current pavement type; 8) RPS of adjacent road sections; 9) importance of the RW; 10) cost relative to life cycle; 11) type of road.

It was soon realized that these items cannot all, as such, be used as criteria. For some of them, their impact heavily depends on the type of road and the location of the works. For instance, for works in a small street in town, considering "heavy truck traffic" is irrelevant because inexistent, while it has a strong impact on a highway, because it causes rutting and cracking, hence reducing the service life of a RPS. Similarly, the impact of bad or medium performance with respect to "safety" (item 5) or "ride comfort" (item 4) is different on a highway and a local road or a parking lot.

So, the best choice for a RPS depends on the type of road and the location of the RW. A categorization of RW types was established by the working group (see section 2.2). The preference model had thus to be adapted to the type of works. The option taken was to develop a model suited to the most important category of works and adjust its parameters to reflect the different impact of some criteria in other categories of works. As for the criteria, they remain the same in all types of RW.

2.1. The criteria

The list of criteria finally retained is the following. It is composed of 5 quantitative and 7 qualitative criteria. The evaluation of quantitative criteria has an objective character; it results from real data or physical simulation measures or from using computer simulation programs (as those developed by the BRRC) based on real data. The quantitative criteria are:

1. Cost (€/m²): estimation based on document (MET 2002) and discussions in working group; depends on works characteristics (intensity of heavy truck traffic); to be minimized;
2. Rutting (*orniérage*): measured (mm) through laboratory simulation in standardized conditions; to be minimized;
3. Skid resistance (*résistance au dérapage*): measure of the tangential friction coefficient (dimensionless) by a measurement device called *odoliographe* (CRR 2019); to be maximized

4. Cracking rate (*taux de fissuration*): computed by an external “dimensioning module” (depends on the traffic load); dimensionless; to be minimized;
5. Noise generated by the vehicles running on the RPS: measured (dB) in standardized conditions in the lab; to be minimized.

The qualitative criteria are the following:

1. Drainability;
2. Perturbation due to the works: depends on the works location;
3. Ease of inlets insertion (sewer openings, gulleys, inlet cover, manhole cover, etc.);
4. Suitability given the current pavement of adjacent zones;
5. Suitability given the works location (independently of the current pavement);
6. Maintenance requirements;
7. Ease of implementation (given the current pavement).

The GM and three persons among the RMs and EDs in the group assessed these aspects for the different RPSs. The choice of the criteria scales is discussed in Section 3.1.

We refer in the sequel to quantitative (resp. qualitative) criteria by their number preceded by QUANT (resp. QUAL) : QUANT1 to QUANT5 (resp. QUAL1 to QUAL7).

2.2. Categorization of road works

Two types of attributes characterize RW. The first is the type of road. These have been categorized in the following 9 types, referred to as RW1 to RW9 in the sequel.

1. Crossing ;
2. Agricultural access road (*chemin de remembrement*) ;
3. Parking lot ;
4. RESI : roads connecting cities and villages (allowed speed < 90 km/h) ;
5. RGG : highways and main roads ;
6. Road in commercial zone : streets; permanent access ;
7. Road in industrial zone: heavy trucks traffic ;
8. Local road : few vehicles ;
9. Urban roads : streets in towns.

Besides the type of road, several other parameters describing the works are important. These are:

1. Current road pavement (five types of RPs listed in Appendix A);
2. Current road pavement of adjacent zones (five types of RPs listed in Appendix A);
3. Length (m) and surface (m^2) of the road works;
4. Inlet insertion such as sewer openings, gulleys, inlet cover, manhole cover, etc. (*pose d’avaloirs d’égouts, de couvercles de trous d’homme, etc*) (yes/no);
5. Traffic load (daily number of commercial vehicles, i.e., heavy trucks) ;
6. Works duration (number of working days).

In the sequel, we refer to the parameters describing the RW by their number preceded by DescrRW: DescrRW1 to DescrRW6. An additional descriptor (DescrRW7) will be considered later (the “frost index” associated to the works location, see Section 3.4).

Example E411. We illustrate the description of RW by an example of works on the E411, the highway linking Namur to Luxemburg. Its characteristics are the following:

- Type of road: RGG (RW5);
- DescrRW1 (Current road pavement): BAC;
- DescrRW2 (Current road pavement of adjacent zones): BAC;
- DescrRW3 (Length and surface of the works site): 5000 m;
- DescrRW4 (Inlet insertion): no;
- DescrRW5 (Traffic load): 5280 trucks/day;
- DescrRW6 (Number of working day): 365;
- DescrRW7 (Frost susceptibility): works close to Bastogne.

2.3. Choice of a model

At an initial stage, OP made a presentation of MCDA ranking[1] methods, focusing on additive value functions on the one hand, and on outranking methods on the other hand (see e.g., (Vincke 1992)). The GM explicitly excluded the use of methods based on pairwise comparisons (such as outranking methods, which he knew about). He wanted "quantitative evaluations" of the solutions. The reasons for that statement were not made explicit. We hypothesize that there were two main reasons. The first one is that the decision-aiding software was to be used by engineers who are trained to think in terms of numbers. The second reason probably relates to the GM's perception of ranking methods based on outranking relations (which he heard about in conferences given at Université libre de Bruxelles) as being problematic. Indeed, a ranking is not obtained directly (due to possible incompleteness and cycles in the outranking relation), but after a deep result analysis following an "exploitation phase" (see, e.g., (Roy and Bouyssou 1993) or (Belton and Stewart 2002)).

In any case, we (OP, AF and MP) decided to start working in the framework of the additive value function model. We explained to the working group the meaning of the parameters of such a model, mainly the marginal value functions and the tradeoffs. Consequently, our working hypothesis was that criteria can be considered as mutually preference independent (Dyer, Multiattribute Utility Theory (MAUT) 2016). In particular, *ceteris paribus* reasoning was possible, i.e., one can compare alternatives that have the same evaluations on a subset of criteria without specifying these common evaluations.

Without further assumption, this model is *not* quantitative. Although, at the end, alternatives are associated a value (obtained as a weighted sum of marginal value functions), these values cannot be used to compare alternatives quantitatively. In particular, the comparison of value differences is not meaningful. For instance, if the value of alternative *a* is 8 and that of *b* is 6, while alternative *c* is valued 10 and *d* is valued 9, saying that *a* is more preferred to *b* than *c* is preferred to *d* is not a meaningful statement. However, in the additive value function model, the marginal value functions do represent the differences of preference on each *single criterion*. In particular, equal differences in the marginal values on a criterion represent equal preference differences. In this model, the value difference between two alternatives is the sum of the differences of their marginal values (weighted by tradeoffs) on all the criteria. Since these represent the preference differences on each criterion, when comparing two alternatives, we may meaningfully compare the pros and cons of each alternative by looking at their differences of preference on all criteria.

[1] Although the problem is to *choose* a RPS, we proposed to *rank* all possible RPS. Ranking offers better control on the preference model and is better suited for validation purposes. Indeed, when decision makers see that RPS are ordered in a sensible way, this generates confidence in the recommendations. Second, but not least, this offers more opportunities to adjust the model's parameters (or even change the model) when the DMs disagree with or raise questions about the position of some RPSs in the ranking.

3. Evaluation process

Given the choice of the additive value function model, each alternative (RPS) has to be evaluated on each criterion. Then, for each criterion, a marginal value function, incorporating the preferences (or the values) of the DM into the evaluations, has to be constructed. Finally, tradeoffs between criteria must be determined. In our case, the working group acted as the DM. It had to end up with a consensual model. After discussion, the GM who was leading the working group had the final say.

A crucial additional question is the following: do the evaluations, or the marginal value functions, depend on the road works category (see section 2.2: nine categories)? Consider for instance the noise criterion (QUANT5). Its evaluation results from a standardized measure "in vitro" of the noise (in dB) generated by a vehicle running on each RPS. In this case, the evaluation does not depend on the position of the RW. However, clearly, the level of noise generated by a RPS has a different impact depending on whether the noise is generated in an urban environment (RW9) or in the countryside (RW2), or on a highway (RW5). Actually, we need a model for each RW category and possibly depending also on some other parameters. There has been much discussion in the working group on whether marginal value functions should be elicited for each of the 9 road works categories. The conclusion has been the following:

- For some qualitative criteria, such as QUAL2 (Perturbation due to the works), the evaluation depends on the works category and, possibly, some other parameters describing the works. For others it doesn't, as, for instance, QUAL1 (drainability).
- The tradeoffs will be modulated to take the type of RW into account and in particular its location. For instance, the tradeoff associated with the noise criterion (QUANT5) will be less for works in the countryside (RW2) than for works in an urban environment (RW9).

So, in conclusion, we have to elicit a *family* of additive value function models in which some criteria evaluations and/or some tradeoffs depend on RW category and parameters.

In practice, it was decided that the RW experts in the group (GM, RMs and EDs) would elicit the marginal value functions for the type of RW that is the most important in terms of impact, namely, on highways (RW5). It was even suggested that they would keep in mind the example of the E411 road, linking Namur to Luxemburg (which is one of the most problematic roads in Wallonia, with heavy trucks traffic, perpetually hindered by RW). Anticipating a bit, we can say that this approach worked well. The impact discrepancy of a criterion depending on the RW location was eventually modelled by adjusting tradeoffs to RW.

3.1. Qualitative criteria

Description. For each qualitative criterion, a more detailed description of the aspects covered by the criterion has been established. For instance, for criterion QUAL2 (Perturbation due to the works), it has been decided that it would cover the following aspects : number of lanes closed due to the RW ; accessibility, possibility of alternate route, works duration, increase in journey time. Initially this criterion was split in two : (i) Inconvenience to road users during the works ; (ii) Perturbation of local residents due to the works. Experts evaluated them both. When discussing their evaluations in a session of the working group, it appeared that some aspects were redundantly taken into account in both criteria (and also, that some aspects from other criteria, such as noise (QUANT5) were taken into account by some experts when evaluating (ii) Perturbation of local residents). Therefore, these two criteria were merged into a single one and the list of aspects incorporated was limited to the five listed above.

Scales. It was decided that the experts would assess the RPS's on the same scale from 0 to 10 for all 5 qualitative criteria. The worst possible value is 0 and the best is 10 for all criteria. Three reference points, namely, 2, 5 and 8, were defined for each qualitative criterion. For instance, for QUAL1 (drainability), some RPS's are porous and let water penetrate their structure, while some others only drain water on their surface and still others don't drain water at all. Therefore, value 2 on the drainability scale was defined as "weak surface drainability", value 5 corresponds to "excellent surface drainability" and value 8, "satisfactory drainability into the mass". We suggested to the experts that the values 2, 5 and 8 should be labelled by satisfaction levels w.r.t. the criterion in such a way that the levels corresponding to 2 and 8 are equidistant from 5 in terms of preference. Obviously, it is not easy to define the states corresponding to 2, 5 and 8 in such a way. By this suggestion we wanted to stack the odds in favor of directly obtaining a marginal value function which represents the order on preference differences ((Von Winterfeldt 1986), Sect. 7.3) as is the case in the additive value model. This was explained in detail during a working group session. Whenever the experts in the working group assess an RPS on the scale of a qualitative criterion, they position the RPS w.r.t. the equally spaced (in terms of preference) levels 2, 5, and 8.

Assessment. Four experts (GM and 3 RMs, one RM was not available at the time) from the working group were asked to assess the 22 alternatives (RPSs) w.r.t. the qualitative criteria on a [0,10] scale (taking into account the definition of the reference values 2, 5 and 8). The evaluation of criteria QUAL1 (drainability), QUAL3 (ease of inlets insertion) and QUAL6 (maintenance requirements) only depend on the RPS. The evaluations of QUAL2 (Perturbation due to the works) and QUAL5 (suitability given the works location) depend on the RW category (8 cases for each criterion, excluding RW1 (road crossing), which is assessed according to its location; for instance, works on a crossing located on an urban road is assessed as works on an urban road (RW9)). The evaluation of criteria QUAL4 and QUAL7 depend on the current pavement in the adjacent zone (QUAL4) and the works itself (QUAL7). For each of the 5 possible current pavements, we thus need an evaluation of QUAL4 and QUAL7. For each RPS, in total, 1+8+1+5+8+1+5 = 29 evaluations are required. After appropriate training and explanations, each of the four experts was asked to fill in 29 forms such as the example in Appendix B. The experts worked on their own because the evaluation process would have taken too long in a working group session. Figure 1 shows the evaluations produced by the four experts for criterion QUAL1 (drainability); some values are missing.

						Mean	Max Diff		
RBIT / BB-1	4	2	2	2		2.5	2.0		OK
RBIT / RMD	5	4	5	5		4.8	1.0		OK
RBIT / SMA	5	4	2	4		3.8	3.0		OK
RBIT / RMTO	5	6	5	7		5.8	2.0		OK
RBIT / RUMG	5	6	5	5		5.3	1.0		OK
RBIT / ED	8	8	8	8		8.0	0.0		OK
RBIT / Enduit superficiel	5	6	2	5		4.5	4.0		Ecart > 3
RBIT / RBCF	4	4	2	1		2.8	3.0		OK
REME / RMD	5	4	5	5		4.8	1.0		OK
REME / SMA	5	4	2	4		3.8	3.0		OK
REME / RMTO	5	6	5			5.3	1.0		OK
REME / RUMG	5	6	5	5		5.3	1.0		OK
REME / ED	8	8	8	8		8.0	0.0		OK
REME / Enduit superficiel	5	6	2	5		4.5	4.0		Ecart > 3
BCOM / RMD	5	4	5			4.7	1.0		OK
BCOM / SMA	5	4	2	4		3.8	3.0		OK
BCOM / RMTO	5	6	5			5.3	1.0		OK
BCOM / RUMG	5	6	5	5		5.3	1.0		OK
BCOM / ED	8	8	8	8		8.0	0.0		OK
BCOM / Enduit superficiel	5	6	2	5		4.5	4.0		Ecart > 3
BBIC (Béton bicouche)	4	5	2	5		4.0	3.0		OK
BAC (Béton armé continu)	4	5	2	4		3.8	3.0		OK

Figure 1 RPS evaluations on criterion QUAL1 (drainability) by four different experts. "Max Diff" stands for "Maximal difference"

As shown in Figure 1 (and it was also the case for all other evaluations tables), the evaluations by the experts can exhibit large discrepancies. It was decided that items for which the range of the four evaluations is larger than 3 units (the difference between the reference values 2, 5, 8) should be discussed during a session of the working group. Such items are marked by "Ecart > 3" in the rightmost column in Figure 1. Discussion revealed for instance that some experts have included some aspects belonging to other criteria into their evaluation. Since discussing all such large discrepancies would take time, it was provisionally decided to proceed with the current evaluations and work with their average (column labelled "Mean" in Figure 1).

Figure 2 shows the average evaluations of all WPS w.r.t. the 29 combinations (qualitative criterion x RW category and characteristics) described above. Depending on the RW category and the other RW parameters, the related evaluations for the 7 qualitative criteria will be used in an additive value function model.

Alternatives	Drainability	Perturbation / RW2	Perturbation / RW3	Perturbation / RW4	Perturbation / RW5	Perturbation / RW6	Perturbation / RW7	Perturbation / RW8	Perturbation / RW9	Ease of inlets insertion	Suitability / Adj. Section RBIT	Suitability / Adj. Section REME	Suitability / Adj. Section BCOM	Suitability / Adj. Section BBIC	Suitability / Adj. Section BAC	Suitability / Location RW2	Suitability / Location RW3	Suitability / Location RW4	Suitability / Location RW5	Suitability / Location RW6	Suitability / Location RW7	Suitability / Location RW8	Suitability / Location RW9	Maintenance requirements	Ease of implement. if RBIT	Ease of implement if REME	Ease of implement. if BCOM	Ease of implement. if BBIC	Ease of implement. if BAC
RBIT / BB-1	2.5	7.0	7.1	6.4	6.3	5.8	5.6	6.4	5.5	6.0	7.8	6.3	4.0	2.5	2.0	6.7	5.3	5.8	3.5	7.8	3.8	5.8	7.0	3.0	6.5	4.7	5.0	5.0	5.0
RBIT / RMD	4.8	7.0	7.1	6.4	6.5	5.8	5.6	6.4	5.4	6.0	7.8	6.3	4.0	2.5	2.0	4.5	4.8	7.3	4.0	7.8	4.0	6.5	7.8	2.8	6.5	4.7	5.0	5.0	5.0
RBIT / SMA	3.8	7.0	7.1	6.4	6.5	5.8	5.6	6.4	5.4	6.0	7.8	6.3	4.0	2.5	2.0	4.5	5.0	7.5	4.8	8.0	4.0	6.5	8.0	3.0	6.5	4.7	5.0	5.0	5.0
RBIT / RMTO	5.8	7.0	7.1	6.4	6.5	5.8	5.6	6.4	5.4	6.0	7.8	6.3	4.0	2.5	2.0	3.8	4.8	7.3	3.5	7.8	4.0	6.5	7.8	3.0	6.5	4.7	5.0	5.0	5.0
RBIT / RUMG	5.3	7.0	7.1	6.4	6.5	5.8	5.6	6.4	5.4	5.5	7.8	6.3	4.0	2.5	2.0	4.3	5.0	6.8	3.5	7.8	4.0	6.5	7.8	2.3	6.5	4.7	5.0	5.0	5.0
RBIT / ED	8.0	7.0	7.1	6.4	6.5	5.8	5.6	6.4	5.4	5.5	7.8	6.3	4.0	2.5	2.0	3.5	4.8	7.5	3.8	7.8	4.0	6.5	7.8	3.0	6.5	4.7	5.0	5.0	5.0
RBIT / Enduit superficiel	5.3	7.0	7.1	6.4	6.5	6.0	5.8	6.4	5.6	5.5	7.8	6.3	4.0	2.5	2.0	4.3	5.0	6.3	2.8	5.8	3.8	6.3	5.8	2.0	6.5	4.7	5.0	5.0	5.0
RBIT / RBCF	2.8	7.0	7.1	6.1	6.0	6.0	6.0	6.5	5.8	6.0	7.8	6.3	4.0	2.5	2.0	5.7	4.3	6.5	2.8	7.3	3.8	6.3	7.3	2.0	6.5	4.7	5.0	5.0	5.0
REME / RMD	4.8	6.8	6.9	5.9	6.1	5.6	5.8	6.4	5.3	5.3	7.8	7.8	4.8	3.0	2.5	4.0	6.5	6.5	6.3	6.3	6.3	5.0	5.3	4.0	5.8	6.7	6.3	6.0	6.0
REME / SMA	3.8	6.8	6.9	5.9	6.1	5.6	5.8	6.4	5.3	5.3	7.8	7.8	4.8	3.0	2.5	4.0	5.3	6.8	7.0	6.3	6.3	5.0	5.3	4.3	5.8	6.7	6.3	6.0	6.0
REME / RMTO	5.3	6.8	6.9	5.9	6.1	5.6	5.8	6.4	5.3	5.3	7.8	7.8	4.8	3.0	2.5	3.3	6.5	6.5	5.8	6.3	6.3	5.0	5.3	4.0	5.8	6.7	6.3	6.0	6.0
REME / RUMG	5.3	6.8	6.9	5.9	6.1	5.6	5.8	6.4	5.3	4.8	7.8	7.8	4.8	3.0	2.5	3.7	5.3	6.0	5.8	6.3	6.3	5.0	5.3	3.5	5.8	6.7	6.3	6.0	6.0
REME / ED	8.0	6.8	6.9	5.9	6.1	5.6	5.8	6.4	5.3	4.8	7.8	7.8	4.8	2.5	2.0	3.0	5.0	6.8	6.0	6.3	5.0	5.0	5.3	4.0	5.8	6.7	6.3	6.0	6.0
REME / Enduit superficiel	4.5	6.8	6.9	5.9	6.0	5.9	5.5	6.4	5.5	4.8	7.8	7.8	4.8	2.5	2.0	3.7	5.3	5.5	4.3	5.0	4.8	4.7	4.0	3.0	5.8	6.7	6.3	6.0	6.0
BCOM / RMD	4.7	3.1	4.0	2.4	2.6	1.9	2.8	3.0	1.6	2.0	6.3	7.0	6.3	4.0	4.0	1.8	6.5	5.0	7.8	3.5	7.5	3.0	1.8	5.5	5.0	6.0	4.0	3.0	3.0
BCOM / SMA	3.8	3.1	4.0	2.4	2.6	1.9	2.8	3.0	1.6	2.0	6.3	7.0	6.3	4.0	4.0	3.3	6.8	5.5	8.8	3.5	7.5	3.0	1.8	5.8	5.0	6.0	4.0	3.0	3.0
BCOM / RMTO	5.3	3.1	4.0	2.4	2.6	1.9	2.8	3.0	1.6	2.0	6.3	7.0	6.3	4.0	4.0	2.0	5.8	5.0	7.3	3.5	7.5	3.0	1.8	5.5	5.0	6.0	4.0	3.0	3.0
BCOM / RUMG	5.3	3.1	4.0	2.4	2.6	1.9	2.8	3.0	1.6	2.0	6.3	7.0	6.3	4.0	4.0	2.0	6.8	4.3	7.3	3.5	7.5	3.0	1.8	5.0	5.0	6.0	4.0	3.0	3.0
BCOM / ED	8.0	3.1	4.0	2.4	2.6	1.9	2.8	3.0	1.6	2.0	6.3	7.0	6.3	3.0	3.0	1.8	5.8	5.3	8.0	3.5	6.3	3.0	1.8	5.3	5.0	6.0	4.0	1.7	1.7
BCOM / Enduit superficiel	4.5	3.1	4.0	2.4	2.8	2.0	2.6	3.0	1.8	2.0	6.3	7.0	6.3	3.0	3.0	2.0	6.3	3.0	5.5	3.8	6.0	2.8	2.0	4.3	5.0	6.0	4.0	1.7	1.7
BBIC (Béton bicouche)	4.0	3.3	4.0	2.1	2.4	1.3	2.5	2.6	1.3	1.8	1.8	1.8	4.5	8.0	7.5	3.8	5.8	4.0	8.3	3.5	8.0	2.7	1.8	8.0	5.8	3.7	3.3	3.7	3.7
BAC (Béton armé continu)	3.8	2.9	3.4	1.6	2.0	0.8	2.1	2.4	1.0	1.5	1.8	1.8	4.5	7.5	8.5	4.0	6.3	4.3	8.8	3.3	8.3	2.3	1.5	8.0	5.8	3.7	3.3	2.7	3.7

Figure 2. Evaluations of 22 RPs w.r.t. 29 combinations of qualitative criteria and RW categories

For example, in the case of the works of category RW5 on the E411 (described in the end of Section 2.2), for assessing the first RPS, which is RBIT/BB-1, we extract the relevant evaluations of the qualitative criteria from Figure 2; they are shown in Table 1 and justified by the characteristics of this RW.

Criterion	Eval	Justification
QUAL1 (Drainability)	2.5	Independent of RW characteristics
QUAL2 (Perturbation due to works)	6.3	Type of RW is RW5: RGG
QUAL3 (Ease of inlets insertion)	10.0	DescrRW4 : no inlets
QUAL4 (Suitability given adjacent zones)	2.0	RP in adjacent zones is RP5: BAC
QUAL5 (Suitability given works location)	3.5	Type of RW is RW5: RGG
QUAL6 (Maintenance requirements)	3.0	Independent of RW characteristics
QUAL7 (Ease of implementation)	5.0	Current RP is RP5:BAC

Table 1. Evaluation of qualitative criteria used for RW on E411

3.2. Quantitative criteria

We first give some detail about the (objective) evaluation of the 5 quantitative criteria. Some of them depend on the RW category.

QUANT1: cost. The construction cost of a RPS chiefly depends on its thickness. The latter is mainly determined by the traffic of commercial vehicles (heavier than 3.5 tons). Given the characteristics of the RW, the cost of any RPS can be computed by using the data in the MET database. The cost evaluation is expressed in €/m². The useful range of the cost criterion is the interval [5,40].

QUANT2: rutting. The rutting resistance of a RPS is computed by using a traffic simulator with standard traffic conditions (available from BRRC). The result is a rut depth expressed in millimeters.

The useful range is the interval [0,20]. This criterion is to be minimized. The danger threshold is a 16 mm rut depth. From this value on, the road surfacing must be repaired.

QUANT3: skid resistance. This corresponds to the (dimensionless) "transverse friction coefficient", which can be measured using an appropriate apparatus ("odoliographe"). The useful range is [0.40; 1.00]. This criterion is to be maximized. The statement of work for roads in the Walloon region stipulates that the friction coefficient should be at least 0.45.

QUANT4: cracking rate. The MET's Design Software, DimMET© (SPW Mobilité 2012) , is used for evaluating the (dimensionless) cracking rate taking the traffic load and the type of road structure into account. When the cracking rate reaches 50%, the RPS must be replaced. The useful range is [0, 50], expressed in %. This criterion is to be minimized.

QUANT5: noise. The noise generated by a tyre rolling on a RPS is measured in the lab (CRRB) under standard conditions. The unit is the decibel (dB). The useful range is [70, 85]. This criterion is to be minimized.

Note that the evaluations of QUANT1 and QUANT4 depend on the parameters of the RW, while those of the other quantitative criteria do not.

Marginal value functions. The shapes of the marginal value functions are displayed in appendix B. These shapes have been determined during a session of the working group. The process was supported by showing the shapes of the functions on a screen in the room. Experts could react and ask for changes. The reasonings that led to these marginal value functions are outlined below. For all quantitative criteria, we tried to build a function that represents differences of preference on the criteria. In the additive value function model, it is meaningful to compare preference differences on each criterion without specifying common values on the other criteria. Reaching a consensus on the shapes or the marginals, based on comparisons of value differences, was relatively easy.

Note that all marginal value functions represented in appendix B are non-decreasing even those corresponding to criteria to be minimized. In these cases, reasonings have been held in terms of value loss. A negative tradeoff is assigned to them when computing the overall additive value function.

QUANT1: cost (first figure in Appendix B). The marginal value function for the cost is linear in the logarithm of the cost. This corresponds to comparing costs in relative values (e.g., "RPS X is 10% more expensive than RPS Y"). A cost increase of a given percentage is represented by the same value difference independently of the initial cost. In particular, whenever cost doubles, from 5€ to 10€ to 20€ and to 40€, the losses in marginal value are equal. Therefore, the marginal value losses associated with 5, 10, 20, 40 are respectively 0, 33.3, 66.67, 100 on the [0,100] value scale.

QUANT2: rutting (second figure in Appendix B). It is known that from 16 mm rut depth, the road surfacing needs repairing. Therefore, the disutility for 16 mm is maximal (100). The experts felt that the marginal value function is concave. They estimated that around 8 mm (resp. 12 mm) rut depth, the road surfacing has left 75% (resp. 95%) of its marginal value. From 0 to 8 mm, they judged that the loss of value was linear. A concave curve fitted the points (8, 75), (12, 95), (16, 100).

QUANT3: skid resistance (third figure in Appendix B). It was estimated that 80% of the value lies in the interval [0.45, 0.65]. A friction coefficient less than 0.45 is not allowed for roads in the Walloon region. Therefore, the marginal value is 0 below 0.45. For lack of further insight, the working group assumed that it is piecewise linear on the rest of the domain, i.e., on the interval [0.45, 1], with a breaking point at (0.45, 80).

QUANT4: cracking rate (fourth figure in Appendix B). It was estimated that 85% of the marginal value of a RPS is lost when the cracking rate reaches 15%. For lack of further insight, the working group assumed that the loss is piecewise linear on the domain, i.e., on the interval [0, 50] %, with a breaking point at (15, 85).

QUANT5: noise (fifth figure in Appendix B). For lack of insight, the working group assumes that the marginal value function is linear on the domain, i.e., on the interval [70, 85] dB.

3.3. Tradeoffs

DMs would have been ready to assess criteria weights by reasoning in terms of criteria importance. This would have been "the most common critical mistake"((Keeney 1992), p. 147). Criteria weights or tradeoffs were estimated by means of indifference judgments made by four experts from the working group. The reference criterion is the cost (QUANT1). For example, the question for eliciting the tradeoff for the rutting resistance (QUANT2) is :

Which price am I willing to pay for improving a RPS1 costing 10 € with 8 mm rut depth into a RPS2 with 4 mm rut depth (all other evaluations being equal) ?

RPS1 : (8 mm, 10 €) ~ RPS2 : (4 mm, ? €)

Similar questions were raised for assessing the tradeoffs for quantitative criteria (with reference to the cost criterion). For qualitative criteria the question has to be adapted. For instance, for drainability (QUAL1), the question reads :

Which price am I willing to pay for improving a RPS1 costing 10 € with weak surface drainability into a RPS2 with excellent surface drainabiltity (all other evaluations being equal) ?

RPS1 : (2, 10 €) ~ RPS2 : (5, ? €)

(We recall that 2 (resp. 5) is the value associated to weak (resp. excellent) surface drainability.)

Each tradeoff (except that of the cost criterion which was set to one) was determined by the answer to one question.

Tradeoff estimation. Consider for example the tradeoff between cost and rutting resistance. Assume that an expert declares he/she is willing to pay 20 € instead of 10 € for reducing rut depth from 8 mm to 4 mm, all other evaluations being equal. In the additive value model, this means that :

$$k_{cost}\ u_{cost}(10) + k_{rut}u_{rut}(8) = k_{cost}\ u_{cost}(20) + k_{rut}u_{rut}(4)$$

Using the values $u_{cost}(10) = 100 - 33.3$, $u_{rut}(8) = 100 - 75$, $u_{cost}(20) = 100 - 66.67$, $u_{rut}(4) = 100 - 37.5$ (that can be read from the first two figures in Appendix B) and setting $k_{cost} = 1$, we get : $k_{rut} = \frac{33.34}{37.5} = 0.89$.

Standard conditions. Of course, such indifference judgments can be polluted by the RW category and other parameters of the works. For instance, the tradeoff between cost and noise is likely to be different whether the expert has in mind RW in an urban environment (RW9) or in the countryside (RW2). Therefore, the experts were asked to consider a standard situation, namely that of a highway

(RW5), more specifically works on the E411 road (for which the other parameters are familiar to the experts), for all their indifference judgments in assessing tradeoffs.

Results. At the end of a working group meeting, four members (the GM and three out of the RMs and EDs) were assigned the task of making the required indifference judgments for the next meeting. The four experts worked independently. The corresponding computed tradeoffs are shown in Figure 3 (the reference tradeoff for cost is set to 1).

	JW	ZK	ML	BS	Mean
Rutting resistance (Orniérage)	0.338	0.756	0.522	0.433	**0.512**
Skid resistance (Adhérence)	0.317	0.317	0.220	0.317	**0.292**
Cracking rate (Taux de fissuration)	0.155	0.501	0.287	0.223	**0.292**
Noise (Bruit)	0.132	0.293	0.293	0.293	**0.253**
Drainability (Drainabilité)	0.422	0.422	0.293	0.422	**0.390**
Perturbations due to works	0.153	0.359	0.422	0.293	**0.307**
(Perturbations dues aux travaux)					
Inlets (Impétrants)	0.153	0.293	0.153	0.153	**0.188**
Suitability adjacent zones	0.293	0.153	0.293	0.293	**0.258**
(Adéquation sections adjacentes)					
Suitability works location	0.153	0.483	0.153	0.153	**0.236**
(Adéquation emplacement voirie)					
Maintenance (Entretien)	0.541	0.359	0.652	0.652	**0.551**
Ease of implementation	0.293	0.293	0.153	0.153	**0.223**
(Facilité de mise en œuvre)					

Figure 3. Tradeoffs obtained through the indifference judgments made by four experts

Discrepancies between tradeoffs assessed by experts can be large. Due to time constraints, it was not considered realistic to try to reach a consensus of the experts about the tradeoffs. It was decided to use the average value of the four tradeoffs in the model. The working group has considered that the judgment of each expert, even divergent, had to be taken into account, hence using an arithmetic mean (instead of discarding "extremes", for instance). These tradeoffs will be used for determining which is the best RPS for works on the E411 road and more generally on highways (RW5).

3.4. Revision

The parameters values previously elicited were finally reviewed and some revisions took place. In particular, the table in Figure 2 was modified into that in Figure 4. Changes were made within a technical working group composed of OP and three experts in the road domain (from BRRC and FEBELCEM, the Federation of the Belgian Cement Industry), who had not been involved previously. These changes were endorsed by the MET working group. The main adjustments made are the following:

1. the RPS "crossing" was removed (as not specific);

2. the list of alternatives was revised (see Figure 4, first column: DG stands for “*dalles goujonnées*” (“dowelled slabs”));
3. some combinations “criterion x RW” (corresponding to columns in Figure 2 were aggregated: “suitability to pavement of adjacent zones x {BBIC, BAC}” need not be distinguished; they are substituted by “suitablility to pavement of adjacent zones x Concrete”; also, “Easiness of implementation x {RBIT, REME}” can be merged together; finally, “Easiness of implementation x {BBIC, BAC}” are substituted by “Easiness of implementation x Concrete”;
4. adding a new criterion named *frost susceptibility* proved necessary (see below);
5. some evaluations in Figure 2 were modified;
6. some RPSs may not be used in certain categories of RW. This is mainly the case for RW2 (agricultural access roads). These incompatibilities are represented by black cells in Figure 4.

All revised evaluations are displayed in Figure 4.

Alternatives	Drainability	Perturbation / RW2	Perturbation / RW3	Perturbation / RW4	Perturbation / RW5	Perturbation / RW6	Perturbation / RW7	Perturbation / RW8	Perturbation / RW9	Ease of inlets insertion	Suitability / Adj. Section RBIT	Suitability / Adj. Section REME	Suitability / Adj. Section BCOM	Suitability / Adj. Section Concrete	Suitability / Location RW2	Suitability / Location RW3	Suitability / Location RW4	Suitability / Location RW5	Suitability / Location RW6	Suitability / Location RW7	Suitability / Location RW8	Suitability / Location RW9	Maintenance requirements	Ease of implement. if RBIT/REME	Ease of implement. if BCOM	Ease of implement. if Concrete	Frost susceptibility
RBIT / BB-1	2.5	6.5	6.6	6.4	6.0	5.8	5.6	6.4	5.5	6.0	9.0	6.0	3.0	2.5	9.0	9.0	7.0	3.5	9.0	3.8	9.0	9.0	3.0	9.0	6.0	6.0	7.0
RBIT / RMD	4.8	6.9	7.0	6.4	6.4	5.8	5.6	6.4	5.4	6.0	9.0	6.0	3.0	2.5	7.5	7.0	8.0	4.0	7.0	6.5	0.5	7.0	2.8	9.0	6.0	6.0	5.0
RBIT / SMA	3.8	6.7	6.8	6.4	6.2	5.8	5.6	6.4	5.4	6.0	9.0	6.0	3.0	2.5	6.5	8.0	8.5	4.8	8.0	6.5	0.5	7.0	3.0	9.0	6.0	6.0	6.0
RBIT / RMTO	5.8		7.0	6.4	6.4	5.8	5.6	6.4	5.4	6.0	9.0	6.0	3.0	2.5		3.0	6.5	3.5	2.0	2.0	1.0	4.0	3.0	9.0	6.0	6.0	3.0
RBIT / RUMG	5.3	7.3	7.4	6.4	6.8	5.8	5.6	6.4	5.4	5.5	9.0	6.0	3.0	2.5	6.0	4.0	8.0	3.5	0.0	3.0	2.0	3.0	2.3	9.0	6.0	6.0	5.0
RBIT / ED	8.0		6.8	6.4	6.2	5.8	5.6	6.4	5.4	5.5	9.0	6.0	3.0	2.5		2.0	6.5	3.8	0.0	2.0	0.0	4.0	3.0	9.0	6.0	6.0	2.0
RBIT / Enduit superficiel	5.3	7.1		6.4	6.6	6.0	5.8	6.4	5.6	5.5	9.0	6.0	3.0	2.5	7.5		7.0	4.0	0.0	2.0	5.0	3.0	2.0	9.0	6.0	6.0	8.0
RBIT / RBCF	2.8	7.5	7.6	6.1	7.0	6.0	6.0	6.5	5.8	6.0	9.0	6.0	3.0	2.5	6.0	5.0	4.0	3.0	1.0	2.0	7.0	4.0	2.0	9.0	6.0	6.0	7.0
REME / RMD	4.8	6.7	6.8	5.9	6.0	5.6	5.8	6.4	5.2	5.3	7.8	9.0	3.0	3.0	7.5	6.5	8.0	6.3	6.0	6.5	5.0	5.0	4.0	9.0	6.0	6.0	5.0
REME / SMA	3.8	6.5	6.6	5.9	5.8	5.6	5.8	6.4	5.0	5.3	7.8	9.0	3.0	3.0	6.5	7.5	8.5	7.5	7.0	6.5	5.0	5.0	4.3	9.0	6.0	6.0	6.0
REME / RMTO	5.3		6.8	5.9	6.0	5.6	5.8	6.4	5.2	5.3	7.8	9.0	3.0	3.0		2.5	6.5	5.8	1.0	2.0	1.0	2.0	4.0	9.0	6.0	6.0	3.0
REME / RUMG	5.3	7.1	7.2	5.9	6.4	5.6	5.8	6.4	5.6	4.8	7.8	9.0	3.0	3.0	6.0	3.5	8.0	5.8	0.0	3.0	2.0	2.0	3.5	9.0	6.0	6.0	5.0
REME / ED	8.0		6.6	5.9	5.8	5.6	5.8	6.4	5.0	4.8	7.8	9.0	3.0	3.0		1.5	6.5	6.0	0.0	2.0	0.0	2.0	4.0	9.0	6.0	6.0	2.0
BCOM / RMD	4.7	3.0	3.9	2.3	2.5	1.8	2.7	2.8	1.5	2.0	6.3	7.0	9.0	4.0		3.0	4.2	7.8	3.0	7.5	3.0	1.8	5.5	2.0	4.0	2.0	5.0
BCOM / SMA	3.8	2.8	3.7	2.1	2.3	1.6	2.5	2.6	1.3	2.0	6.3	7.0	9.0	4.0		3.0	4.5	8.0	3.5	7.5	3.0	1.8	5.8	2.0	4.0	2.0	6.0
BCOM / RMTO	5.3		3.9	2.3	2.5	1.8	2.7	2.8	1.5	2.0	6.3	7.0	9.0	4.0		3.0	4.0	7.3	0.0	4.0	1.0	1.0	5.5	2.0	4.0	2.0	3.0
BCOM / RUMG	5.3	3.4	4.3	2.7	2.9	2.2	3.1	3.2	1.9	2.0	6.3	7.0	9.0	4.0		3.0	4.5	8.0	0.0	5.0	2.0	2.0	5.0	2.0	4.0	2.0	5.0
BCOM / ED	8.0		3.7	2.1	2.3	1.6	2.5	2.6	1.3	2.0	6.3	7.0	9.0	4.0		2.0	4.0	8.0	0.0	4.0	0.0	1.0	5.3	2.0	4.0	2.0	2.0
DG / BDénudé	5.5	4.0	5.0	3.5	3.5	3.5	4.0	4.0	3.0	3.0	1.8	3.0	4.0	9.0	7.0	8.0	8.0		3.0	7.0	5.0	3.0	7.5	4.0	3.0	3.0	8.0
DG / BBicouche	5.3	4.0	5.0	3.5	3.5	3.5	4.0	4.0	3.0	3.0	1.8	3.0	4.0	9.0	4.0	7.0	8.0		3.5	6.7	3.0	3.3	7.0	4.0	3.0	3.0	8.0
BAC / BDénudé	5.5	3.6	4.5	2.9	3.1	2.4	3.3	3.4	2.1	1.5	1.8	3.0	4.0	9.0		5.0	6.0	8.8	3.0	8.3	2.0	1.5	9.0	4.0	2.5	2.5	8.0
BAC / BBicouche	5.3	3.6	4.5	2.9	3.1	2.4	3.3	3.4	2.1	1.5	1.8	3.0	4.0	9.0		4.0	6.0	8.3	3.5	8.0	0.0	1.8	8.5	4.0	2.5	2.5	8.0

Figure 4. Revised evaluations of RPS w.r.t. 27 combinations of qualitative criteria and relevant RW category

QUAL8: frost susceptibility. Some types of RPS are not recommended in regions exposed to intense frost during long periods. The experts assigned a (qualitative) frost susceptibility value (from the [0,10] interval) to each RPS. The associated marginal value function, obtained by means of indifference judgments, is represented in Appendix C. The weight (tradeoff) assigned to this criterion depends on the works location. It is computed as a linear function of the frost index of the city in Wallonia that is closest to the works (referred to as DescrRW7 in the list of works descriptors at the end of Section 2.2). A table reports the frost index of the most important cities in Wallonia. This index (expressed in °C day) is maximal in Bastogne and minimal in Tournai. The criterion tradeoff varies from 0.138 for works close to Tournai to four times as much (i.e., 0.555) for works close to Bastogne.

4. Tuning based on RW type

Since tradeoffs were elicited using a standard situation (works on E411 highway), the corresponding model will not fit well in all other RW situations.

Initially, three other road works cases were studied. The ranking obtained using the “standard” model was confronted to the experts’ judgment. On this basis,

- the tradeoffs attached to some criteria were modulated depending on the RW category (and perhaps the parameters of the RW);
- the evaluations of some criteria were revised.

Finally, not only the RW category had to be taken into account but also other works characteristics (see list of six parameters in Section 2.2, to which the position of the works has to be added in order to determine the works frost index).

4.1. Computing the value associated to a RPS for a given RW

The value *u(x)* of a RPS *x* is a sum over qualitative and quantitative criteria of the corresponding marginal values of the RPS weighted by the tradeoff associated to the criterion and the RW type :

$$u(x) = \sum_{i \,\in\, \text{QUANT} \cup \text{QUAL}} k_i^{\text{RW}} u_i(g_i^{\text{RW}}(x))$$

where

- the evaluations $g_i^{RW}(x)$ of x w.r.t. qualitative criteria, are taken from Figure 4. Some values not only depend on the RPS but also on RW characteristics, namely, type of RW (RW2 to RW9), Current road pavement (DescrRW1), Current road pavement of adjacent zones (DescrRW2) ; the marginal values u_i for qualitative criteria are linear except for the *frost sensitivity* criterion (see Appendix C) ;
- the marginal values $u_i(g_i^{RW}(x))$ of RPS for quantitative criteria are computed using the functions illustrated in the five figures in Appendix B;
- the weights or tradeoffs k_i^{RW} depend, in general, both on criterion i and on characteristics of the RW. We detail below how these tradeoffs are assessed.

4.2. RW-dependent tradeoffs

The tradeoff values in Figure 3 were assessed for the RW5 case; they are adequate for works on highways. Since these tradeoffs were assessed by indifference judgments in terms of cost differences, it was asked to estimate the fraction of the cost difference corresponding to other types of RW. The reference tradeoffs were thus modulated using these estimated fractions, according to the type of road works and to characteristics of the works.

Rutting. The tradeoff related to the “Rutting resistance” criterion (QUANT2) is modulated depending on the intensity of heavy trucks traffic. The tradeoff in Figure 3 (0.512) is multiplied by the coefficients in Table 2 according to the number of trucks per day on the road (this parameter is specified as DescrRW5 in the works description).

Number of trucks per day (NT)	Coefficient
NT < 250	0.3
250 ≤ NT < 2000	0.6
2000 ≤ NT	1

Table 2. Multiplicative coefficient to be applied to the weight of the “Rutting resistance” criterion according to the number of trucks per day

Type of road. According to the type of road (RW2 to RW9) on which the works is located, a multiplicative coefficient is applied to the reference tradeoffs. Figure 5 displays these coefficients. The value “0” indicates that the criterion is irrelevant for the type of RW.

	Cost	Rutting resistance	Skid resistance	Cracking rate	Noise	Drainability	Perturbations	Inlets	Suitability Adjacent	Suitability location	Maintenance	Ease of implementation	Frost
RW2: Agricultural access road	1	1	1	1	0.5	0.5	0.5	0.5	1	3	0.5	1	1
RW3: Parking lot	1	1	0.5	1	0	0.5	0.5	0.5	0.5	3	0.5	1	0.5
RW4: RESI roads connecting cities	1	1	1	1	1	1	1	1	2	3	1	1	1
RW5: RGG highways, main roads	1	1	1	1	1	1	1	1	1	3	1	1	1
RW6: Roads in commercial zone	1	1	1	1	0.5	1	2	1	1	3	1	1	1
RW7: Roads in industrial zones	1	1	1	1	0.5	1	2	1	1	3	1	1	1
RW8: Local road	1	0	0.5	1	0.5	0.5	0.5	1	1	3	0.5	1	0.5
RW9: Urban roads, streets	1	1	1	1	1	1	2	1	1	3	1	1	1

Figure 5. Multiplicative coefficients to be applied to criteria tradeoffs in the different types of RW

Frost susceptibility. The tradeoff value is a linear function of the *frost index* of the city closest to the works (see Section 3.4). The tradeoff thus ranges from 0.138 (works close to Tournai) to 0.555 (works close to Bastogne).

The validity of these coefficients was checked on real RW examples (which sometimes led to adjust previous values of the coefficients). The process of validating the model on cases is described in the next section.

5. Validation

We distinguish two aspects in the validation process. One related to the analysts (i.e., the participant(s) who is (are) expert(s) in MCDA methods) and another related to the members of the working group that are experts in RW.

5.1. Logical validity

It is a basic requirement of decision-aiding processes that the analyst(s) should be convinced that the chosen method(s) is used properly, which implies that the way of eliciting the method parameters should not betray the spirit of the method. That is what we call here "logical validity" (see e.g., (Bouyssou, Perny, et al. 1993) and (Bouyssou, Marchant, et al. 2006)). We made every effort to ensure that questions posed to the experts did not cheat with the concepts of additive value function theory. Tradeoffs have been elicited as tradeoffs, not in terms of criteria importance. The construction of marginal value functions is consistent with the model. The value function can meaningfully be used to rank order the alternatives; in addition, differences of preferences on each criterion can be meaningfully compared because the marginal value functions have been constructed with a view to represent the ordering on single criterion preference differences[2].

[2] We do not assume that overall preference differences are correctly represented by value differences (as in the measurable value function model (Dyer and Sarin 1979)), because we felt unlikely that the experts could reliably compare overall preference differences. In any case, no attempt has been made to test the validity of the representation of overall value differences by the value function model. Only the validity of the

For eliciting the marginal value functions, we could not use the most rigorous methods, such as building standard sequences by means of indifference judgments ((Von Winterfeldt 1986), section 8.1 or (Bouyssou and Pirlot 2016)), due to practical reasons (size of the working group, time constraints). Nevertheless, we paid attention to correctly represent preference differences on each criterion. Moreover, questions regarding tradeoffs were formulated in a rigorous manner. Of course, due to the large number of assessments required from the experts, one cannot expect that all assessments are accurate. So, even though the process seems logically consistent with additive value function theory, there was a need to confront the model to a number of decision situations that are well understood in a holistic manner[3] by the experts. This is described in Section 5.2.

5.2. Validation by cases

A dozen real RW examples with representative characteristics and specified location were analyzed. The computed values of the RPS allowed to rank them from the most desirable to the least. The experts in the working group checked whether the RPSs ranking produced by the model in the cases was in agreement with the experts' experience. In most of the cases, the RPS rankings were found to be correct by the experts in the working group. Detailed histograms such as in Figure 6 were helpful to analyze the contribution of each criterion in the value assigned to the alternatives. It allowed, in particular, to validate the fact that an alternative is better ranked than another. Some anomalous inversions in the RPS rankings were detected and analyzed, mainly on the basis of Figure 6. Parameter adjustments were made, especially regarding the multiplicative coefficients applied to tradeoffs for taking the RW category into account (Figure 5 contains the values eventually adopted).

Example.

The characteristics of works on the E411, the reference case used for assessing criteria tradeoffs, are the following:

- Type of road: RGG (RW5);
- Current road pavement: BAC;
- Current road pavement of adjacent zones: BAC;
- Length and surface of the works site: 5000 m;
- Inlet insertion: no;
- Traffic load: 5280 trucks/day;
- Number of working days: 365;
- Frost susceptibility: works close to Bastogne.

The corresponding RPSs ranking is illustrated in the histogram represented in Figure 6. The RPSs values are ranked in decreasing order (the larger the better). Each bar is decomposed in smaller bars representing the weighted marginal value of each criterion. Users can appraise at a glance the contribution of each criterion to the value of the RPS. They can compare these contributions in different RPSs and track the reasons why an RPS is ranked better than another. Such a graphic tool enables to identify the strong points (long segment corresponding to the contribution of a criterion in a bar) and weak points (short segment).

The results raised the following comments: "The alternatives BAC/BDénudé and BBicouche appear on top of the ranking and well ahead, as expected. Their advantage over the other solutions is

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representation of single criterion preference differences has been checked and then used in the case-based validation process described in Section 5.2.

[3] By this we mean that the experts are familiar enough with these cases so that they are able to judge whether the ranking of the RPS by the model makes sense in such a context. In other words, they are able to detect anomalies in the ranking.

consistently reflected in the lengths of the colored bars. In the 3rd and 4th places arrives RUMG as surface layer, which is correct. RBITs are logically relegated to the bottom of the ranking".

A similar analysis was performed in working group for all validation cases.

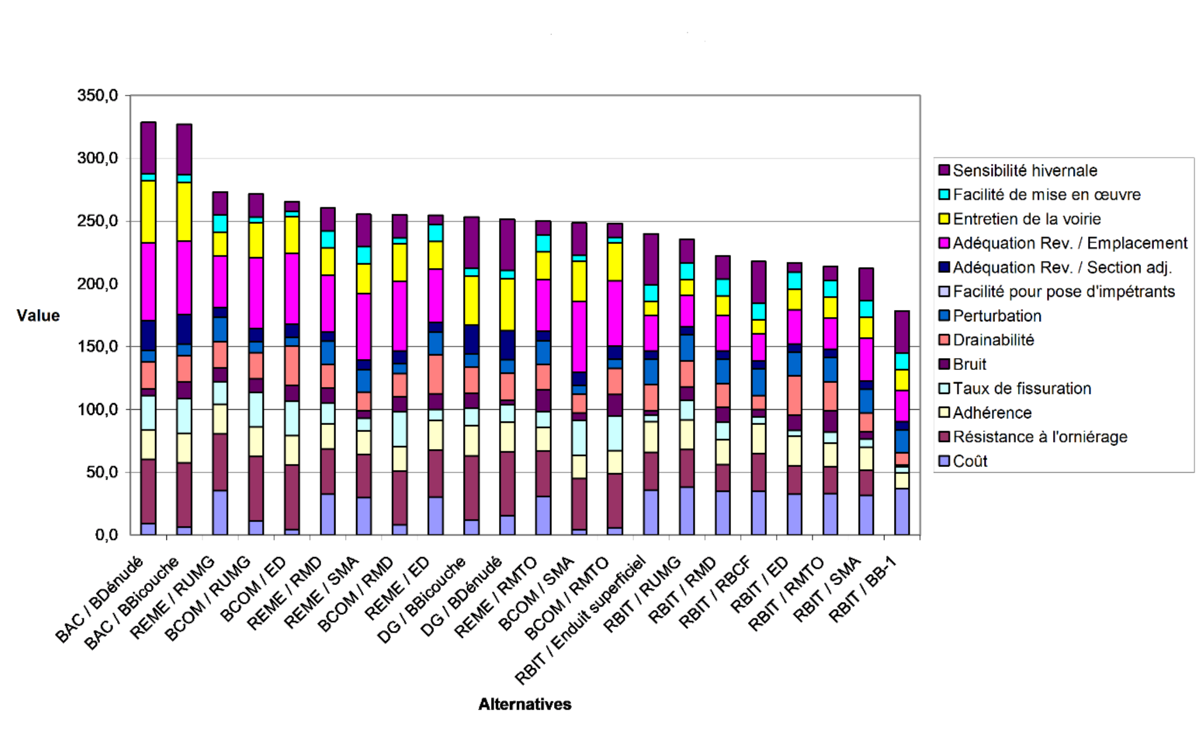

Figure 6. Values of the RPSs ranked in decreasing order in the case of works on E411

6. The decision-aiding software EVAL-MET

The development of a decision-aiding software implementing the additive value function model was the object of a contract between the MET and University of Mons. The software was written in Java. The data was stored in a database containing the list of alternatives (RPS), that of road works types (RW), the evaluations of the alternatives w.r.t. the criteria (including the auxiliary models used to compute evaluations whenever they depend on RW characteristics such as trucks traffic load), the marginal value functions, the tradeoffs and the multiplicative coefficients used to adapt tradeoffs to RW. The program also makes calls to external technical modules, such as the design software *dimMET©* (SPW Mobilité 2012), to compute the thickness of the RPSs and the cracking rate as a function of traffic load and characteristics of the RPS layers.

6.1. Interface

Figure 7 shows the user interface of the decision-aiding software devised to help the RW manager choose the best possible and most suitable RPS.

- The user enters the characteristics of the RW in the bottom left part of the screen ("Paramètres du chantier").
- The criteria weights, normalized and un-normalized, appear in the upper part of the screen ("Poids des critères"). The weights (tradeoffs) determined by the working group are the default. The user may enter his/her own weights and experiment with them.

- Below, is a sheet where the RPS evaluations w.r.t. all criteria are displayed ("Score des revêtements"). They are computed internally, taking into account the RW characteristics. They cannot be modified by the user. The last two columns show the values (or scores) of the RPS computed using the model; the last (resp. last but one) column displays the scores computed using the weights entered by the user (resp. the default weights).
- The bottom right part is a graphical representation of the scores ("Plots/Scores détaillés"). The histogram in Figure 7 represents the scores (and their decomposition w.r.t. the criteria) for the user's weights. The same representation is available for the default weights (by selecting "Pds par défaut" in the upper part of the screen). The RPSs can be sorted in decreasing or increasing order of their scores (default or user defined). In the histogram in Figure 7, one can see that the yellow part (corresponding to criterion "Rutting resistance" or "Orniérage") is dominant in all bars. This is a direct consequence of the large weight assigned by the user to criterion "Rutting resistance).

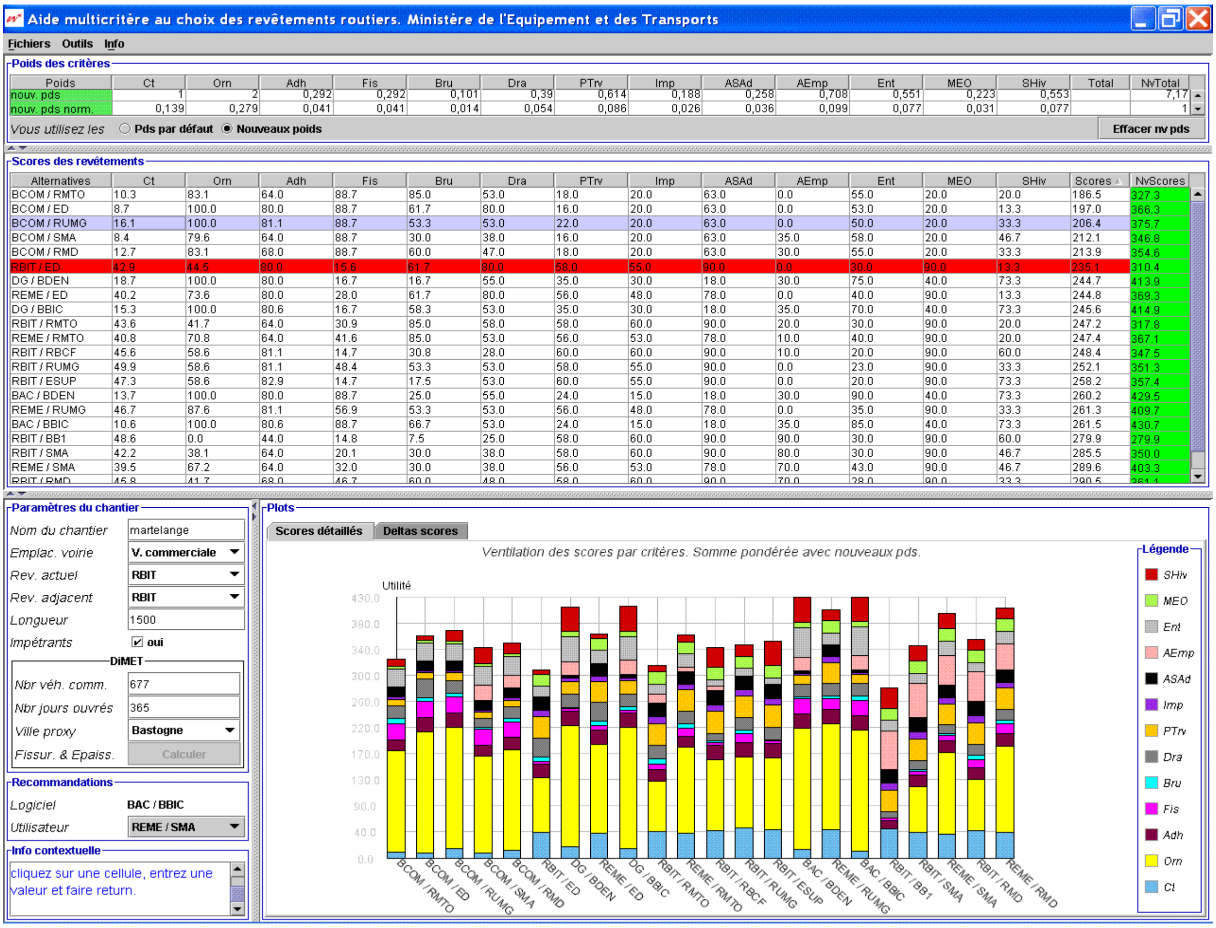

Figure 7. A view of the interface of the decision-aiding software EVAL-MET

By selecting two rows in the spreadsheet in Figure 7 (one blue and the other red), one may contrast the corresponding two RPSs. The bar diagram in Figure 8 is visible in the "Deltas scores" tab. It shows on which criteria the alternative BCOM/RMTO has an advantage w.r.t. alternative RBIT/ED (for a given RW and the default weights); the score difference on a criterion in favor of BCOM/RMTO are represented by the height of the red bars. The blue bars show where and how much RBIT/ED has an advantage over BCOM/RMTO. This may help the user understand why an alternative is ranked before another. It may start a process calling the model's parameters into question.

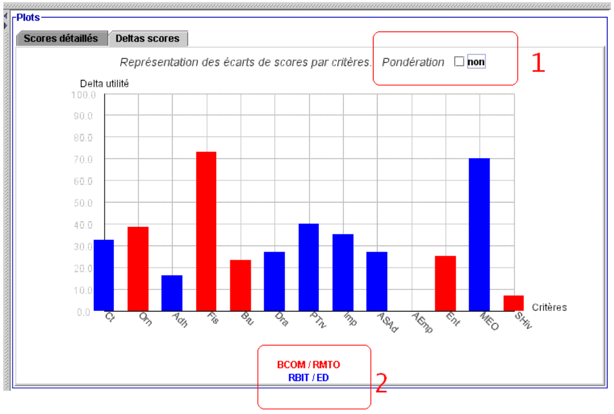

Figure 8. Score difference per criterion: in favor of BCOM/RMTO in red; in favor of RBIT/ED in blue

6.2. Using the decision-aiding tool EVAL-MET

Indications on how EVAL-MET should be used were given by the direction of the MET. The RW manager must use the software to choose the most adequate RPS for a given RW. As soon as he/she introduces the parameters of the RW, the program computes the value of each RPS by using the default tradeoffs (those elaborated by the working group). The RW manager can use the software to:

- compare an alternative to another and examine the strengths and weaknesses of one as compared to the other;
- modify the default tradeoffs and examine the changes in the RPSs ranking produced;
- depart from the best solution(s) recommended by EVAL-MET provided he/she writes an explicit justification for another RPS and reports to the MET about his/her decision; arguments justifying the choice of another RPS may rely on using the software with tradeoffs chosen by the user. Of course, using different tradeoffs requires justifications that can be challenged by the hierarchy.

In a first step, it is planned to dispatch the program to the RW managers on a CD. To ease the maintenance of the software and of the database, as well as the program evolution, it is advisable to move to a decision-aiding tool installed on a central server; the users would access the program through an internet connection. This evolution was not implemented.

6.3. The acceptance issue

The model and the decision-aiding tool were presented to the users, i.e., the Field Engineers managing RW, in a meeting organized by the MET (February 22, 2006). The decision-aiding tool was not warmly received. According to some participants, choosing a pavement or a wearing course is the engineer 's role and function; a software cannot help an engineer because it cannot consider all the cases and contextual issues.

At this stage, the mission which was the object of the contract was complete. The contract didn't involve neither users training nor model or software maintenance. The BRRC could have taken over these tasks. OP continued to work for BRRC until August 2007. He provided assistance to use the model and the decision aiding tool upon request from Field Engineers.

In subsequent months, the GM changed the rules for preparing public contracts by adding the use of Eval-MET into the specifications. He received complaints from some Field Engineers (we do not have precise information on the substance of these complaints). When he retired in October

2008, the use of this software was made optional by the new GM. The project of providing assistance to the Field Engineers for choosing appropriate RPS in RW fizzled out. The BRRC did not pursue in this direction either. Historically, the BRRC's role was to provide scientific expertise on road techniques to the actors, public and private, involved in maintaining and developing the road network in Belgium. Developing or maintaining a decision-aiding tool was probably a bit unusual for the BRRC which focusses on technical expertise.

Despite the criticisms about Eval-MET, the pavement of a major road project was chosen using this software. The engineer in charge of managing this RW was convinced of the great usefulness of this multi-criteria decision-aiding tool. Therefore, he used the EVAL-MET software, with the help of OP, to choose the RPS of the Couvin bypass, a 14 km long road with a twin layer-continuously reinforced concrete pavement (BAC/BBicouche).

7. Looking back on the process

We briefly analyze the process of this intervention in terms of strengths, difficulties and procedural approaches to face process weaknesses. We finish with some conclusions.

7.1. Strengths

Our main assets in this intervention were twofold:

- The involvement of OP who was the project linchpin as a researcher at BRRC and student or ex-student at University of Mons. OP played the key role of a translator - interpreter. He was ideally positioned to explain decision-aiding concepts to the MET, and the goals, constraints and technicalities of road management to the team at UMONS.
- The commitment and leadership of the MET top management. Its determination in regulating and optimizing the decisions regarding the choice of RPS in RW was the project driving force.

Not all RMs and EDs members of the working group were convinced by the approach; some were skeptical and were mildly resisting the top management's will. It was useful to understand dynamics and internal logics of the organization. The involvement of the working group experts in the validation cases was essential to detect and analyze some anomalous inversions of the alternatives in the rankings

7.2. Difficulties and process weaknesses

The main difficulties were the following:

- Field Engineers (FEs) had not been involved in the project elaboration process. We underlined the risk associated with this decision without any result.
- Being forced to use a normative tool such as the EVAL-MET software reduces the FE's freedom and autonomy in decision. We anticipated resistance. The initial views of the top management were that the program would determine the best choice, which should be followed by the FE in charge of the RW. We insisted the right concept was decision-aiding not decision-making. During the working group sessions, we negotiated that the software should be used by the RW manager, but the recommendation issued by the software could be challenged and dismissed by setting out rational arguments, reported to the MET administration. This was accepted. However, it seems that little has been done in advance to convince the FEs that using the software could be beneficial.
- The model and the software were validated in several ways before they were presented to the users but not tested in real situations. It is quite likely that feedback by the users of

encountered problems (e.g., inconsistencies in rankings issued by the model) would have led to reworking the model and the software.

- Software maintenance issues could not be anticipated. Alternatives (i.e., RPSs) change with technical progress and experience. Evaluations probably need revision. Feedback from the users must be examined and should trigger changes in the model and software. To avoid proliferation of different versions, it will be necessary to provide a regularly updated official version available through internet on a server.

Some **process weaknesses** needed specific approaches and sometimes generated model fragility:

- There was no consensus among the experts in the working group regarding the evaluations of alternatives w.r.t. certain criteria, and regarding tradeoffs. The dispersion of experts' assessments was sometimes substantial, and heavy time constraints limited discussion and analysis of specific misunderstandings. Averaging the experts' assessments was compulsory but it could blur judgment variability.
- The multiplicative coefficients applied to the reference tradeoffs dispensed from the time and energy consuming task of eliciting tradeoffs for each RW type (which was not an option). But the resulting models might be only a rough approximation of the models that would have resulted from eliciting the tradeoffs.
- The validation and fine tuning of the models was based on a dozen of real RW cases. Despite this non exhaustive validation, the fact that no ranking sounded strange to the experts helped build trust in the model.

7.3. Success or failure?

It is difficult to state a final judgment on this intervention since it could not be fully developed due to the priority shift of the MET top management. The latter sort of event is not uncommon in decision-aiding interventions (Brown 2009). In our case, the reasons for that shift are the arrival of a new direction after the retirement of the general manager. The involvement of the FEs in the project elaboration process could perhaps facilitate the complete development of the intervention.

Had the priorities of the new direction remained the same, the process could have been pursued. The key issue at that stage was to develop ownership of the model and decision-aiding tool by the FEs. It was necessary to allocate resource and time to let the model and the software evolve interactively with the FEs in charge of RW. In that way, acceptance of the tool and of its usage rules could probably be reached.

Assuming that the necessary resource was dedicated to the users' acceptance process, the model's maintenance would have required continuous attention. Moving to a centralized version is a vital necessity. It is also imperative to rely on internal resource and skills (either in MET or BRRC) to maintain and evolve the model and the software, as well as to manage the interactions with the users. A monitoring committee should also have been constituted to supervise the evolution of the tool. Occasionally, experts in decision models could be consulted to ensure the logical consistency of the evolving model.

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Appendix

A. Alternatives

The first column in the table below specifies the type of road pavement (5 types, RP1 to RP5); the second column specifies the possible surfacings (wearing course) for each type of road pavement.

Type	Wearing course
RP1 : Asphalt concrete (RBIT: revêtement bitumineux)	BB-1 RMD SMA RMTO RUMG ED Surface dressing (Enduit superficiel) RBCF
RP2: High modulus asphalt concrete (REME: revêtement bitumineux avec enrobé à module élevé)	RMD SMA RMTO RUMG ED Surface dressing (Enduit superficiel)
RP3: Composite concrete (BCOM: béton composite)	RMD SMA RMTO RUMG ED Surface dressing (Enduit superficiel)
RP4: Two-layer concrete (BBIC: béton bicouche)	-----
RP5: Continuously Reinforced Concrete Pavement (BAC: béton armé continu)	-----

ED : porous asphalt ; RUMG : ultra-thin, grained coating ; RMTO: ultra-thin, open-textured coating ; RMD: thin, open-textured coating ; BB: bituminous concrete ; RBCF: slurry seal ; SMA : stone mastic asphalt.

The latter two groups of alternatives (RP4 and RP5) were restructured as follows in the revision phase (see Section 3.4).

RP4: Dowelled slabs (DG: dalles goujonnées)	Nude Two-layer
RP5: Continuously Reinforced Concrete Pavement (BAC: béton armé continu)	Nude Two-layer

Example of form filled by each expert for each of the qualitative criteria (Figure 9).

1. DRAINABILITE DU REVÊTEMENT											
	2 =	drainabilité de surface faible									
	5 =	drainabilité de surface excellente									
	8 =	drainabilité dans la masse satisfaisante									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RBIT / BB-1											
RBIT / RMD											
RBIT / SMA											
RBIT / RMTO											
RBIT / RUMG											
RBIT / ED											
RBIT / Enduit superficiel											
RBIT / RBCF											
REME / RMD											
REME / SMA											
REME / RMTO											
REME / RUMG											
REME / ED											
REME / Enduit superficiel											
BCOM / RMD											
BCOM / SMA											
BCOM / RMTO											
BCOM / RUMG											
BCOM / ED											
BCOM / Enduit superficiel											
BBIC / Béton bicouche											
BAC / Béton armé continu											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Figure 9. Form to be filled for the evaluation of qualitative criteria. Example : QUAL1, drainability

B. Marginal value functions for the quantitative criteria

Marginal value function for cost (Figure 10)

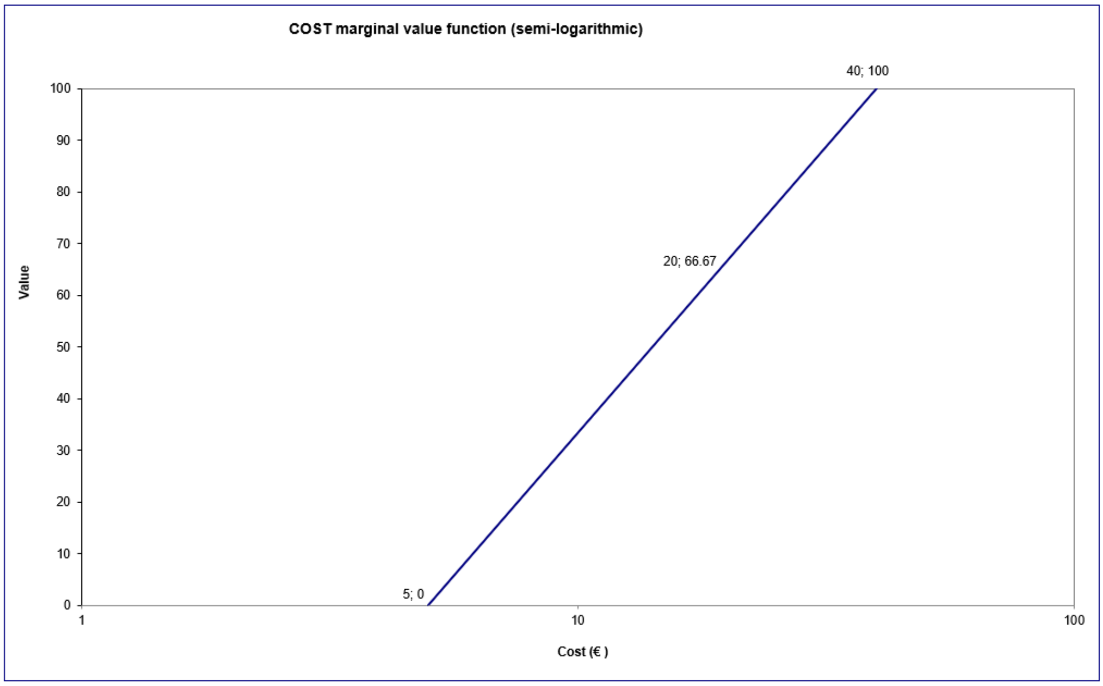

Figure 10. Marginal value function for cost (logarithmic scale for cost) on the [5,40]€ cost interval

Marginal value function for rutting resistance (Figure 11)

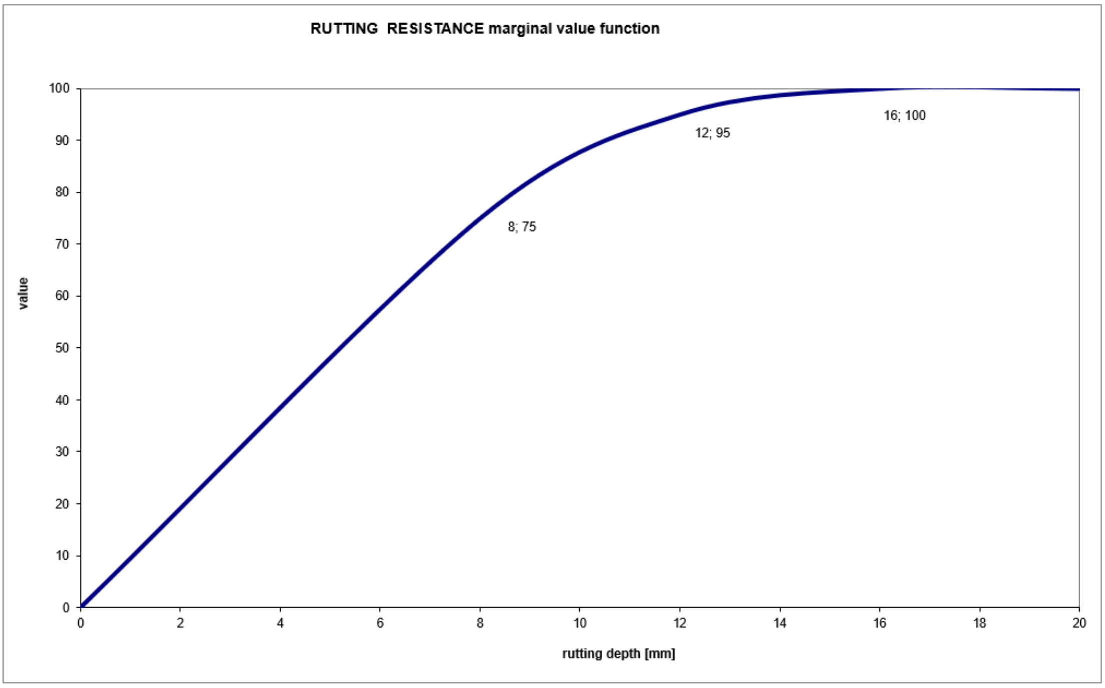

Figure 11. Marginal value function for rutting resistance on the [0,20]mm interval

Marginal value function for skid resistance (Figure 12**)**

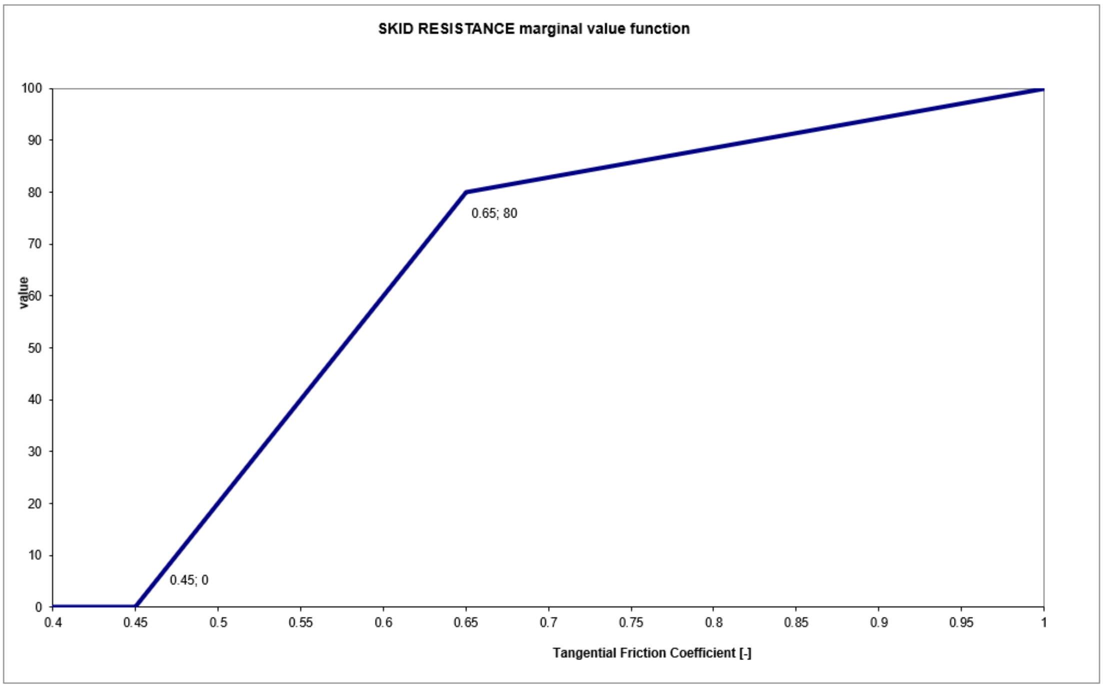

Figure 12. Marginal value function for skid resistance on the [0.45, 1] interval

Marginal value function for cracking rate (Figure 13**)**

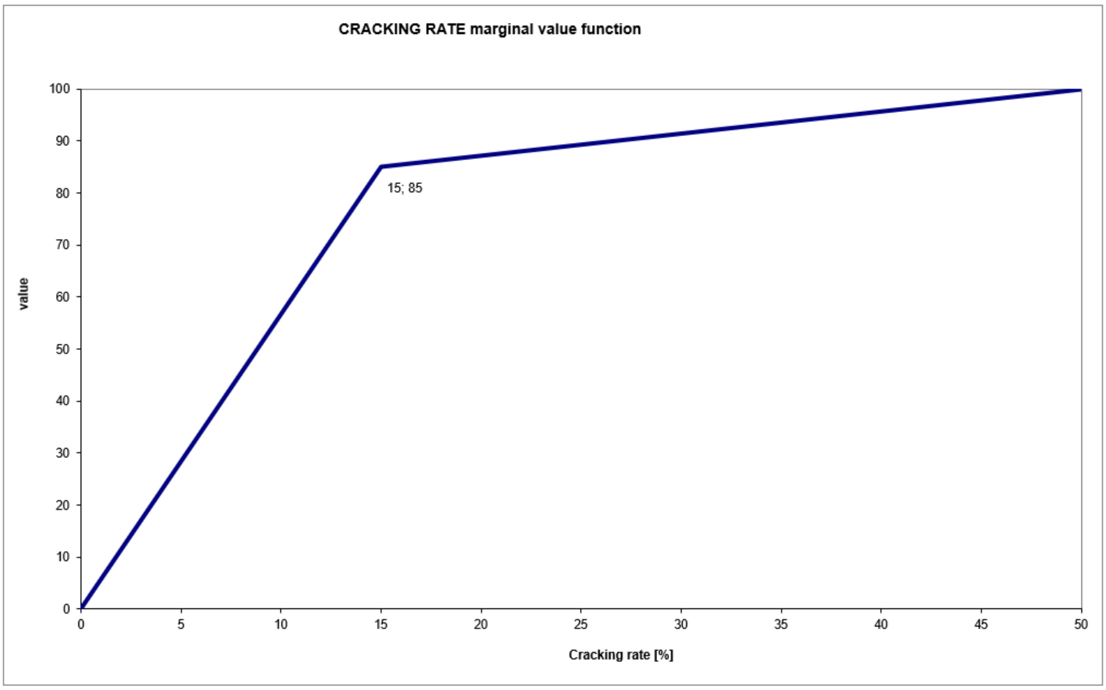

Figure 13. Marginal value function for the cracking rate on the [0, 50]% interval

Marginal value function for noise (Figure 14**)**

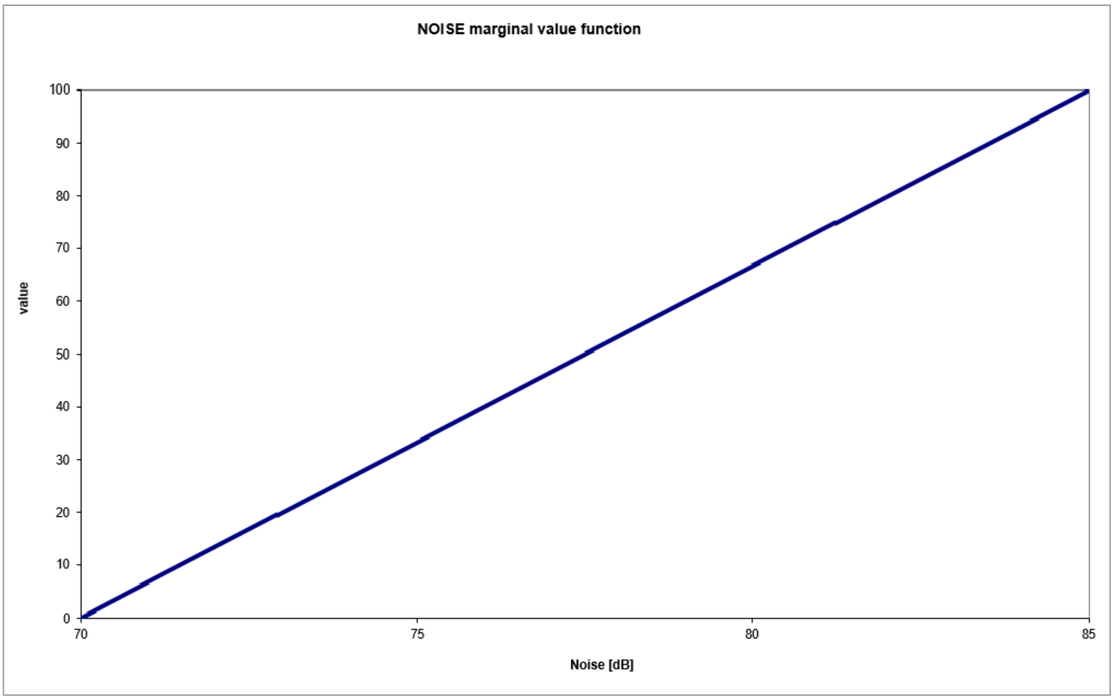

Figure 14. Marginal value function for the noise on the [70,85] dB interval

C. Marginal value function for Frost Susceptibility (Figure 15)

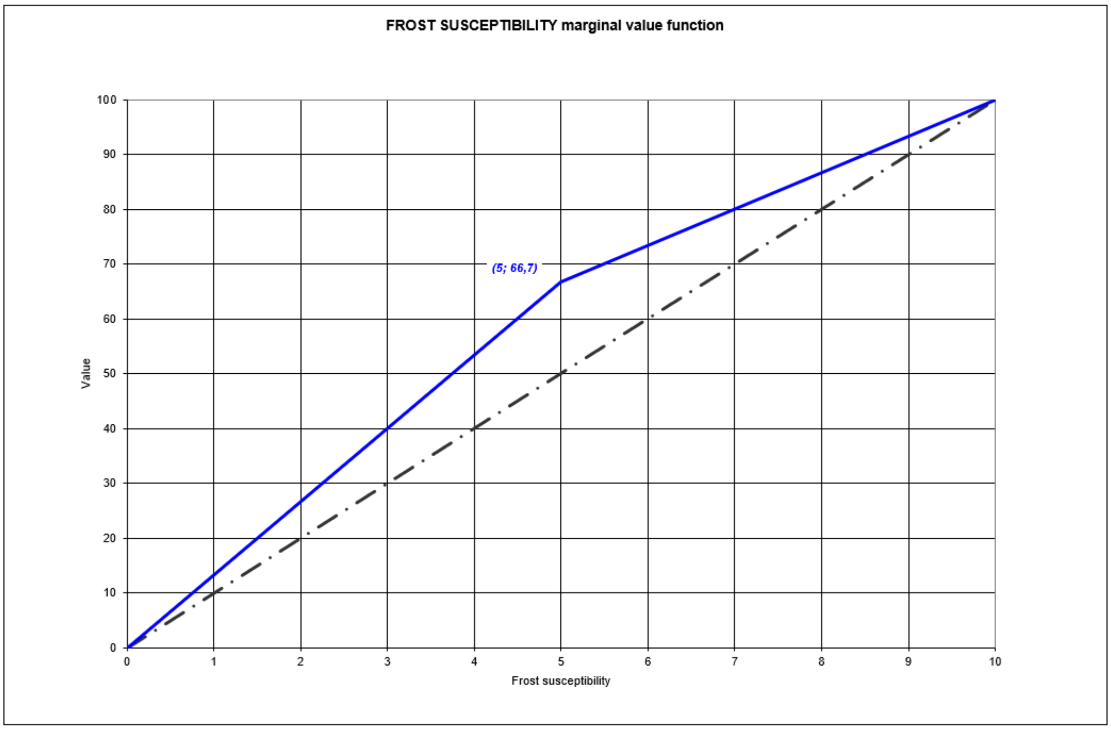

Figure 15. Marginal value function for the frost susceptbility qualitative criterion