The Synergetic Coexistence of Distributed Integrated Testbeds and Data Farming

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ABSTRACT

Besides of MTDS distributed testbeds are ideally capable simulate different technical or tactical scenarios using virtual simulators in a war gaming manner for operational analyses. In addition, Data Farming has been established in the analytical domain within Germany and other NATO countries, providing full scale investigation of possible outcomes of scenarios under scrutiny and giving profound decision support for real operational questions based on constructive simulation models.

Until now both simulation methods have been developed and applied disjointedly and different architectures and procedure models on how to conduct related experiments have been established over the years. This paper presents results of a distributed integrated testbed named System Demonstrator VIntEL which was an R&T project from 2008 – 2015 led by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw) where one main goal was to apply both simulation methods in a combined approach.

The benefits of enriching distributed integrated testbeds with Data Farming experiments are demonstrated herein based on the use case CD&E project 'Air Mobile Brigade' that was conducted to support the deployment of German Army Cavalry elements. The synergetic coexistence of Data Farming and distributed testbeds will be presented as well as how other barriers of employment had to be mastered.

1. INTRODUCTION

Existing successfully as an entrepreneur nowadays requires skills that allow for mastering the prevailing rapid pace of change that most authors capture with a standard vocabulary: the VUCA (volatility, uncertainty, complexity and ambiguity) world (Hicks Stiehm & Townsend, 2002, p. 6). Our human brain structure and capacity is well limited in impeccably carrying the related challenges and the managerial discussion on whether decisions made with a subjective gut-feeling or intuitions are superior to advanced decision supporting techniques are ongoing controversially (Gigerenzer, 2007).

The contemporary environment urges organizations to strive for an exploitation of supporting methods and technologies positively affecting the quality of their decisions. Amongst technologies of this group is modeling and simulation (M&S) with its ability to produce robust and objective data in a transparent manner. This applies also to non-profit organizations, public administrations and even to Armed Forces which are equally pushed to permanently improve their efficiency in times of ever scarcer budgets.

The German Armed Forces, nationally referred to as Bundeswehr (Bw), have recognized that a remedy thereto cannot only be created through mechanisms of permanent improvement to the status quo or transparency (e.g. lessons learned, continuous improvement program, controlling etc.) but also require a deliberate application of advanced methods and their sincere adaptation to the specific environment. Amongst these methods is modeling and simulation (M&S) whose potential spans a variety of use-cases when employed in the Bundeswehr. Its application requires a solid conceptual basement including a permanent review derived from the contemporary operational reality. The Bundeswehr has managed to anchor M&S in a sequence of concepts and strategic terms and definitions .

The 2013 released *Bundeswehr Concept (KdB)* as a conceptual fundament on strategic level constitutes the provision of M&S in the Bundeswehr generally and delegates the detailed embodiment to subsequent concepts (*Teilkonzeptionen*) such as the *Bundeswehr M&S concept (TK M&S)* inaugurated in 2006 (repealed for revision in 2013). The hitherto existing M&S concept is still under exertion in which modeling and simulation supports processes in four areas of application: *Analysis and Planning*, *Procurement*, *Missions* and *Training and Exercises*.

Although this taxonomy is not fully selective and many use-cases can be assigned to more than one area, a major differentiation usually exists between simulation applications with an analysis purpose and those for training as regards their basic requirements. The former usually provide higher accuracy and representation correctness and are predominantly engaged to support procurement of technology or developing best practices in effectively applying technology for military purposes. The latter have a high level of immersion and predominantly focus on a change in behavior of trainees.

The German Constitution tasks the Federal Defense Administration to satisfy the Armed Forces' requirements for materiel and services which in consequence obliges the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw) to “ensure that the Bundeswehr demand is met by supplying state-of-the-art technology and modern equipment at economic conditions” (BMVg, 2014). BAAINBw has acknowledged the positive contribution of M&S towards its main task of equipping the Bundeswehr with efficient and safe materiel and has decided to launch R&D/R&T activities pushing the development of M&S support into procurement which is in perfect accordance with TK M&S. The BAAINBw commitment to render support to an objective analysis of alternatives or a sincere exploration or development of technology with means of M&S has induced the establishment of a common armament testbed for integration intending to create BAAINBw’s capability for a rapid and effective representation of technical or technological solutions in a realistic operational test environment (Bossdorf, 2013, p. 12).

This cross-sectional application of M&S in the Bundeswehr is represented by the System Demonstrator VIntEL (SD VIntEL) which brings existing simulation systems of many project departments and defence and military science agencies together in a network, involving the infrastructure of the Bundeswehr Simulation and Test Environment (SuTBw). The resulting capability can be employed for all areas of application presented above.

In a NATO publication on SD VintEL, Neugebauer et al. (2009) outlined the contemporary achievements of employing testbeds in the German Armed Forces for "an evaluation of solutions to support all phases of the development and procurement cycle of material and equipment as well as the other application areas of M&S". In their review the primary focus is on the architectural aspects of a distributed integrated test bed. The respective content covers one of three pillars of the German Armed Forces' general rationale on testbeds as this had become initially formulated with the inauguration of SD VIntEL in 2008. When limiting the view on architectural aspects the relevant key success factors of test beds predominantly concern technical criteria like reproducibility, reusability and reliability of the simulation results and leave holistic process definitions, cost considerations or the satisfaction of the operational reality out of scope.

The concept of the SD VIntEL basically builds on three pillars which cover different core challenges of (distributed) simulation applications. Figure 1 visualizes the three pillars:

- The first pillar "Architecture" strives for a functional *architecture* enabling to couple real, simulation and control systems and provide common services e.g. for fair-fight conditions,
- the second pillar "Data Farming" enriches testbeds with a broad understanding of a system's behavior through comprehensive a priori parameter analyses according to the *Data Farming* methodology and operates as scenario driver with computer generated forces (CGF) to testbeds,
- the third pillar "Control" emphasizes standardization requirements for testbeds, the preparation of relevant data and databases and the process models alleviating realization and *control* of testbed

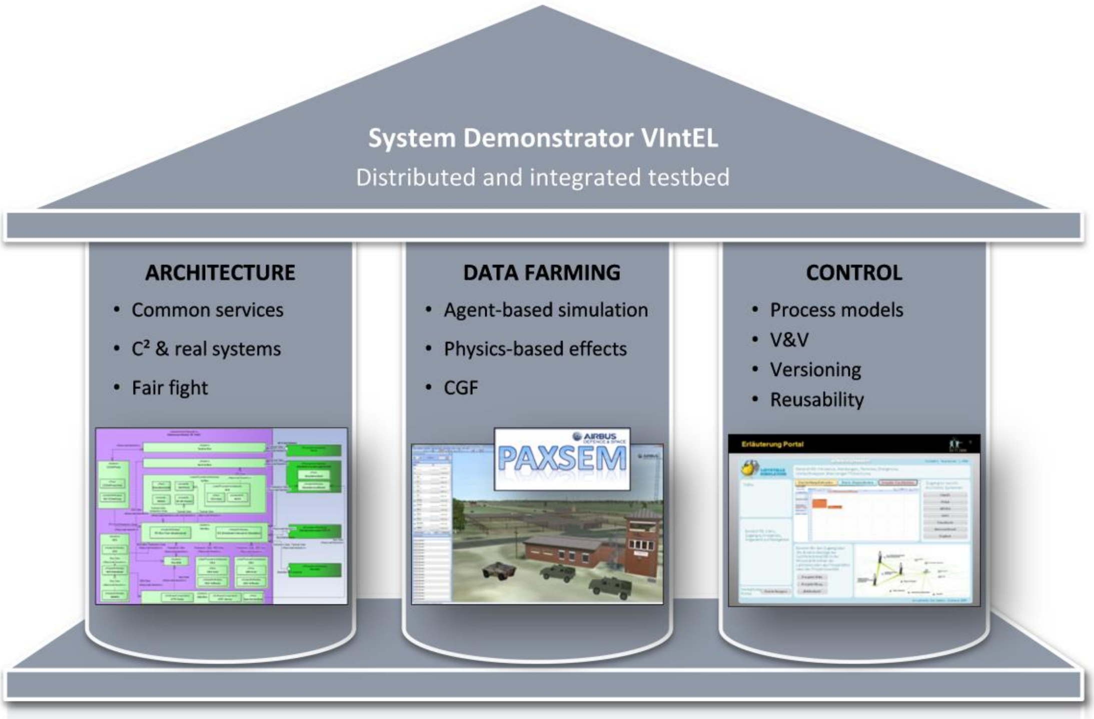

Figure 1: BAAINBw's SD VIntEL pillars

This paper amends the above mentioned publication and outlines the significance of constructive agent-based simulation for any testbed in the SD VIntEL sense hence bridging the first and second pillars of the corresponding Bundeswehr rationale. It also describes the positive influence of employing *Data Farming* experiments before and after establishing a testbed like this had been the initial conviction of the Federal Office of Defence Technology and Procurement (BWB, renamed in 2012 into BAAINBw) when starting its SD VIntEL journey.

2. SD VINTEL'S SECOND PILLAR: DATA FARMING

2.1 The Data Farming background

Prior to deducing how Data Farming experiments can be beneficial to the execution of a testbed the relevant SD VIntEL pillar is described.

Data Farming was initially defined in 1999 by the U.S. Marine Corps' (USMC) 'Project Albert' which aimed at finding a way of investigating and answering questions and phenomena for which traditional simulation methods and models did not bring about satisfying results. In its early phases, Project Albert largely employed agent-based simulation models in conjunction with the DF method of investigating a parameter space in a wide approach (Brandstein & Horne, 1998). Both the U.S. Naval Postgraduate School and NATO are still investing in Data Farming (Figure 2).

Figure 2: Organizations pushing the Data Farming development

Agents are entities that act in a simulation in a bespoke way separating agent-based modeling and simulation (ABMS) from traditional M&S. Each agent follows his own set of behavioral rules that are derived from reality representing the way real-world entities operate empirically. Agents have further similarities as they are equipped with sensors to perceive their environment as well as effectors to influence that environment. Sensors and effectors are represented according to real physical data and as detailed as the examination purpose requires. The resulting mutual interference of all agents excites what sociology calls 'emergence'. The differentiating criterion to traditional simulations is that the overall system behavior cannot be unambiguously predicted prior to a simulation run. Minor changes to the setup can cause massive effects on the outcome of a simulation run which literally invites researchers to explore the plausible wide sample space upon critical success factors or the quantification of system alternatives. ABMS hence allows to approximately represent reality much more accurately than with traditional approaches.

Data Farming (DF) in its simplest definition is a deliberate method for controlled parameter variations across a wide value space. For a more detailed definition refer to Horne & Meyer (2010, p. 2). DF is commonly applied in combination with ABMS. Data farming provides the capability for executing enough experiments so that statistical outliers might be captured and examined for insights. DF is not intended to predict an outcome; it is used to aid intuition and to gain insight. Anomalous outcomes are invited to appear in DF experiments, and these are often found in the analysis harvest. Finding the cause of why a model behaves in an unexpected way leads to a deeper understanding of the system under scrutiny (or also to the discovery of an error in the model or its assumptions). DF provides data that did not exist from empirical sources and to balance data scarcity.

Today the Data Farming endeavor has matured to grown-up simulation tools like PAXSEM from AIRBUS and detailed process models (see chapter 3.3 for details) supporting the method's application.

2.2 PAXSEM's double role in VIntEL

PAXSEM is a constructive analytical simulation environment developed on behalf of BAAINBw. It has been used in a series of activities (R&T, studies, etc.) of the Bundeswehr, NATO, AIRBUS itself and other consortium projects where it fulfils different functions:

- Simulation plot visualization (2D/3D viewer) in distributed federations (see Figure 3)
- CGF and stimulus injector to other systems
- Local simulation calculations
- DF client on numerous high performing computer nodes

In the SD VIntEL context PAXSEM as a tool plays a double role:

- inject a scenario stimulus to other systems *in the testbed* (architectural pillar) and
- provide the vehicle to *execute DF experiments* (DF pillar).

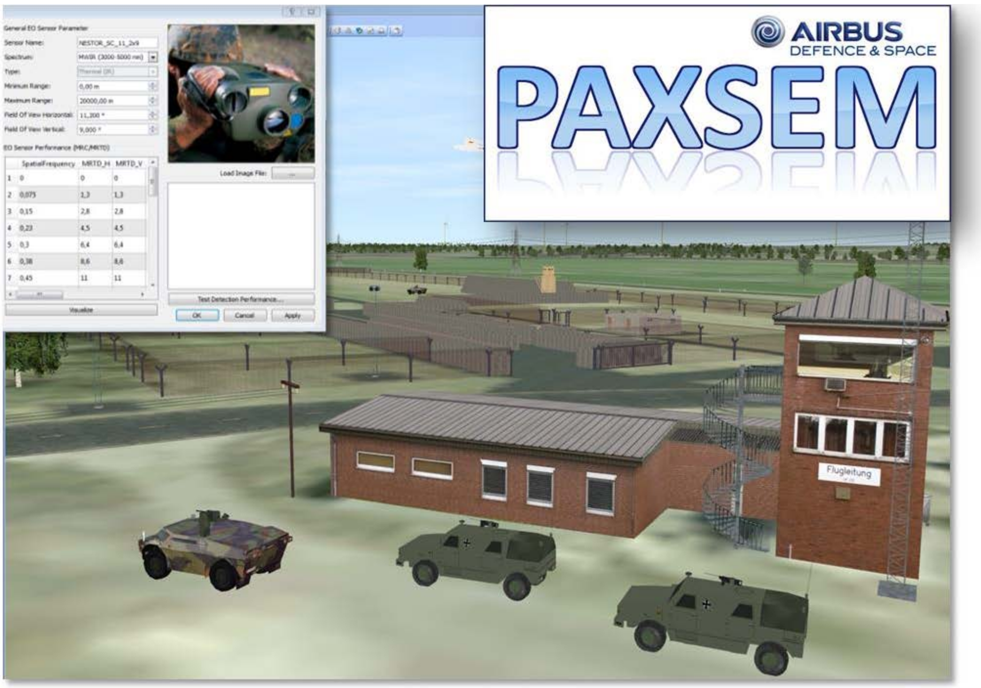

Figure 3: PAXSEM 3D appearance

As such PAXSEM represents the tool layer ready to play in both worlds and it is the Bundeswehr tool representing the German Forces' DF capability.

2.3 Enriching testbeds with Data Farming

This section provides a generic description of the synergetic coexistence of DF and testbeds. For a description of how the two should be practically engaged in combination refer to section 3.3. The synergies between DF experiments and testbeds arise in the following fields:

1. *Same qualifying preparations*: Both DF and testbeds involve simulation which requires a lot of input data. The artefacts created for a DF experiment (data, scenario or codified knowledge extracted from subject matter experts, etc.) can be fully exploited for a subsequent testbed.

2. *Exploitation of artefacts*: In SD VIntEL the potential for exploitation of DF outputs is enhanced through an overlap in the tooling. Due to PAXSEM's standardized interfaces and coherence to common services (e.g. Weapon Effect Service) its DF scenarios can be instantaneously injected into a testbed.

3. *System comprehension*: Within a testbed several instances are connected with the idea of equally operating in a common virtual scenario. In order for the virtual elements to both act as required and still provide flexible behavioral dynamics upon the real operators' inputs, a concise understanding of the virtual elements is required. This affects the knowledge of initial values of simulation parameters.

4. *Validation of DF findings*: Results from DF experiments are taken as 'one step towards reality' with a testbed. Virtual entities crucial to the examination subject are replaced with real operators and the scenario is played again in the testbed. The final benefit resides in a comparison of the generated data/the output.

5. *Validation of testbed findings*: Testbeds are executed with a rigorous analysis plan to limit the resources required. Results hence cannot cover a wide parameter space as can DF. Findings from testbeds can be stress-tested with DF in a wide parameter band leading to a confirmation or denial of those.

These should be the main aspects why SD VIntEL combines DF with testbeds according to the BAAINBw rationale.

3. COMPLEMENTARITY OF DF AND ARCHITECTURAL PILLAR

When coupling distributed real and virtual systems and simulators, the challenges are not uniquely of a technical nature. Once standards and architectural requirements are fulfilled and a realization is feasible, the need for a process model arises describing best practices in conducting a testbed. Interestingly, SD VIntEL does not provide a common process model, but two separate ones, one for architectural and one for DF aspects.

3.1 VEVA – the architectural process model

In the course of exploring the SD VIntEL BAAINBw awarded a study to initially create a process model for the proper application of the SD VIntEL architecture: *VEVA (Vorgehensmodell für den Einsatz der VIntEL-Architektur)* (Ufer, et al., 2009). For this study elements from the IEEE-standard FEDEP (Federation Development and Execution Process) were adopted and enriched with national considerations. Along with the maturation of the SD VintEL, VEVA itself also underwent many adaptations and improvements mainly driven by lessons learned. It currently exists as VEVA 3.0 codifying the experiences gained so far.

VEVA has a center of gravity on the setup of the overall system which is in excess of the FEDEP. It is best compatible with the TK M&S areas of application of 'analysis & planning' and 'procurement' (Laux, 2009, p. 27). VEVA differentiates between three resources (customer, contractor, V&V) and twelve roles (task initiation, handling, domain expertise, IT admin, implementation, config mgmt, direction, M&S admin, modeling, quality mgmt, security mgmt, analysis) which are assigned to seven individual process steps according their respective contributions as depicted in Figure 4.

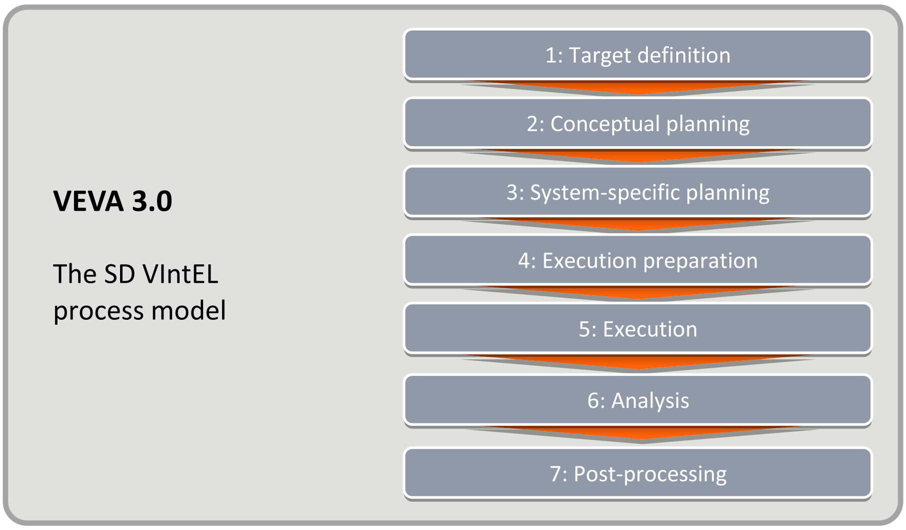

Figure 4: Bundeswehr architectural process model VEVA

Like any other process model, VEVA describes working of a testbed in order to have maximum benefit thereof. However, as its title already reveals, VEVA addresses uniquely the architectural elements of a testbed covering only one out of three pillars of the SD VIntEL.

VEVA does not contain information on how to apply DF in favor of a testbed nor on how the two pillars should beneficially interact. A valid element where an interconnection could be implemented, two VEVA information elements (2.4 'input values' and 2.5 'input data') in its Phase 4 could be adopted from a LSABw analysis or DF experiment.

3.2 LSABw - the Data Farming process model

DF has a proven raison d'être per se and there have been indeed far more national projects when DF has been executed in isolation than as part of a testbed which is why a separate Data Farming process model can make sense at all.

As PAXSEM matured technologically, DF was applied in a series of national concept development and experimentation (CD&E) or procurement studies. The maturation of the DF code of practice from practitioner approach to a detailed process definition achieved academic appreciation with two German Armed Forces studies finally providing a *guideline for simulation-based analyses of the Bundeswehr (Leitfaden für simulationsgestützte Analysen der Bundeswehr)*, LSABw (ITIS GmbH, 2011). This guideline defines inputs, stages, roles, Key Performance Indicators (KPIs) and outputs generically and remains thus applicable beyond DF experiments.

The LSABw sets in where an initial question is formulated reflecting specific user requirements. A guided approach identifies whether simulation appears to be a valid method to purposefully examine the particular subject or whether some alternative approaches are needed (e.g. logical deduction). Once this is positively ascertained, the process scheme foresees nine steps to be performed. The scheme in Figure 5 depicts the

LSABw in its full deployment assuming an idealistic existence.

The LSABw is indifferent regarding its customer. Once a DF experiment adheres to the process flow depicted it requires dedicated qualifying input to create valid output. In any case, value is only created if the initial question receives its appropriate answer.

LSABw hitherto does not interconnect to VEVA leaving the pillars in isolated coexistence. To provide the Bundeswehr with a holistic sequence of testbed-oriented activities in the SD VIntEL sense, it appears reasonable to combine both process models. Such a combined state could be addressed as the SD VIntEL '*modus operandi*'.

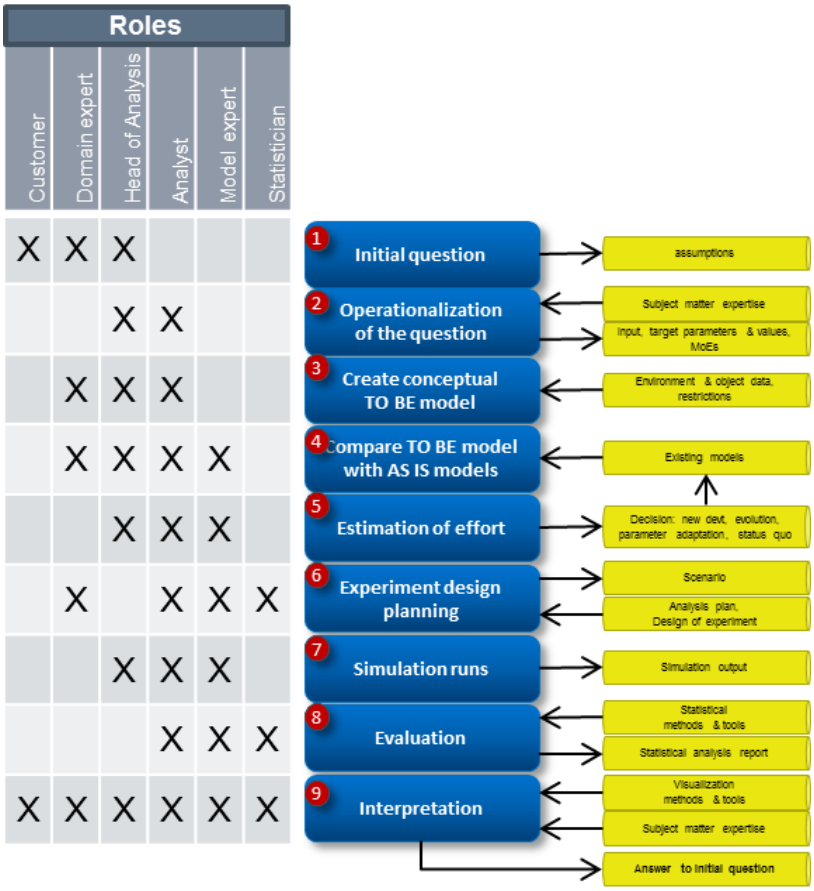

Figure 5: Bundeswehr process model for simulation-based analyses (LSABw)

3.3 Towards a SD VIntEL modus operandi

The idea of the *modus operandi* is to engage the SD VIntEL as a whole to generate operational benefit (Ulrich & Brockbank, 2005).

Figure 6 depicts this as a sequence of proposed activities that are initially triggered by an **operational question** from the real world. This question is a central element to any subsequent activity and so is its compulsory **conditioning** (data acquisition, collaboration with experts, scenario modeling etc.). The quality of this step is essential for the overall analysis success (ITIS GmbH, 2011, p. 10). As a rule of thumb (remembering that much of the flow depends on the question itself) an **initial DF experiment** can establish a broad understanding of the wider system's behavior that is under scrutiny before a **distributed integrated testbed** takes over the M&S artefacts assembled and replaces virtual entities with their real counterparts (to be done according to the examination subject). This takes the DF results 'one step towards reality'. In a **second DF experiment** the findings from a testbed are validated in its wider context when extensive parameter intervals are covered. Finally the initial **operational question is answered** decidedly. The overall answer has to respect any generated insight relevant in the military decider's **mission reality**.

Figure 6: The SD VIntEL modus operandi

The following section contains a description of an exemplary realization of DF and the testbed.

3.4 Exemplary use-case: Cavalry deployment preparation

When the Bundeswehr performed its Concept, Development and Experimentation (CD&E) project 'Air Mobile Brigade' the preparation of the deployment of Army cavalry elements was an examination subject. Tasked to support the examination, a DF study was awarded to AIRBUS.

The refined examination question focused on the operational value of a TIGER helicopter crew in support of infantry forces in an ambush situation. On an operationalized level the task was to identify a best suited tactical behavior along prevailing degrees of freedom (DoF) of the TIGER crew (see Figure 7):

- C^2-relationship between the two helicopters
- height offset between two helicopters
- horizontal distance to ambush hotspot
- flight level
- flight profile and
- available weapons.

The scenario was developed and modeled on several a geo-specific Afghanistan terrain cells, enemy forces were defined to vary in behavior and equipment amongst other noise factors. The design of experiment finally presented 4,536 different parameter combinations simulated covering more than 13,600 flight hours of the TIGER helicopter.

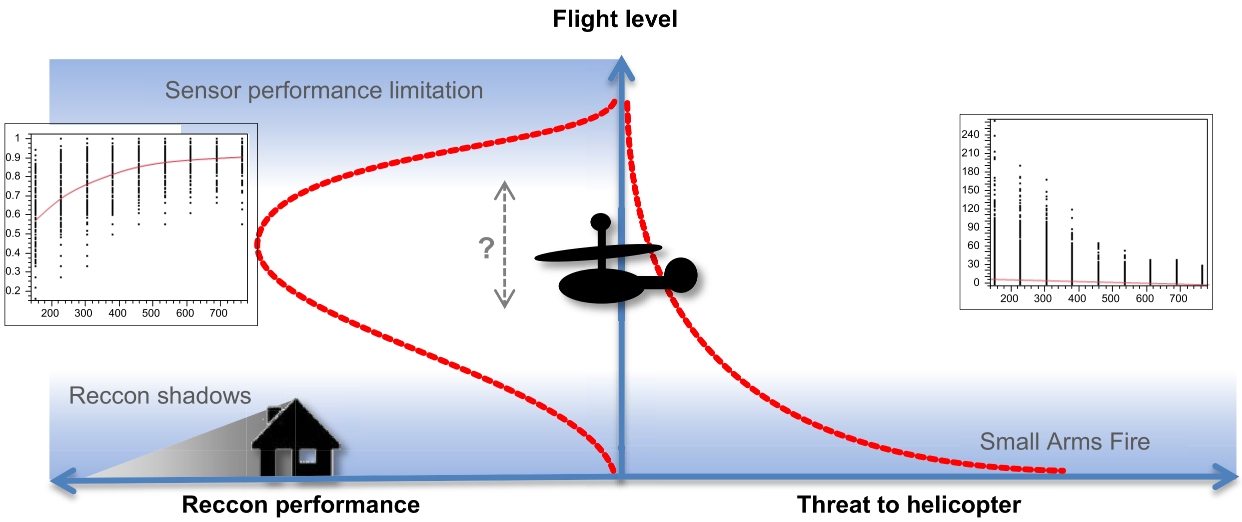

Figure 7: Implications of pilot DoF flight level

Finally German Cavalry elements developed their conceptual mission preparation (i.e. combat operating procedures) on the findings resulting thereof which triggered a second study for a validation of the results with a testbed replacing the artificial helicopter with a live simulator. For this AIRBUS Helicopter's Simulation Cockpit (SimCo; see Figure 8) was chosen. Originally developed for software testing the SimCo's architecture largely fulfilled standardization requirements and was hence compatible with PAXSEM due to equal visualization components (fulfilling the VIntEL fair fight requirements etc.).

Figure 8: AIRBUS Helicopter's SimCo TIGER simulator

From the wide variety of parameter combinations (see list of DoFs above) only a countable few can be taken into a testbed which is where the DF experiment could provide a significant support to the testbed setup. Hence simulation runs with interesting outcomes were selected for in the testbed (it is a trivial testbed limitation that test participants learn over the sequence of individual simulation runs and adapt their behavior. This is why only very few testbed runs can be performed with no/little bias) and an analysis plan was created. The experience from this project has contributed to formulating key success factors of a beneficial interplay of DF and testbed as captured in section 2.3.

4. CONCLUSIONS

The R&T project SD VIntEL pointed out several aspects to enhance future simulation and analysis models. Based on its service-oriented approach, the project revealed solutions and opportunities as well as problems and challenges in the domain of M&S interoperability to be dealt with in potentially subsequent studies.

DF has been established in the analytical domain within the German Armed Forces, providing full scale investigation of possible outcomes of scenarios under scrutiny and giving profound decision support for real operational questions. Beyond this standalone application where it has already proven its value to operations, DF is now ideally included in the process of conducting testbeds, as outlined in this paper. Thereto other barriers of employment are to be mastered.

As a research project for about 8 years, SD VIntEL has evolved in its architecture and prototype implementation but yet not been applied by the Armed Forces operators themselves. It is now important to transfer the R&T results into a mature product, e.g., the German Simulation and Testing Environment *SuTBw*. This will dramatically reduce the effort and costs coming along with installation and operation of the current system demonstrator VIntEL, hence implicating starting difficulties and aggravating rapid deployment.

In addition to this, the process of verification, validation and accreditation (VV&A) needs further focus when going from R&T to a product environment. Lack of VV&A will lead to a lack of acceptance concerning simulation results in spite of their quality.

The new possibilities and benefits offered by the combined application of DF and testbed need to be communicated and advertised to increase the awareness level and to lead to real operational applications of the approach. As a first step, the results of SD VIntEL were presented in the fall of 2015 to potential future customers represented by the Bundeswehr Planning Office and the German Armed Forces´ departments, respectively, and the corresponding M&S representatives of the different service branches. A clear offer has been made to stipulate particular solutions to enhance their current training capabilities and to take a further step towards an interoperable and overarching training simulation environment.

For now the widely recognized main application area of SD VIntEL is supporting distributed training, where it may support and improve the capability of cross-linking different training simulations in a heterogeneous environment. A potential use case for additional DF support might for example be the definition or preselection of different training scenarios. DF may be used to quickly scan and analyze a huge variety of different scenario flows and select interesting or surprising ones.

Many of the technical barriers have been researched and future work will focus more on soft factors.

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