GM-VV Illustrated: An Educational Example from the Human Driving Behavior Research Domain

Martijn van Emmerik
Manfred Roza
Jeroen Voogd
TNO Defense, Safety and Security
P.O.Box 23, 3769 ZG
Soesterberg, The Netherlands
martijn.vanemmerik@tno.nl, manfred.roza@tno.nl, jeroen.voogd@tno.nl

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ABSTRACT: *The Generic Methodology for Verification and Validation (GM-VV) to support acceptance of models, simulations and data is a new standard under development within SISO. GM-VV provides an abstract framework to efficiently develop an argument to justify why identified models, simulations, underlying data, outcomes and capabilities are believed to be acceptable for deployment in a specific operational context. This argument is intended to support stakeholders in their acceptance decision making process on the utilization of the aforementioned Modeling and Simulation (M&S) assets for their business goals (i.e. intended purpose).*
GM-VV is a generic methodology which means that it is defined independently from a M&S application domain or technology. This makes the methodology generally applicable and compatible to any class of V&V problems in the M&S domain. However, this makes GM-VV also an abstract and meta-level defined methodology that has to be instantiated, specialized, extended and optimized. This is described in the GM-VV documentation. In order to apply GM-VV effectively and efficiently, a set of examples is desirable. The purpose of this paper is to present the first results of developing such an illustrative and educational example for GM-VV. The example originates from the human driving behavior research domain in which driving simulators are used to test and evaluate new technologies, procedures and policies to improve traffic safety. This example is chosen because of its relative simplicity and the availability of all needed data and information.

1. Introduction

The Generic Methodology for Verification and Validation (GM-VV) was developed in an international joint project called REVVA. This cooperative effort between several European nations (France, The Netherlands, Sweden and Denmark) together with Canada aimed at the development of a uniform and generic framework for verification and validation of models, simulations and data, which were shared between these nation's defense organizations. The GM-VV is currently awaiting approval to become a standard within SISO.
GM-VV is a generic methodology which means that it is defined independently from a direct distinctive or particular M&S application and technology. This makes the methodology generally applicable and compatible to any class of V&V problems inside the M&S domain. However, this also makes GM-VV an abstract and meta-level defined methodology that has to be instantiated, specialized, extended and optimized for such a particular M&S application or technology. Metaphorically speaking, GM-VV can be compared to an alphabet, which is a symbolic representation to write words independent of language. Each language, however, has special rules for combining those symbols to form meaningful units (words) and many have extended the set of symbols, or optimized it for their specific purpose (think of characters like the German 'ß', or the use of accents to change pronunciation: à, ç,č, orñ). Furthermore, the rules for combining these symbols are different in each language (and are not specified in the alphabet itself).

1.1 GM-VV Basic Principles and Concepts

Within GM-VV, any model or simulation is approached as a system (the M&S system). Resolving a problem or need of the M&S users and stakeholders should consider the M&S system as a whole. For this means, GM-VV adopts a four-world view to structure the world in which the problem is addressed (Figure 1). In the first of these four worlds, the real world, a need may arise that requires certain decisions or actions. These translate into a problem statement which has to be solved in the problem world. Within the context of GM-VV, the M&S world is the way to solve this problem through a well-controlled employment of an M&S system. This M&S system is the result from a systems engineering process within the product world.

GM-VV considers VV&A as a separate problem domain with its own specific objectives and issues. This domain is referred to as the VV&A world.

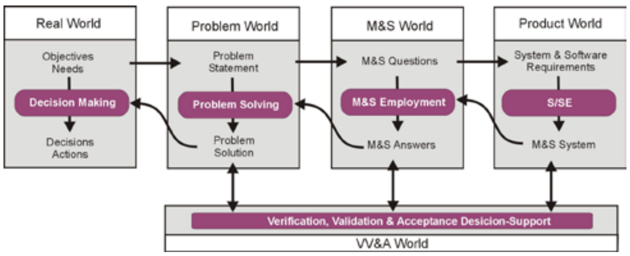

Figure 1: M&S based problem solving four world view and the VV&A world

Parallel to the four previously mentioned worlds, the VV&A world is concerned with the evaluation of the M&S system utility *(product world)*, confidence with respect to the intended use of the M&S outcomes or answers *(M&S world)* to solve an actual problem as stated *(problem world)*.

In this regard GM-VV's objective is to provide necessary information and arguments to support M&S users and stakeholders in the acceptance decision-making process on the utilization of models, simulations, underlying data and outcomes to satisfy their business goals in the real world.

The four world diagram also clearly demonstrates that the system of interest for VV&A extends beyond the M&S system itself in the product world. The VV&A system of interest also includes the evaluation of the operational context in terms of the M&S system employment and outcome utilization process and organization. Such an operational context could be a complete training system in which M&S systems are embedded.

Within the GM-VV 'VV&A world view', verification refers to evaluation of the M&S system correctness and validation refers to evaluation of the M&S system validity and M&S system utility. Acceptance decision-support refers to compiling a VV&A acquirer agency oriented acceptance recommendation based upon the verification and validation outcomes. Each of these three interrelated property classes addresses and provides a set of metrics for evaluating a specific part of an M&S system (Figure 2):

- Correctness properties assess whether the M&S system implementation conforms to the M&S specification, is free of error and of sufficient precision. Correctness metrics are also used to assess the consequences of implementation discrepancies on both the M&S system validity and utility.
- Validity properties are used to assess the level of agreement of the M&S system replication of the real world systems it tries to represent i.e. the M&S system fidelity. Validity properties are also used to assess the consequences of fidelity discrepancies on the utility of the M&S system.
- Utility properties are used to assess the effectiveness and efficiency of an M&S system in solving a problem statement in the problem world. Utility properties address three related areas: value, cost and use risk.

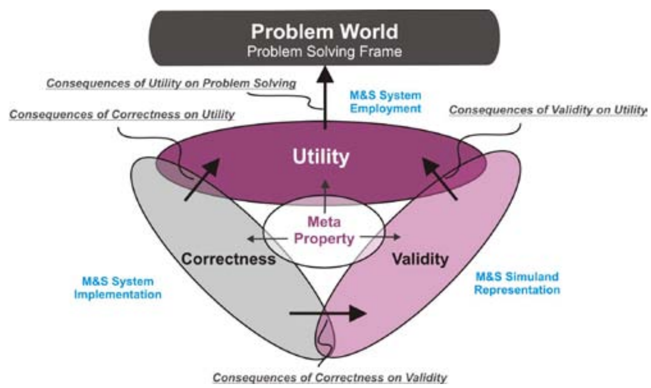

Figure 2: Correctness, validity, utility & meta properties relationship diagram (Source [4])

Besides these properties, GM-VV also proposes the use of meta-properties to evaluate the quality with which the utility, validity and correctness properties of a M&S system have been assessed. Meta-properties include aspects such as completeness, consistency, independency uncertainty, relevance, reliability and balance.

Based on the three properties, correctness, validity and utility, GM-VV ultimately should support an organization in making a justifiable, traceable, and evidence based M&S acceptance decision. This is supported by the use of a goal-oriented requirements engineering approach to derive and justify the acceptability criteria for each relevant M&S property along with an evidence-based argumentation approach for transforming any collected evidence into acceptability claims. These acceptability claims for each M&S property are further aggregated by argumentation into a claim(s) on whether the M&S system as a whole is acceptable for its intended use.

1.2 GM-VV Product, Process and Organization Pillars: A Matrix View

Models and simulations do not exist in isolation but are developed and employed to fulfill the needs of their intended users and other stakeholders. Therefore, GM-VV can be applied to the whole operational context in which the benefits, cost, and risks of utilizing models or simulations have to be assessed in order to make well informed acceptance decisions on using their outcomes. For this means, GM-VV has adopted a three-pillar view to structure and translate its underlying VV&A approach, concepts and methods into a single consistent methodology (Figure 3).

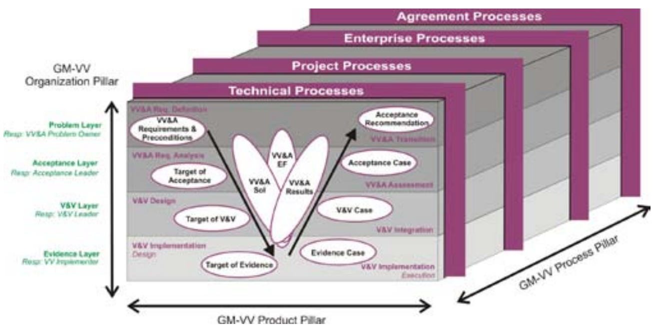

Figure 3: GM-VV Matrix View

These GM-VV pillars are the VV&A product, process, and organization pillars:

- The product pillar specifies all principle VV&A products that should be developed throughout a VV&A endeavor.
- The process pillar specifies all VV&A technical and related life-cycle processes that deliver the VV&A products in the aforementioned pillar.
- The organizational pillar provides the minimal organizational context for conducting VV&A by means of a layered structure. This context is specified in terms of assigned authority, responsibilities and obligation relationships with respect to the required VV&A products and their delivery processes.

1.3 Perspective and steps to take

In the current paper we will take the perspective of the VV&A problem layer. This layer gives the operational context in which the VV&A project is initiated, contracted, performed and the produced deliverables are deployed. While this is an iterative process, we will nevertheless try to describe a logical ordering in steps to be taken.

As a starting point, the VV&A problem owner should specify the VV&A requirements and the associated VV&A preconditions for the project. These typically comprise information about the M&S system intended use, use risks, requirements, constraints and the M&S system (architecture, design, models, capabilities, etc.).
All this information is needed in order to make a well-informed acceptance decision at the end of the project. By doing so, the VV&A problem owner (i.e. the agent that will use the acceptance recommendation, in the acceptance decision procedure to support decisions regarding the M&S System) has to constrain the scope of the M&S system, hence specifying an initial VV&A system of interest (SOI). Moreover, specification of the system of interest is usually accompanied by an initial definition of the expected necessary VV&A experimental frame (EF) and results (R). This provides the operational context in which the VV&A project is initiated, contracted, performed and the produced deliverables are deployed. After finishing this step, we have defined a top level acceptance goal specifying what acceptance problem we need to answer.

In the next steps, each of these three products (SOI, EF, and R) will be iteratively defined more specific and more formal. This is done using an argumentation framework (Goal Network, see figure 4) to decompose this top level goal into smaller goals and finally into a set of practical solutions that can be used to formulate an answer to the acceptance problem).
The result of the first transformation is a specification of requirements for acceptance (Target of Acceptance / ToA) of the M&S system. The ToA serves as a means to systematically develop and document a set of precise and well argued acceptability criteria (AC in figure 4) that need to be evaluated to yield an acceptance recommendation for the M&S system. The ToA serves as the vehicle to refine in here stated VV&A question, “why and what needs to be assessed” into a well defined set of high-level acceptance goal(s) and concrete acceptability criteria and reach agreement on this with the VV&A

problem owner. Furthermore, it serves as the input for the acceptance planning part of the VV&A project plan.

The second transformation involves the translation of acceptance criteria into evidence criteria (EC in figure 4), which specify the requirements for what items of evidence must be constructed and how to integrate these items of evidence in order to demonstrate whether one or more acceptability criteria defined by the ToA are met or not. This part of the VV&A Goal Network is called Target of Verification and Validation (ToVV).

The third transformation results in the so-called Target of Evidence (ToE). Here, the evidence criteria from the ToVV are decomposed into evidence solutions (ES in Figure 4). Evidence solutions specify a set of solutions of how VV&A results must be produced, justified and integrated into items of evidence that comply with the evidence criteria specified by the ToVV.

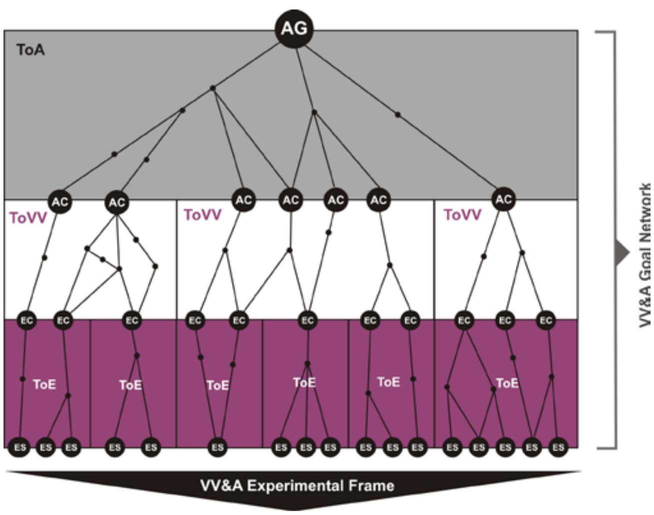

Figure 4: GM-VV VV&A Goal Network Illustration

At this point, the evidence solutions contain the specific and concrete information to define tests and experiments (experimental frame) that have to be performed on the VV&A system of interest to elicit VV&A data, process it and induce evidence data from it (results).

The results of applying the EF to the SOI are Evidence Data Items that can in their turn serve as input for a reversed (re-composition) process into a Claim Network (Figure 5) that maps on the Goal Network. The evidence data items (IDE, Figure 5) are used to aggregated into Items of Evidence (IoE) in the Evidence Case.

The VV-Case requires endorsement and integration of items of evidence into well argued acceptability claims on the utility, validity and correctness of the M&S system and its deployment for usage.
Transformation of the Acceptability Claims (AbC) into a top-level Acceptance Claim (ACC) is the focus of the Acceptance Case (A-Case). This ACC is an assertion for the M&S system and its deployment on whether or to what extent its results can effectively be utilized with acceptable consequences (i.e. cost and use risk) inside the problem world.

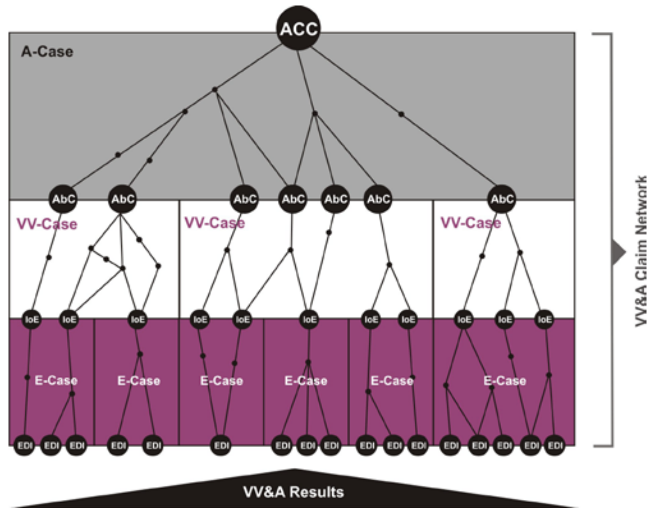

Figure 5: GM-VV VV&A Claim Network Illustration

Eventually all this VV&A information must be properly filtered, aggregated and expressed in an Acceptance Recommendation. This recommendation should be formulated in such a way that it meets the VV&A problem owner needs and level of understanding as formally expressed by the VV&A requirements.

2. Example context: flashing lights

In this section we describe a practical example of how the above described steps can be applied in practice. The case is a simulation of flashing lights of emergency service vehicles and the way traffic participants react to them.
Below we first describe the transformation of the customer's question into the four-worlds paradigm to arrive at requirements and preconditions and show the ToA with (parts of) an argumentation network.

2.1 The four worlds

Real world

When emergency services arrive at the site of a traffic accident on a busy road they should be able to operate safely to avoid further harm in terms of (human) casualties. At the same time, the traffic circulation should be kept going to prevent additional economical damage due to traffic jams[1]. These are two goals that easily conflict. Obviously it would be desirable if drivers adapted their speed, stayed in their lanes and smoothly continued their journeys. Morbid curiosity, however, seems to be a human trait that entices many drivers to get distracted from their main task: rubbernecking drivers cause sharp reductions in speed, resulting in further traffic jams (gaper's blocks) and sometimes even additional accidents.

Problem world

Rijkswaterstaat (RWS), the implementing body of the Dutch Ministry of Transport, Public Works and Water Management, asked TNO to investigate the effects of one specific directive aimed to

- reduce the speed of passing cars before they reach the incident site by using one vehicle in fend-off position with working flashing lights placed 100 meters in front of the accident and
- prevent further speed reductions around the incident site by having the vehicles at the incident location switching off their flashing lights (Figure 6).

M&S world

Because of several reasons, the problem world question cannot easily be approached in a real environment. It is undesirable to create an accident on the emergency lane of a highway because of the risk of traffic jams or additional accidents. Furthermore, it is difficult to collect all necessary information on the drivers and their driving behavior as they approach the accident site and pass it. Also, the atmospheric conditions and traffic density will differ between drivers. Finally, when investigating under different lighting conditions (e.g. time of day - or night), the amount of light cannot easily be controlled or replicated. Considering these arguments, an experiment with human drivers in a virtual environment has many advantages. However, before starting such an experiment our customer wanted to know if it was possible to elicit realistic behavior from the drivers using the simulator.

Figure 1: Birds-eye view of the simulation showing the directive "Flashing lights off on location". The fend-off car signals (blue) flashing lights, the emergency vehicles have their flashing lights turned off.

Product world

The product world refers to the physical implementation of the M&S solution to support the argument of feasibility for the current research. Because the TNO driving simulator has already gained acceptance as a research tool for investigating human driver behavior [e.g., 5, 6] the driving behavior of the participants in general was assumed to be realistic in this case as well. Therefore, it was decided to focus on the realism of the flashing lights as TNO had not simulated these before. More specifically regarding the drivers reactions to simulated flashing lights from emergency vehicles it was investigated if the norms for flashing lights with regard to magnitude, color, and dynamics could be convincingly presented in the simulator. For this purpose, the flashing lights were implemented in software (to show the effects of the lights on the virtual environment) as well as in hardware (by using an additional projector) to simulate the reflections

[1] The Dutch Traffic Information Centre estimated the total cost of traffic jams (in the Netherlands) in 2007 at over a billion Euros [5].

in the mockup. The intensity of these hardware flashes varied depending on the distance of the observer to the lights and were synchronized with the software light effects.

2.2 Requirements and preconditions

A M&S system is always used within a particular application context. This context, for a large part, defines the requirements and constraints on the use of the M&S system, its intended use, use risk, and the M&S system architecture (design, models, capabilities, etc.). Thus, defining the context has consequences for the definition of the Acceptance Goal.

In the study used in this case, two different context layers could be defined. At the top level, our customer (RWS) wanted to know how the color and number of flashing lights at the site of a road accident affected road safety and traffic circulation in terms of behavior of the passing drivers. In addition they also asked us to investigate this during broad day-light as well as under reduced lighting conditions.

At a more fundamental level, however, they wanted to have confidence about the feasibility of the simulator to elicit realistic human behavior in reactions to the flashing lights. In other words, TNO had to prove their claims about the validity of the TNO-driving simulator for measuring driver behavior as well as showing its feasibility to create convincing flashing lights in the first place. This has been elaborated for the current paper.

From this context, we derived the following requirements and constraints that lead to the acceptance goal as shown in figure 7.

With regard to use risk it is envisioned that people might react differently to the simulated flashing lights than they would to real ones in the real world. When this difference becomes too large, interpretations of the results is likely to lead to wrong decisions or actions, which jeopardizes safety or impacts economical costs in the real world. The customer indicated that no absolute behavioral similarity is required but rather a relative similarity would suffice. This implies e.g. that a reduction in speed that is smaller than in reality would still be acceptable. Key aspect of the VV&A question is that it is possible to distinguish between conditions with one versus multiple flashing lights. Therefore, the characteristics of the flashing lights should be modeled as realistically as possible.

The acceptance goal to be demonstrated can now be defined as: the TNO Driving simulator is suitable to evaluate the guideline “flashing lights off on location”. This goal is the top-goal of the VV&A goal model and start point for developing the ToA (Figure 7 and 8).

2.3 De-composition

To evaluate the simulator for the present acceptance goal and context, (suitability) we have chosen a strategy related to the validity of the individual simulator components. The top-node contains the goal that has to be demonstrated and as such it links to the strategy node that marks *how* this should be done. Another link from the top-node connects to the specific context for this example. This explicitly limits the scope of the V&V effort and can be used to allocate resources to the different V&V activities.

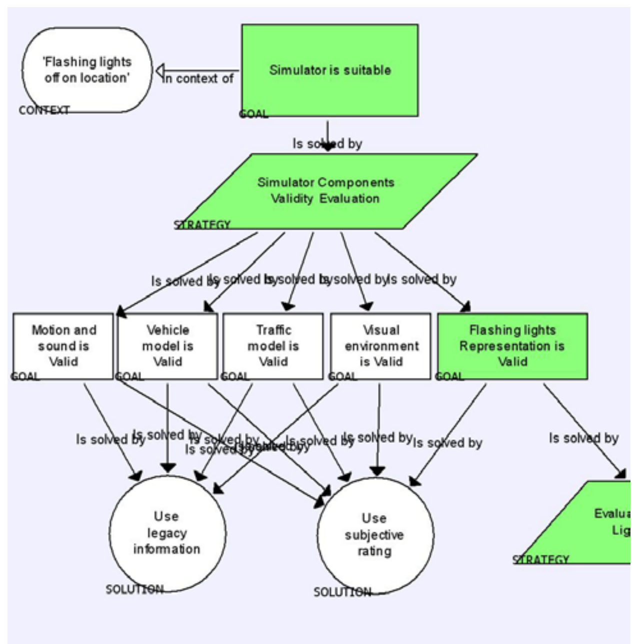

Figure 7: Part of the ToA network (cont. in Fig. 8)

The selection of the strategy results in a decomposition of the top-level goal into sub-goals: if it can be shown that each component of the simulator (motion and sound, vehicle model, etc…) is valid, it can also be argued that the simulator is valid. These sub goals are the acceptability criteria for this specific ToA.

In the current example, most components of the simulator have been used before, on several occasions, for measurement of driver behavior. Therefore, a large body of legacy information has been collected that was expected to give sufficient support for demonstrating the sub-goals. An additional solution comprises the subjective ratings that have been collected by asking a number of simulator experts to give their opinion on the validity of the simulator and its sub-systems. The solutions that are presented at the ToA level still need further elaboration in the ToVV and ToE. At this stage they will suffice for communicating the feasibility of being able to demonstrate the acceptability criteria to the VV&A problem owner, in order to obtain approval from him for this ToA. The V&V problem owner will not be involved in the deeper level analyses.

Only one acceptability criteria has not been demonstrated before is particularly important in the current context: the validity of the representation of flashing lights in the simulator. Besides the evidence that is collected by means of subjective ratings and measurements this goal is further decomposed in figure 8. The way this is done is comparable to the initial decomposition of the top-level acceptance goal.

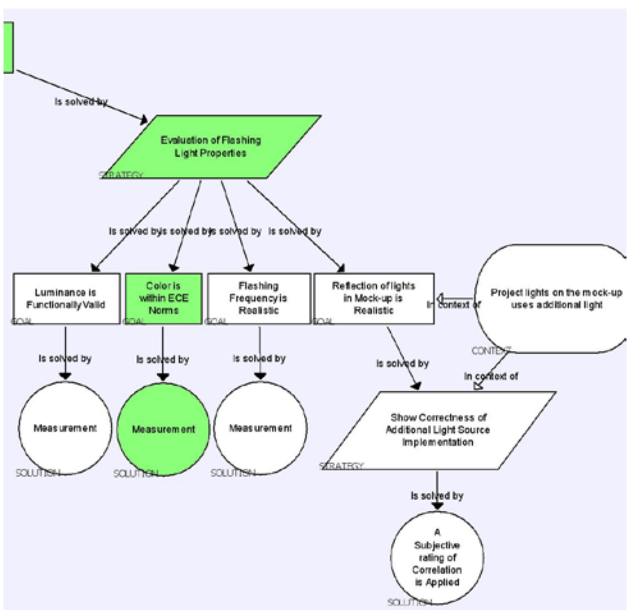

Figure 8: ToA continued (from Fig. 7)

The developed ToA provides only a description of *what* needs to be demonstrated to the V&V problem owner (and *why*). This has to be elaborated further in the ToVV and ToE. For sake of convenience this example only explores one of the aspects which has to be evaluated.

As can be seen in figure 8, the validity of the flashing lights is further decomposed into several sub-goals, each relating to a specific property (e.g. luminance, color, frequency) of the flashing lights. In the current example the property 'color' is further elaborated into a ToVV and ToE. After having decided that color is a property relevant for evaluating the validity of the flashing lights, the ToA ends with the decision to measure it. The ToVV for this property should describe *how* to do this and what items of evidence need to be constructed. In practice this comprises determining *what* should be evaluated in relationship to M&S intended use, use risks, resources, and implementation constraints (risk based tailoring [2]). For measuring color we have concluded that these have to be gathered by application of spectroradiometry and compared against the ECE65 Norm (see figure 9). The ECE65 Norm is the locally defined referent for this particular property of the VV&A system of interest or what is called in GM-VV, the oracle [3]. The oracle and the spectroradiometry measurement method together specify one of the end nodes of the whole ToVV, and are called the evidence criteria in the GM-VV.
Each other property of the flashing lights that should be measured will also have to be decomposed starting from the ToA end nodes into a complete ToVV.

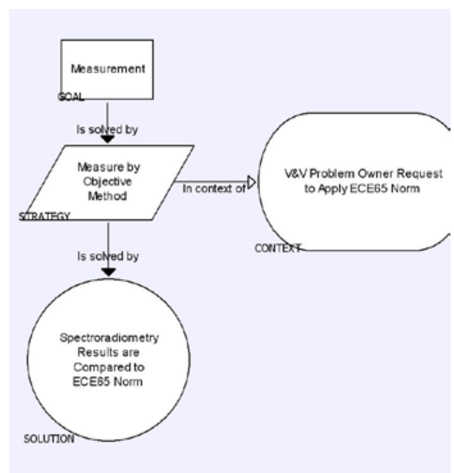

Figure 9: Partial ToVV

By decomposing goals into solutions, the GM-VV processes enforce an iterative strategy that becomes more and more detailed reaching it's final level of detail in the ToE. The ToE as in Figure 10 specifies the information on *how* to perform the measurement in order to produce the required evidence using the measurement method and oracle specified by the evidence criteria. In the case of spectroreadiometry, multiple measurements at different positions in the simulator have to be performed in order to assure proper coverage in the whole simulator mock-up and statistical significance. Such measurements requires the utilization a spectroradiometer sensitive to radiation in the range of 380 - 780 nm; comparing the measurement against standardized CIE curves to determine the x,y,z, coordinates of the color and then checking if these values fit within the boundaries as specified in the ECE 65 standard color space for blue flashing lights. At each of the five specified mock-up locations three independent measurements are performed. This so-called evidence solution thus specifies a complete test and evaluation protocol, which can be directly executed.

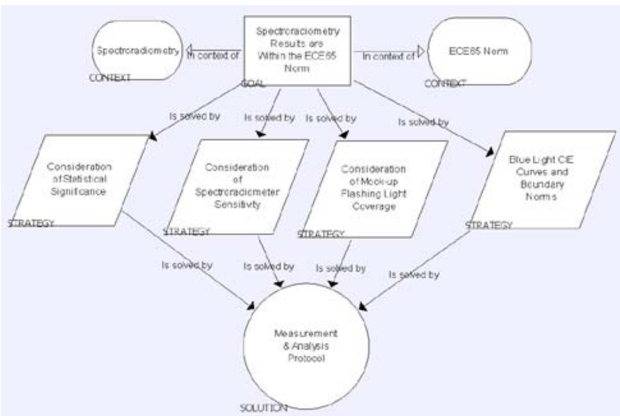

Figure 10: Partial ToE

When this decomposition process has been completed for all Evidence Criteria of the ToVV we have specified our VV&A experimental frame in terms of evidence solutions (Figure 4): we know *what* tests to do en *how* to do them to get our evidence related to our VV&A system of interest.

2.4 Re-composition

To obtain an adequate Acceptance Claim (ACC), it is now required to construct a VV&A claim network by means of re-composition strategies or arguments. These describe the argumentation (rule of reasoning) for selecting appropriate evidence data items (EDI) from the VV&A results set, and recursively aggregate them into well argued items of evidence and intermediate (sub)claims based upon this underlying items of evidence (IoE) or other supporting sub-claims.

In our current example the Evidence-Case (E-Case) is used to argue firstly that the measurements of the color property of the simulated flashing lights have been done properly. Secondly argue that the VV&A results set with evidence data items is acceptable to be used as evidence (IoE) for supporting the Acceptability claim (AbC) that the flashing light color is convincing (VV-Case). The basis for that are the evidence criteria and solutions specified in the ToE, along with other possibly discovered (circumstantial, indirect, corroborating, conflicting, etc.) evidence data items and quality arguments about the VV&A results set (relevance, reliability, convincing force, etc.). The acceptability claim for flashing light color properties, combined with items of evidence for the other flashing light properties in turn should support the higher level claim that all aspects of the flashing lights themselves are simulated convincingly. Hence the claim that the flashing light representation is valid can be asserted. If we can prove this for all Acceptability Criteria specified by the ToA, we can aggregate this info to support our top level Acceptance Claim which asserts that the simulator is feasible to evaluate the directive “Flashing lights off on location”. Such a utility claim implies that the driving simulator is suited for the M&S intended use as specified by the VV&A preconditions.

2.5 Acceptance recommendation

An acceptance recommendation presents the VV&A claim network and other relevant VV&A project information in such a form that VV&A problem owner can understand and practically use it in his or her acceptance decision making process. Since the VV&A problem owner needs were formally expressed by the VV&A requirements these should serve as the basis for developing an adequate acceptance recommendation. In general this means that an acceptance recommendation will provide well-argued advisory information to the VV&A problem owner in support of his or her decision making process on the M&S system and its intended or actual deployment within a problem domain or world. Such an advice will be a kind of management summary style report stating, depending on the VV&A question, how the M&S system can be utilized and under what kind of possible conditions (limits, risks, etc.) or what modifications are required to provide better utility. It is up to the VV&A problem owner responsibility to decide on whether he or she thinks that the M&S system can be accepted based on the acceptance recommendation.

3. Conclusions

The Generic Methodology for Verification and Validation (GM-VV) is a new comprehensive approach to VV&A aimed to the development of well informed acceptance recommendations. Its technical framework as discussed in this provides a systematic and traceable approach to develop acceptability criteria, design V&V experimental frames, evaluating V&V results and developing evidence based acceptance recommendations using argumentation frameworks.

Currently, the methodology is still a work in progress within SISO GM-VV PDG and the case described in this paper is a first attempt at application of the generic methodology in a real setting. The paper presents a first cycle in an iterative development process of an acceptance recommendation. In such first cycle the majority and focus of the work is on developing the VV&A requirements and preconditions. These are rooted in application and problem domain knowledge. It was shown how the GM-VV four world concepts can be utilized to support the elicitation and specification of such knowledge. Secondly, following the GM-VV technical process model, a first VV&A goal model centered round the VV&A system of interest is developed on the VV&A requirements and preconditions. An initial VV&A experimental frame is created and possible VV&A results are gathered. All this is done to tailor an optimal and feasible solution, i.e. VV&A plan, to obtain the desired acceptance recommendation. For this purpose also a premature VV&A claim model has to be constructed. The paper has attempted to illustrate with a birds-eye view this initial development cycle within a VV&A project.

What can be concluded from this work? First of all GM-VV seems a very promising and commonly applicable methodology for VV&A. However, this comes at the price of abstractness and meta-level defined elements that have to be instantiated, specialized, extended and optimized for a particular M&S application or technology. Therefore, from an educational perspective what is needed to make GM-VV better accessible for the whole M&S community, is an easy to read introductory document which companions the existing document set as is standardized at this stage. This document should give a global overview of all its elements and how they can be glued together into a single applicable methodology. In this manner it serves as a portal into the standardized document set. Furthermore, what is need are several educational examples from various types of case studies, from simple ones to more complex. These examples will support the learning process and pragmatic application of GM-VV as described by the current GM-VV RPG. It will also provide a pragmatic basis for the development of GM-VV support tools and techniques, which implement all three GM-VV pillars as defined by the GM-VV reference manual.

NATO has recognized the importance of case studies to further enhance the methodology with more problem- or application domain oriented recommended practices and unlock the GM-VV for a larger community. For the next two years the NATO NMSG-73 group will primarily focus on contributing to this effort. The example presented in this paper is selected as one of the candidate case studies within this NATO group. This means more iteration cycles are foreseen in the future to deepen the work. This will then result in a more complete, detailed and better balanced educational example on how to apply GM-VV in solving real life VV&A problems.

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Author Biographies

MARTIJN VAN EMMERIK is a member of the scientific staff at the Training Innovations Department of TNO Defense, Security and Safety. He holds a M.Sc. in

Human Factors Psychology (Utrecht University) and a Ph.D. in Social and Educational Sciences from the University of Twente. His research interests include transfer of training, vehicle simulator training, cybersickness, serious gaming, and validity.

MANFRED ROZA is a member of the scientific staff at the Training Innovations Department of TNO Defense, Security and Safety. He holds a M.Sc. and Ph.D. in Aerospace M&S Technology from the Delft University of Technology. He specializes in specification, verification and validation of models and simulation, in particular for simulation-based training systems.

JEROEN VOOGD is a member of the scientific staff at the Modeling and Simulation Department of TNO Defense, Security and Safety. He holds a Ph.D. in Computational Physics from the University of Amsterdam in the field of modeling and simulation biophysical systems on parallel distributed computation platforms. His current research interests include decision support with simulation, validity and agent technology.