

THE EU FRAMEWORK V PROJECT “GEMCAR”: USER REQUIREMENTS ANALYSIS

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Abstract: The initial task of the GEMCAR project was an investigation of user requirements for modelling in support of automotive EMC engineering. The analysis showed that the requirements are highly dependent on the nature of particular modelling task and the anticipated use of the model results. The results also confirmed that electromagnetic modelling is commercially viable for most of the possible tasks that were identified. Nonetheless, even those applications that do not appear feasible for the passenger car market (perhaps because there is not sufficient time available in the development programme) may be viable in the development of more specialized types of vehicles. Consultation with selected representatives from the range of potential user groups has confirmed that the use of modelling is perceived to be desirable and of potential benefit.

1. Introduction

Electromagnetic modelling for automotive EMC and related applications remains an emerging technology at present. Consequently, the issue of user requirements could only be investigated by developing a series of draft requirements, based on the existing experience of the consortium members, and then discussing these draft requirements with selected representatives from European vehicle manufacturers, test houses, sub-system and component suppliers, as well as appropriate standardization and certification bodies. The user requirements were investigated with regard to a variety of possible applications of electromagnetic modelling, such as:

- vehicle and sub-system design and development;
- development of EMC standards and test methods;
- supporting testing for vehicle development and certification purposes.

The aim of this analysis was to enable the consortium to define the following:

- scope of models needed for different purposes (including CAD requirements);
- parameters that would be required from simulations;
- accuracy of model results required for particular applications.

The requirements of interest therefore fall into two basic groups: those that are associated with model development, and those that are associated with the exploitation of model results. However, both of these groups of requirements need to be satisfied in order for electromagnetic modelling to achieve commercial, rather than purely technical, viability.

2. Potential users and applications

All groups that are involved in automotive EMC must be prepared to accept electromagnetic modelling if it is to become an integral part of automotive EMC engineering. The vehicle EMC engineering process can be considered in terms of five main user groups with an interest in electromagnetic performance issues:

- system integrator;
- sub-system suppliers;
- test houses;
- standardization bodies;
- certification authorities.

The system integrator is responsible for the overall vehicle system, including defining the performance requirements for systems that are to be provided by the sub-system suppliers. Although the system integrator has traditionally been the manufacturer of the chassis and major mechanical components, it is possible that this may change as the electronic and software content of the vehicle increases. Nonetheless, the bodyshell and wiring harness can have a significant impact on the electromagnetic performance of the vehicle system as a whole, and the ability to model such effects is potentially of significant benefit to the automotive industry. Numerical modelling offers considerable promise in the design and specification stages, where little objective information is currently available.

Electromagnetic modelling is no less valuable in the support of EMC testing activities. As the number of systems and operating frequencies that are used in modern vehicles increases, the EMC testing burden is becoming increasingly onerous. In the later stages of the vehicle or system development lifecycle, modelling techniques could be used to support better targeted testing, by reducing reliance on physical testing. In addition, modelling can also be applied in the design and development of improved test facilities and equipment as well as developing basic understanding of EMC phenomena and measurements.

The requirements for immunity and emissions performance are defined by international standardization bodies, as are the tests that are to be performed in order to demonstrate compliance with the performance requirements [1-3]. These are very difficult tasks, given the complexity of the systems of interest. Consequently, modelling techniques are potentially of benefit to the standardization community in applications such as the investigation of measurement methods [4], or the definition of emissions and immunity limits.

Finally, the evidence to support manufacturers' claims that their products conform to the relevant legislation is reviewed by certification authorities. The latter will therefore become indirect users of modelling results as the other user groups begin to exploit electromagnetic modelling techniques.

Thus, modelling techniques could be used in a wide range of roles in automotive EMC and antenna engineering. However, the details of the model, as well as the requirements in terms of input data and the quality of the results, will depend on the user and the nature of their particular application. Techniques for identifying and classifying the requirements are therefore vital, both for constructing the initial proposals and for presenting them to potential users in a readily understandable form in order to promote dialogue and feedback.

3. Requirements for model building

Electromagnetic modelling of real-world equipment and test configurations is not normally possible without introducing many approximations. The aim of this process is generally to minimize the computational requirements, but the resulting model is of no practical value if the results become so poor that they are no longer suitable for the intended purpose. The objective of the analyst, therefore, is to reduce the model to the simplest representation of the system that can provide results of the desired "quality".

Identifying the nature of the models required for particular analysis tasks is a key issue in determining requirements for geometry and the quality of the results. The quality that is required from modelling results is likely to be very varied, ranging from order of magnitude estimates through to precise predictions, depending on the nature of the modelling task. Moreover, the quality of the geometry that is available when the results are required is also likely to be very variable. Thus, the identification of model requirements can be difficult, and the conclusions may not be obvious.

3.1 Quality issues

Given the inherent uncertainty and repeatability problems of EMC measurements, as well as the wide variations in model fidelity and modelling tasks that can be expected, it is not easy to quantify the accuracy of simulation results. Presupposing that the basic numerical analysis techniques are sound, and that they are correctly implemented in the simulation software, the factors that determine the "quality" of the results, in terms of how well they represent the real world, are:

- fidelity of the geometry used to build the model;
- accuracy of the electrical properties that are assigned to different materials;
- nature of the discretization that is applied when the geometry is meshed.

An immunity model that is based on plane wave excitation cannot be expected to produce identical results to a measurement carried out using a finite source antenna. Similarly, results that are generated using "intermediate" vehicle geometry cannot be expected to be identical to models or measurements based on the final product. Nonetheless, even imperfect results may be of sufficient quality to make decisions about design options or "worst-case" test configurations. In some cases, information regarding relative performance may be sufficient, while in others confidence that the absolute values are likely to be within a few dB of actual levels may be acceptable.

3.2 Model fidelity

The scope of GEMCAR addresses four main areas: vehicle immunity, vehicle emissions, intra-vehicle EMC and installed antenna performance. Models of all of these phenomena can be considered in terms of two basic elements: the "test object" and the "antenna" (which may be transmitting or receiving). In this context, the "system under test" may in fact be a controlled environment, such as a semi-anechoic chamber or a reverberant room, or another antenna.

The nature of these model elements may range from the "abstract" (eg. for plane wave illumination) to the "detailed" (as required for model validation purposes). It is not possible to describe these aspects in quantitative terms, so a scheme for classifying the model fidelity requirements in qualitative, natural language terms has been used (see Table 1 below).

Table 1: Model fidelity classifications

Fidelity class	Interpretation
Detailed	Detailed geometric models of particular antennas and/or test objects (usually vehicles and harnesses in the GEMCAR context)
Intermediate	Approximate geometry for particular test objects and/or antennas
Representative	Geometric models which reflect the main features of the structures of interest (eg. simple log-periodic antennas, synthetic geometry for "vehicle like" objects, real geometry for similar sized vehicles)
Abstract	Notional representations, such as plane wave illumination, that are difficult or impossible to implement in physical experiments

Although only four fidelity classes are defined in Table 1, the class for the "antenna" and "test object" elements of a model may differ for a particular application, thus giving rise to a much richer spectrum of fidelity classifications.

4. Requirements for exploitation

The primary motivation factors for the introduction of electromagnetic modelling techniques into the vehicle development process are:

- reduced costs;
- fewer design iterations;
- shorter development time;
- more efficient use of physical test time;
- greater confidence in system reliability and performance.

The requirements associated with exploitation of model data that result from these goals could be considered as falling into three basic groups concerned with:

- simulation output;
- quality and accuracy of the results;
- timing and duration of the modelling activity.

The technical ability to carry out electromagnetic modelling is of limited practical engineering benefit if it is not also possible to satisfy these exploitation requirements.

4.1 Simulation output

The output data that can be obtained from electromagnetic models ranges from directly computed parameters, including fields, currents and voltages, to derived quantities such as scattering parameters and far-field characteristics of antennas. The nature of the output that is required will vary between modelling tasks, and presentation requirements may include qualitative visualisation of spatial field distributions or radiation patterns as well as more localised and quantitative frequency response information.

It is anticipated that even directly computed quantities will need to be further processed in order for the user to exploit this information for practical engineering purposes. Although the computing effort associated with such tasks is likely to be much smaller than for the electromagnetic simulation, the effort required in processing and analysing the results may be significant. Consequently, these issues may well impact on the commercial viability of particular modelling tasks.

4.2 Quality and accuracy

Identification of the “quality” requirements of model results is difficult, partly because the limits of usefulness are difficult to define and partly because the nature of model results is such that quality is not easy to describe. Validation results for EMC models encompass a very wide range of frequencies, and the quality of correlation often fluctuates across the frequency band. The nature of the differences may range from simple amplitude differences to more complex shift and stretch of features in the frequency response. These problems are further compounded by the complexity of the experimental reference: measurement uncertainty is relatively large for these kinds of measurements. Thus, it is unreasonable to expect validation results to be better than experimental repeatability.

A simple amplitude error is not a satisfactory measure for this type of application. The “feature selective validation” (FSV) method [5-7] provides a quantitative and objective mechanism for describing the similarity of results such as model validation data, and is proposed as a tool for describing the “quality” of model results in GEMCAR. The nature of the method is such that a perfect match provides a measure of zero, while a value greater than unity represents a very poor result. The repeatability of electric field measurements for a test object in a semi-anechoic chamber, for example, is found to provide a global difference measure (GDM) of 0.2-0.3 [6].

4.3 Scheduling

Scheduling is an issue for the vehicle integrator and system supplier, where the intention is to integrate electromagnetic modelling into the development of specific products. These considerations include both the time needed to build models and complete the necessary simulations, and the integration of modelling activities into the design, development and certification processes. Such work can probably be carried out in parallel with other tasks, but the availability of suitable data and the development programme deadlines will place important constraints on the acceptable timing and duration of electromagnetic modelling tasks.

In a typical vehicle development programme there may be a period of around 18 months between vehicle CAD data becoming available and the cut-off point for changes. The EMC test activity is then perhaps scheduled to begin about 12 months after the preliminary CAD data becomes available.

However, the CAD data may need to be finalised within perhaps 8 months of the preliminary data being issued. This programme is representative of those of passenger cars for volume production. The timing constraints for other types of vehicle, particularly more specialized vehicles for freight transport, construction and other industrial and agricultural applications may be quite different. However, the time to market for passenger vehicles probably represents the worst case, and is therefore considered to be the most useful example for illustration here.

Thus, for this example, any modelling tasks that could impact on the vehicle CAD must be completed within the available eight-month window. However, a further four months are available for the evaluation of test configurations and selection of vehicle variants. The duration of large scale, broadband electromagnetic simulations can be significant, perhaps taking 50 hours to compute results for some 10^4 frequencies (the exact details will depend on the nature of the model). Consequently, these timescales suggest that modelling is commercially viable, and will become even more so as more powerful computing resources become available, particularly if parallel processing is employed to increase model throughput.

In some applications, the aim may be to exploit modelling in a more strategic role. Possible examples include support for standards development (test methods and limits) and the investigation of basic EMC phenomena. Although these applications are primarily associated with the standardization bodies, vehicle integrators and system suppliers may have an interest in improving their understanding of the EMC impact of generic features of their products (non-metallic body panels, for example). In these applications, scheduling issues are unlikely to be critical for success, since the modelling effort is not required to fit into a development lifecycle.

Similarly, in applications such as the development of new test facilities, or specialised equipment such as antennas, scheduling is an issue but is unlikely to be as restrictive as in the vehicle development process. Projects such as the design and construction of an EMC test chamber could be scheduled around the necessary modelling activities, which would be core to the process as a whole. This is quite different to the use of electromagnetic modelling as part of the vehicle development process, where electromagnetic performance is not the pre-eminent driving force in the project timing plan.

5. Definition of user requirements

Modelling requirements for the different classes of user were summarised in a “requirements matrix”, which reflects the requirements and objectives for different types of modelling task that may be relevant to the particular class of user.

The rows in the requirements matrix for each user group were determined by proposing a number of possible modelling tasks. These tasks have differing requirements, depending on the nature of the input data that is needed and the quality of the results that are required. The proposed entries for the columns were then based on practical considerations, such as:

- intended use of the results;
- when the results are required and the time available to generate the results;
- availability and quality of geometrical data;
- availability and quality of data concerning electrical properties of materials.

For example, in trying to identify a “worst case” vehicle variant or illumination configuration for an immunity test, it is probably sufficient to look at relative performance under arbitrary illumination conditions. However, it must be possible to differentiate between the model variants or illumination directions. The implications of this are that while a good representation of the test object is required, and this should be feasible in the later stages of a vehicle development programme, the excitation could reasonably be a simple plane wave. The latter limits both the complexity of the model and the number of configurations that must be simulated. However, if the parameter of interest is the coupling between some portion of the vehicle harness and an on-board antenna, it will probably be necessary to build a detailed model of all elements in order to obtain satisfactory coupling results.

Furthermore, some possible tasks may only be reasonably carried out at stages of development, when detailed information is unavailable. Examples include the assessment of vehicle module and harness placement, or the definition of immunity specifications for the vehicle systems. For these tasks, it may be necessary to use representative geometry based on existing models or early design details, and features such as the harness and interior trim may not be represented. The results that can be obtained from such models will inevitably differ from what might be obtained using the final geometry or a more complete model. Nonetheless, inaccurate information is probably more useful than none at all, and may be sufficient to guide early design decisions.

Sample requirements for users including vehicle manufacturers and test houses are illustrated in Tables A1-A2 of Appendix A, using the FSV GDM value as a measure of the “quality” of the results. The tasks concerned with “worst-case” evaluations are assigned to the test house requirements matrix for convenience, since they are intended to support better targeted testing. However, these tasks could also be carried out by the vehicle manufacturer, either in house or under sub-contract to a third party. Similar investigations could also be appropriate to some system suppliers. No matrix was proposed for system suppliers, as it will be similar in form but narrower in scope than that of the vehicle manufacturer. The certification authorities have a need for overall confidence, rather than specific task requirements, so no matrix was proposed for this class of user either.

6. Feasibility assessment

The requirements matrices described in section 5 were used to develop a set of questionnaires to support the elicitation of feedback from selected individuals through interviews. This information, together with input from the consortium, has been used to assess the feasibility of the proposed tasks and the importance of the results to potential users.

Conclusions regarding the viability and desirability of a number of the modelling tasks that were proposed are summarized in Tables B1-B2 of Appendix B (corresponding to the vehicle manufacturer and test house groups). In this context, the term “viability” represents the ability to satisfy both the technical and commercial requirements for the particular tasks. The “desirability” reflects the views of potential users as to their interest in the proposed task and its perceived benefits. In some cases, such as chamber design, the anticipated demand for modelling support may be relatively small. Nonetheless, the potential benefits may be significant, in terms of reduced cost or better performance of the chamber, and the resulting impact on subsequent business.

Both of these attributes are rated on a scale of 0-10, where “10” would be completely viable or highly desirable while “0” would be totally unviable or of no interest. A value of “5” therefore represents the mid-point of this scale.

7. Conclusions

The analysis of user requirements that was used to initiate and direct the GEMCAR project showed that the requirements are highly dependent on the nature of particular modelling task and the anticipated use of the model results. The results of this analysis also confirmed that electromagnetic modelling is commercially viable for most of the possible tasks that were identified. Nonetheless, even those applications that do not appear feasible for the passenger car market (perhaps because there is not sufficient time available in the development programme) may be viable in the development of more specialized types of vehicles. Consultation with selected representatives from the range of potential user groups has confirmed that the use of modelling is perceived to be desirable and of potential benefit.

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9. References

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Appendix A – User requirements matrices

Table A1: Sample user requirements for vehicle manufacturers

Modelling task	Objectives	Antenna model fidelity	Test object model fidelity	Output data	Quality of results	Timing and duration	Comments
Preliminary evaluation of likely immunity characteristics	Early identification of possible problems, basis for harness and module placement decisions	Abstract	Intermediate	Interior field at selected points, spatial fields for selected areas	Relative performance	Within 8 months of 1 st issue of CAD data	Final, detailed geometry will not be available, plane wave illumination is probably adequate
Design studies for vehicle antennas	Evaluation of antenna placement options	Intermediate	Intermediate	Impedance mismatch, far field gain and patterns	Relative performance	Within 6 months of 2 nd issue of CAD data	General trend assessment is probably feasible without detailed geometry
Prediction of intra-system EMC and/or antenna coupling	Identification of performance defects and EMC protection requirements	Detailed	Detailed	Scattering parameters, wire current and voltage	FSV value $GDM \leq 0.5$ relative to experiment	Within 6 months of 2 nd issue of CAD data	Accurate prediction of coupling is likely to be highly dependent on geometry, placement and termination characteristics
Identification of structural features impacting on test vehicle selection	Maximize quality of vehicle sample used for certification testing	Abstract or representative	Representative /intermediate	Interior and exterior field at key points	Relative performance	Within 8 months of project start	General trend assessment is probably feasible without detailed geometry

Table A2: Sample user requirements for test houses

Modelling task	Objectives	Antenna model fidelity	Test object model fidelity	Output data	Quality of results	Timing and duration	Comments
Evaluation of worst case model variant in immunity tests	Reduce physical test requirements, saving test time and costs	Abstract	Detailed	Fields, wire current and voltage	Relative performance	Within 12 months of 1 st issue of CAD data *	Selection based on relative performance under plane wave illumination is feasible and probably adequate
Evaluation of worst case immunity test configuration	Reduce physical test requirements, saving test time and costs	Abstract	Detailed	Fields, wire current and voltage	Relative performance	Within 12 months of 1 st issue of CAD data *	Selection based on relative performance for plane waves of different direction and polarization is feasible and probably adequate
Design of low frequency test antennas	Design optimisation to meet field strength and uniformity requirements	Detailed	Intermediate	Field distribution, scattering parameters	FSV value $GDM \leq 0.4$ relative to experiment	Project specific	Chamber size and lining properties need to be adequately represented
Design and optimisation of anechoic chambers	Optimise cost and performance of chambers	Abstract or representative	Intermediate	Normalised site attenuation, antenna characteristics	FSV value $GDM \leq 0.4$ relative to experiment	Project specific	Antenna models can be avoided in TLM/FDTD, but chamber size and lining properties need to be adequately represented

Appendix B – Feasibility assessments

Table B1: Feasibility assessment for vehicle manufacturers

Modelling task	Viability	Desirability	Comments
Preliminary evaluation of likely immunity characteristics	8	9	Highly feasible since vehicle geometry is likely to be available in sufficient time.
Specification of system immunity requirements	8	7	Results are highly valued, as potential problems can be identified prior to physical testing of prototypes.
Prediction of emissions from installed systems	5	9	Moderate feasibility because of detail required in module characteristics and harness geometry.
Prediction of intra-system EMC and/or antenna coupling	6	8	Highly desirable, especially in the railway industry where emissions are a greater problem than immunity.
Design studies for vehicle antennas	7	8	Feasible, but requires details of both the vehicle and the antenna geometry.
Quantification of anticipated field exposure due to on-board transmitters	6	7	Increasingly important as the number of antennas and radio based systems deployed in vehicles is expected to rise rapidly.
Identification of key structural features for vehicle test selection	7	9	Feasible for many structures. Highly desirable to improve test sample.

Table B2: Feasibility assessment for test houses

Modelling task	Viability	Desirability	Comments
Evaluation of worst case model variant in immunity tests	8	9	Highly feasible since vehicle geometry is likely to be available some months before testing is required and detailed modelling of antennas can be avoided.
Evaluation of worst case immunity test configuration	8	9	Cost savings are easily identified in terms of reduced reliance on physical tests. Savings of >40% have been reported.
Design of low frequency test antennas	8	7	Highly feasible, since model size is relatively small at low frequency. Demand is unlikely to be great.
Design and optimisation of reverberant rooms	8	8	Highly feasible, since low frequency performance is the problem area, where models are relatively small. Reasonable prospects as reverberation chambers are increasingly popular.
Design and optimisation of anechoic chambers	7	7	Feasible, but most significant problems are model size and determining materials properties for absorbers (chambers) and finite ground (OATS).
Analysis and design of open area test sites (OATS)	7	7	Demand for designing new facilities may be small, but there is also potential for assessing problems and designing upgrades (eg. high frequency performance).