A METHOD FOR EVALUATION AND SELECTION OF C2X COMMUNICATION FUNCTIONS

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ABSTRACT

Car-To-X-Communication (C2X, where X can be Car or Infrastructure) is considered as a key technology for the introduction of new automotive functions and for the improvement of existing autonomous functions. There is a wide range of such functions within the fields of safety, traffic efficiency, infotainment, comfort, and many others. Every attempt to investigate C2X technology must start with a selection of the most promising functions. Generally spoken, a decision process is required. BOSCH corporate research has developed a method for an objective evaluation of functions based on the Analytical Hierarchy Process. In cooperation with the project partners, the approach was successfully deployed in the German project simTD, a large real metropolitan field operational test (FOT).

INTRODUCTION

Car-To-X (C2X) communication is not only an enabler for any predictive automotive function (safety, driver assistance) already realized with in-vehicle sensors like radar and video or for telematics services like driver information. The formation of vehicular networks further provides a framework where many new functions based on cooperative driving behaviour of the involved vehicles can be realized. Together with infotainment and service functions a vast amount of functions is possible.

Any attempt to investigate C2X communication may begin with a more or less complete list of such functions, but must then focus on a relatively small set of the most promising ones. A comprehensible, transparent approach towards them consists of a ranking based on a so-called total grade G assigned to each function by so-called decision makers. These are experts, e. g. from research, marketing, function development divisions, project managers, and so forth. Such rankings naturally are subjective as they base upon individual experiences and interests of the decision makers: a researcher might favour sophisticated functions with a large safety potential while a project manager might focus on a simple function with low development costs. On the other hand, there are certain properties of functions which can be evaluated objectively.

It is possible to separate the objective and the subjective elements of such a grade assignment when a criterion-based approach is used. Here, every function is evaluated according to various criteria (e. g. safety benefit, product costs, technical risk, etc.) by assigning single grades g_i (numbers ranging from 0.0 to 1.0 where 0.0 is the lowest grade, i enumerating the criteria). These single grades are objective: either they are derived from measurements (experiments, simulations) or an unbiased estimation of their results can be made a priori.

The total grade can be calculated from the single grades by means of a weighted sum

$$(1) \qquad G = \sum_i w_i g_i \,, \qquad \sum_i w_i = 1$$

with the weights w_i. The normalization of the weights guarantees that the total grade G also ranges from 0.0 to 1.0.

The weights are assigned to every criterion according to its relative importance so that the subjective element of the grade assignment is confined within them. A method is required to transform these subjective elements into a number.

PREREQUISITES

In the C2X communication research project at BOSCH functions were gathered. To every function a coarse description and various attributes like benefit, risks, hardware requirements, were provided and stored in a so-called function database. These attributes allow to identify duplicates and to unify many similar to one single function. Moreover they were necessary for a fair and comprehensible evaluation, i. e. the grade assignment. This next step in the process also determined the necessary level of detail for the description: it should contain all information for assigning a grade and define the function unambiguously.

CRITERIA AND ASSIGNMENT OF SINGLE GRADES

Criteria for the evaluation were also gathered and described in such a way that an equal evaluation (assignment of single grades g_i) over all functions was possible. This involved an exact definition of the criterion, the allowed levels of evaluation, and an illustration how to perform the assignment.

The criterion “degree of innovation” may serve as an example: here the three single grades 0.0 (corresponding to an already known function with a C2X based supplement), 1.0 (a function which can only be realized with C2X technology), and 0.5 (an intermediate value) were allowed.

ANALYTICAL HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a method for dealing with complex decisions based on mathematics and psychology (1) and has been applied to a wide variety of situations, in fields such as business, industry, government, and so forth. Its main goal is not the achievement of the only in some defined sense “correct” decision. Instead it supports decision makers in finding a solution that best suits their needs. The decision makers are encouraged to provide their evaluations no matter whether they are based on concrete data or not. By providing a conversion method of these evaluations to numerical values the often diverse elements can be compared to one another over the entire range of the problem. This is a unique feature of the AHP with respect to other decision making techniques.

There is general consensus about the AHP’s technically validity and its usefulness. However, there has also been criticism, mainly focusing on

- the scale (restriction values from 1-9 and the mapping of verbal to numerical scale),
- the “rank reversal” phenomenon (additional alternatives may tend to influence the overall result),
- the large effort involved in its application.

A summary and discussion of the major criticisms can be found in (2).

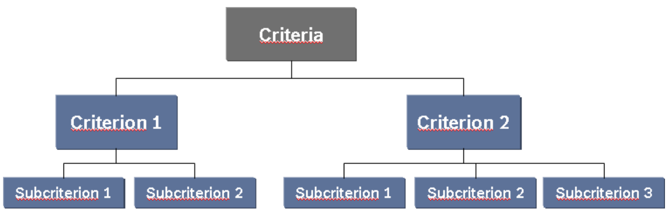

Figure 1. Hierarchy of criteria and sub-criteria

DECISION PROBLEMS: SOME GENERAL REMARKS

A decision problem is defined as a task like “from a set of alternatives identify suitable ones”. In our paper we will exclusively deal with the more special task of assigning a relative importance – a weight w_i – to each criterion from a set while the single grades are handled differently (cf. chapter 1). It should be noted, however, that they could also be determined with the help of the AHP.

Initially, according to Saaty (3) the decision problem is decomposed into a hierarchy of sub-problems (cf. fig. 1), to be analyzed independently, and, presumably, more easily. In our case, we decomposed the set of criteria into subsets comprising similar or related criteria. As an additional benefit this grouping or hierarchical organization supported the identification of gaps among the criteria.

On the one hand the AHP states that most humans encounter difficulties when they must assign weights or a relative importance simultaneously to each member of a large set of alternatives. On the other hand it states that they are considerably good in directly comparing two alternatives A and B and assigning a (verbal) term reflecting their relative importance like "they are equal" or "A is moderately more important than B".

Consequently, the AHP consists of a systematic evaluation of its various hierarchy elements by pairwise comparisons based on either concrete data or on well-founded estimations.

THE HEART OF THE AHP: PAIR COMPARISONS

Two alternatives A and B (from a set of size n) are compared with respect to some criterion yielding to one of the relation terms from table 1. The corresponding intensity number (IN) becomes element V_{AB} of the (n x n-) comparison matrix V. The transposed element is

(3) $$V_{BA} = 1/V_{AB} ,$$

reflecting the fact that if A is strongly more important than B then B will be strongly less important than A. Hence, the main diagonal of V consists of ones.

Intensity number (IN)	Relative importance (verbal)
1	Equal
3	Moderate
5	Strong
7	Very Strong
9	Extreme
2,4,6,8	Intermediate values

Table 1. Fundamental scale for pairwise comparisons

The following example may serve as an illustration: imagine three alternatives A, B, C, where

- A is strongly less important than B → IN=1/5,
- B is very strongly more important than C → IN=7,
- A is moderately more important than C → IN=3.

(4) $$V = V_{AB} = \begin{pmatrix} 1 & 1/5 & 3 \\ 5 & 1 & 7 \\ 1/3 & 1/7 & 1 \end{pmatrix}$$

is the corresponding comparison matrix. The weights are derived from an eigenvalue calculation: V's principal eigenvector [0.19, 0.73, 0.08] - the eigenvector to the largest eigenvalue λ_{max} –, corresponds to the weights w_A, w_B, w_C.
Two concrete advantages of the hierarchical organization become apparent: on the one hand a considerable reduction of the number of required pair comparisons (which is a square function of the number of alternatives) is achieved. On the other hand the comparison task is simplified because there it is no longer required to compare two alternatives so different that they became grouped into different subsets.
For each subset of the hierarchical organization there is a different comparison matrix, and, in a last step, a comparison matrix with the subsets' weights from their pair-wise comparisons has to be generated. Weights reflecting the importance of a criterion within the whole set are obtained from a multiplication of its weight in the subset with the subset's weight (cf. table 2).

Criterion	Sub-criterion	Weight	Total Weight
Criterion 1		0,8	
	A	0,6	0,48=0,8x0,6
	B	0,4	0,32=0,8x0,4
Criterion 2		0,2	
	C	0,8	0,16=0,2x0,8
	D	0,2	0,04=0,2x0,2

Table 2. Calculation of a criterion's weight

An important issue of any decision process is consistency which is largely related to the mathematical property of transitivity: given three criteria (A, B, C), let A be more important than B and B more important than C. Then A should be more important than C. Numerically spoken, consistency implies that if A is preferred to B by an IN of 3 and to C by an IN of 2, then one expects A to be preferred to C by a n IN of 6:

(5) $$V_{AB}V_{BC}/V_{AC} \overset{!}{=} 1 .$$

The left-hand side of eq. (3) will not always be one (if only for sheer arithmetical reasons) which is not critical; in fact the power of the AHP results largely from such deviations as they distinguish the method from a pure assignment of absolute values. However, large deviations should not occur too often, hence it is advisable to measure their frequency and intensity. This is done with the help of the consistency index CI defined as

(6) $$CI := (\lambda_{\max} - n)/(n-1) ,$$

whose value is zero if, and only if the comparison is perfectly consistent. A suitable normalization (with respect to CI calculated from purely random matrices) leads to CR, the consistency ratio, which – from practical experience – should be less than 0.1.

PRACTICAL EXPERIENCE

The AHP sessions were typically held with 3-6 decision makers. They were given a handout with all criteria and their short descriptions as well as cards with the corresponding number to avoid mutual interference by announcing the votes aloud. Every actual pair comparison was shown to them, and they were given about 30 seconds to decide upon their individual vote. It turned out useful to have a moderator whose tasks were

- Presentation of the AHP method and explanation of the criteria.
- Writing down the votes.
- Mediation of situations where the decision makers' opinions differed significantly.

If the decision makers could not quickly agree upon a common vote they were allowed to shortly discuss the matter. After that, a new voting was performed which often lead to common results. If this was not the case either a mean vote was calculated or a runaway value was deleted by the moderator. The overall vote was written down.

A tool was used for writing down votes. It allowed an online calculation of the results, i. e. the weights and the CR values. CR values above the threshold were handled according to the following method (1): of all possible criteria triples (A, B, C) the most critical triple was considered. A triple is most critical if the fraction from equation (3) deviates larger from the ideal value of 1 (in a multiplicative sense) than for all other triples. One of the three corresponding V_{XY} from the comparison matrix became modified such that the deviation of the fraction diminished. This process was repeated – possibly with a new triple that had now become the most critical – until the new CR value did no longer exceed the threshold.

HANDLING AHP'S RESULTS

As expected, the AHP sessions lead to weights that often reflected foci of the involved decision makers. The same was true for the corresponding total grades so that for example a specific business unit frequently favoured a function that fitted well into their portfolio.

In most cases neighbouring functions' total grades did not differ largely with respect to uncertainties in the single grades and the pair comparisons. Moreover, histograms of the distribution of grades unfortunately did not show separate groups of functions. Hence, it was not possible to assign a non-arbitrary threshold (e. g. a total grade of 0.7 or better) to separate most-promising functions from the others.

However, if the entirety of the rankings from various stakeholder groups was considered, it turned out that most of the functions could always be found within the same region of the ranking. For example, a function ranked in the TOP-25 functions of one specific ranking was likely to be ranked among the first 25 functions in all rankings. This suggested a process to identify the most-promising functions from K separate rankings:

- Extract the TOP-M (in the following M is referred to as a 1st process parameter, e. g.

- Count how many times n a function from U had been ranked among the TOP-M ($0 \leq n \leq K$)
- From U create a set S with all functions where $n \geq N$ (N is the 2nd process parameter, N=3 was used)

The elements of set S – the "selection of functions" – were ranked top many times, and, as it turned out, significantly more often than the others.

JUSTIFICATION

Expert reviews of selection S showed that most of its members seemed reasonable. However, there were some functions that systematically became ranked too high, for example a purely C2X-communication-based adaptive cruise control bearing an unacceptable risk because it would immediately fail if a vehicle follows an unequipped target.

The reason for the over-estimation of this function is a consequence of the linear nature of the applied weighted sum. While indeed there existed a criterion i reflecting the risk mentioned above, and while indeed the function's single grade g_i was graded low there, even the relatively large criterion weight of ~0.2 could not counterbalance the function's otherwise excellent grades.

To eliminate such pathologies a justification step was introduced where the experts went through the function list and – rather spontaneously – grouped the functions into useful, useless, or neutral ones by assigning a "+", a "-", or a "o", respectively. Selected functions of set S that obtained a "-" in the justification step were considered as candidates for a re-ranking. Only 3 % of all functions fell into that category which added much to our confidence into the method.

Those functions were investigated closely, and possibly removed. Contrary, functions that obtained a "+" which were not part of the selection S were also discussed among experts, and possibly added to the selection. Hence, this justification step was re-interpreted as a second approach to obtain promising functions and is in the following referred to as a second, equally important approach: the direct approach to be distinguished from the criterion-based approach.

APPLICATION TO SIM^{TD}

In the German FOT sim^{TD} (4) various stakeholders (OEMs, suppliers, telecommunication companies, and local authorities) develop a prototypical communication system for vehicles and road side units to be equipped with C2X communication functions. Both system and functions shall be tested in a real-life environment around the city of Frankfurt/Main.

INITIAL SITUATION IN SIM^{TD}

simTD started with a list containing 18 – coarsely described – functions. They were grouped into the three categories (traffic, driving & safety, supplementary services) and into six principal functions (PA) that served as a container for similar functions. There was also the precondition that any selection should cover all three categories. simTD's project plan defined the following steps for the selection of functions

- Gathering of all relevant functions (leading to a new hierarchy level "use cases")
- Description of all functions on use-case level.
- Evaluation of all functions and selection

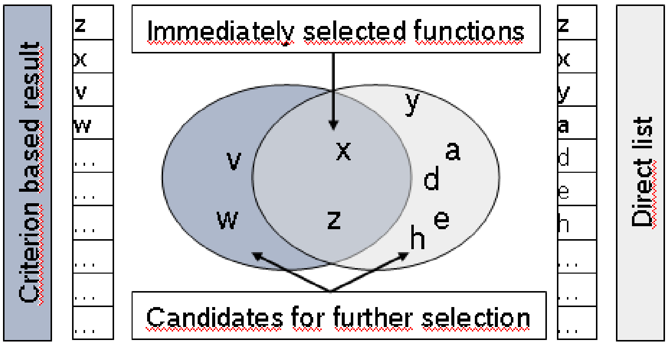

Figure 2. Criterion-based and direct approach: selection of functions from both sets.

Because of the good in-house experiences, BOSCH suggested the method described above for the selection of functions which was accepted by the project consortium. A selection process (SP) team was founded that adapted the method to specific sim^{TD} properties and was responsible for the process. It consisted of those eleven partners involved in the implementation of functions in sim^{TD}.

ADAPTATION OF THE PROCESS TO SIM^{TD}

The SP for sim^{TD} also consisted of a criterion-based and a direct approach applied on the level of use cases, not functions. Both processes were performed independently for each of the eleven partners and had to be united to selection lists like the list S described above. The list from the criterion-based (direct) approach will be referred to as C (D). Threshold parameters M_C, N_C, N_D had to be chosen independently for both approaches.

The functions from the intersection of both sets were immediately selected. If necessary, further functions could be selected from the remaining sets (the symmetric difference in fig. 2). This had to be done when the set violated the global boundary condition that one of the three categories mentioned above had not been considered). Furthermore, providing necessary basic services all functions from PA 1.1 were selected. The following procedure was agreed upon for sim^{TD}:

1) Definition of criteria/sub-criteria and generation of their hierarchical organization in a plenary workshop: 23 sub-criteria were grouped among six (main) criteria

2) Foundation of expert groups that assigned single grades to the functions

3) Organization of AHP workshops with every SP team partner to obtain the partner-specific set of criteria weights

4) Calculation of total grades

5) Approval of the process parameters (M=10, N_C=N_D=2) and determination of the set of selected functions.

6) Application of boundary conditions and review of the SP in a plenary workshop.

Category 1 Traffic	PA 1.2 Traffic Info/Navigation	1 Foresighted road/traffic information
		2 Road works information system
		3 Advanced route guidance and navigation
	PA 1.3 Traffic Management	1 Alternative route management
		2 Optimized urban network usage based on traffic light control
		3 Local traffic-adapted signal control
Category 2 Driving and Safety	PA 2.1 Local Danger Alert	1 Obstacle warning
		2 Congestion warning
		3 Road weather warning
		4 Emergency vehicle warning
	PA 2.2 Driving Assistance	1 In-vehicle signage/traffic rule violation warning
		2 Traffic light phase assistant/traffic light violation warning
		3 Extended electronic brake light
		4 Intersection and cross traffic assistance
Category 3 / PA 3.1 Additional Services		1 Internet-based usage of services
		2 Location-dependent services

Figure 3. Results of the SP: selected functions in sim^{TD} (level "use cases" not shown).

RESULTS: THE SIM^{TD} SELECTION

A check of the global boundary condition stating that functions from each of the three categories should be selected showed that none from category 3 had been selected. The partners agreed upon three use cases (from two functions) to be added to the finalized list (fig. 3), where only the top three levels (categories, PA, functions), but not the level "use cases" is being shown.

CONCLUSIONS

A method based on an established tool from decision theory (AHP) was developed. This criterion-based approach allowed an integration of the views of different stakeholder groups into one consolidated overall view.

Based on practical experiences at BOSCH the method was improved. Most important, a second approach was added where functions were selected directly to support the criterion-based approach.

The method was successfully transferred to the German FOT sim^{TD}. Its initial function list changed considerably. For example, in category (supplementary services) the number of use cases was reduced from 9 to 3. The number of use cases in the other categories increased correspondingly and helped to emphasize the project goals. The common understanding of the functions itself and their contribution to the project goals was considerably improved.

It should be noted that the proposed method is by no means restricted to the above mentioned task and can be applied to almost any decision process.

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