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DATA FARMING SERVICES: MICRO-SERVICES FOR FACILITATING DATA FARMING IN NATO

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ABSTRACT

In this paper the concept and architecture of Data Farming Services (DFS) are presented. DFS is developed and implemented in NATO MSG-155 by a multi-national team. MSG-155 and DFS are based on the data farming basics codified in MSG-088 and the actionable decision support capability developed in MSG-124. The developed services are designed as a mesh of microservices as well as an integrated toolset and shall facilitate the use of data farming in NATO. This paper gives a brief description of the functionality of the services and the use of them in a web application. It also presents several use cases with current military relevance, which were developed to verify and validate the implementation and define requirements. The current prototype of DFS was and will be tested at the 2018 and 2019 NATO CWIX exercises, already proving successful in terms of deployability and usability.

1 INTRODUCTION

1.1 Data Farming in NATO

Data Farming is a quantified approach that examines questions in large possibility spaces using modeling and simulation. It evaluates whole landscapes of outcomes to draw insights from outcome distributions and outliers. This evaluation is made possible by "growing" massive amounts of data through the execution of many simulation runs. The name Data Farming was initially coined in 1997 (Horne 1997). Since that time the data farming community has grown to include people from over a dozen nations. Data farming continues

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to evolve from initial work in a United States Marine Corps effort called Project Albert (Hoffman and Horne 1998) to work in NATO M&S-Groups, national projects and work done at data farming workshops which number 32 to date. In addition to data farming projects in national and international military applications, data farming is also used for civilian applications, like logistics, disaster relief or fight against terrorism. The Scythe is the publication of the International Data Farming Community that contains proceedings of these workshops (e.g. (Meyer and Horne 2017)) and many data farming 'success stories' that can be found at www.datafarming.org.

Data farming normally uses simulation in a collaborative and iterative team environment (Horne and Meyer 2004) that has been used primarily in defense applications (Horne and Meyer 2010). This process ideally has input and participation by subject matter experts, modelers, analysts, and decision-makers. Data farming is a process that has been developed to support decision-makers by answering questions that are not currently addressed. Data farming uses an inter-disciplinary approach that includes modeling and simulation, high performance computing, and statistical analysis to examine questions of interest with large number of alternatives. Data farming allows for the examination of uncertain events with numerous possible outcomes and provides the capability of executing enough experiments so that both overall and unexpected results may be captured and examined for insights.

In 2010, the NATO Research and Technology Organization started the Modeling and Simulation Task Group Data Farming in Support of NATO to assess and document the data farming methodology to be used for decision support. This group was called MSG-088 and it's key achievements are the definition of the six realms of data farming (Horne et al. 2014) and their connection in the data farming workflow, the Loop-of-Loops of data farming. Upon completion of MSG-088, i.e., the codification of data farming, a follow-on task group called Developing Actionable Data Farming Decision Support was initiated by NATO and was designated MSG-124. This task group has completed work in selected application areas important to NATO and was focused on developing methods and tools for actionable data farming in NATO (Horne et al. 2018). A new NATO task group, designated MSG-155 - Data Farming Services (DFS) for Analysis and Simulation-Based Decision Support has since been formed and has begun to develop DFS as a mature toolset to facilitate data farming in NATO.

1.2 Objectives of MSG-155 and DFS

Data farming can support military decision-making throughout the development, analysis, and refinement of courses of action. By performing many simulation runs, a huge variety of alternatives can be explored to allow decision makers to make more informed and robust decisions. Paradoxically, this method can be used to declutter the immense amount of information known and grant commanders and staff improved situational awareness. Data farming allows for the consideration of uncertainties and the discovery of unexpected outcomes that may lead to findings that allow NATO military decision makers in the domains of defense planning, operations, training and capability development to reduce surprises resulting in more robust solutions. The objectives of MSG-155 and DFS are:

1. Provide military decision makers data farming as an enhanced decision making capability in their military working environment as a state-of-the-art IT-service architecture in accordance with NATO's Federated Mission Networking (FMN) concept and specification.
2. Produce a road map for what needs to be done in order for NATO to provide Data Farming Services. This road map will show the way for developing a technical concept for DFS through an integrated toolset. Additionally, the work will produce technical prototypes useful for the implementation of the road map.
3. Support the application and execution of the data farming process as codified in MSG-088 and as applied in MSG-124 in a mature, productive and user-friendly way and support many different application use case areas.

Work on establishing Data Farming Services can promote increased efficiency and affordability of data farming within many NATO contexts. The main factors for this are availability of data farming capabilities for the analyst or decision maker by centrally hosting DFS in, e.g., FMN or a national network as well as allowing widespread collaboration and API connectivity to common NATO tools like TOPFAS. Technical developments in the area of data farming tools and methodologies offer opportunities for providing services that can address current NATO shortfalls, especially in the examination of questions in the areas of Hybrid and Symmetric Warfare.

In the NATO context, MSG-088 and MSG-124 were precursors to the establishment of DFS. In a similar fashion, the NATO Work group MSG-131 began work on the application of a services model to Modelling and Simulation, called “Modelling and Simulation as a Service” (MSaaS) (Siegfried et al. 2015). MSaaS promises to greatly reduce the barriers of cost and accessibility and to result in greater utility of M&S throughout NATO and the Nations. The work from MSG-131 is being carried forth with the goal of making the implementation of Modelling and Simulation to be easier and more flexible for users with continued work by MSaaS task groups MSG-136 (Hannay and van den Berg 2017) and now MSG-164.

2 Concept of DFS

The basis for the concept are the data farming loop-of-loops as developed in MSG-088 (Figure 1, left). The loop-of-loops shows five realms of data farming (with the sixth realm of Collaboration underlying the whole process) as well as the complete workflow. To capture and facilitate the workflow and the realms, the loop-of-loops was translated into services (Figure 1, right).

Five of the six realms of data farming are captured into services. Model development cannot be supported in DFS, since modeling normally happens in dedicated modeling or simulation tools which are standalone desktop applications. Thus, the workflow of DFS starts in an external tool, after the model was developed. Collaboration, the sixth realm of data farming with overarching importance, is captured by designing distributable web services and a multi-user web application to work with these services.

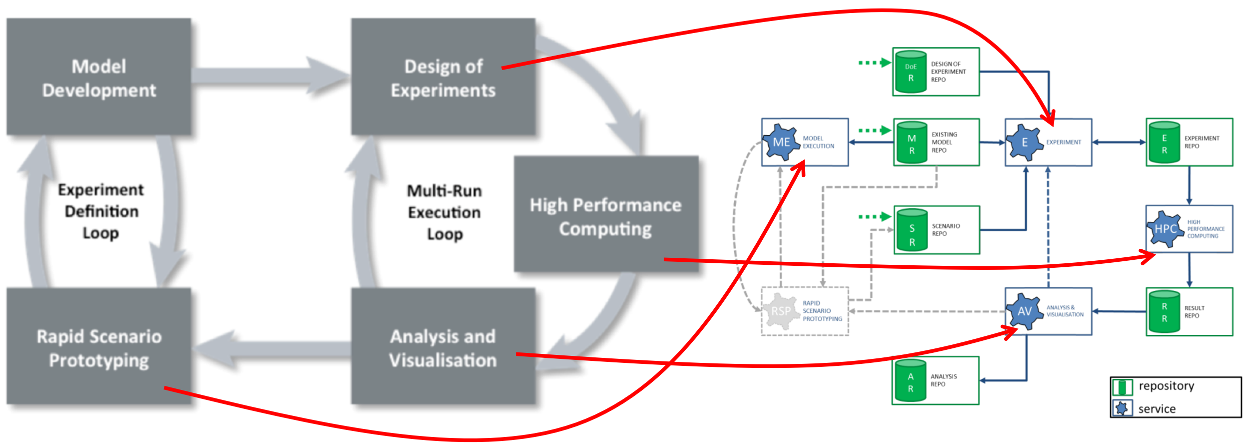

Figure 1: From Data Farming loop-of-loops to Data Farming Services (magnified in Figure 2).

Figure 2 shows all data farming services, those deducted from the loop-of-loops as well as database and management services. More precisely they are service types, i.e., a defined functionality which must be provided by a service implementation. Of each service type there can be several implementations or instantiations, all working in a DFS-mesh.

Following is a short description of all service types:

- **Model Execution**: Service to execute a model configured with a specific input factor combination. Currently this service just provides the simulation outputs, but it is envisioned that the visualization

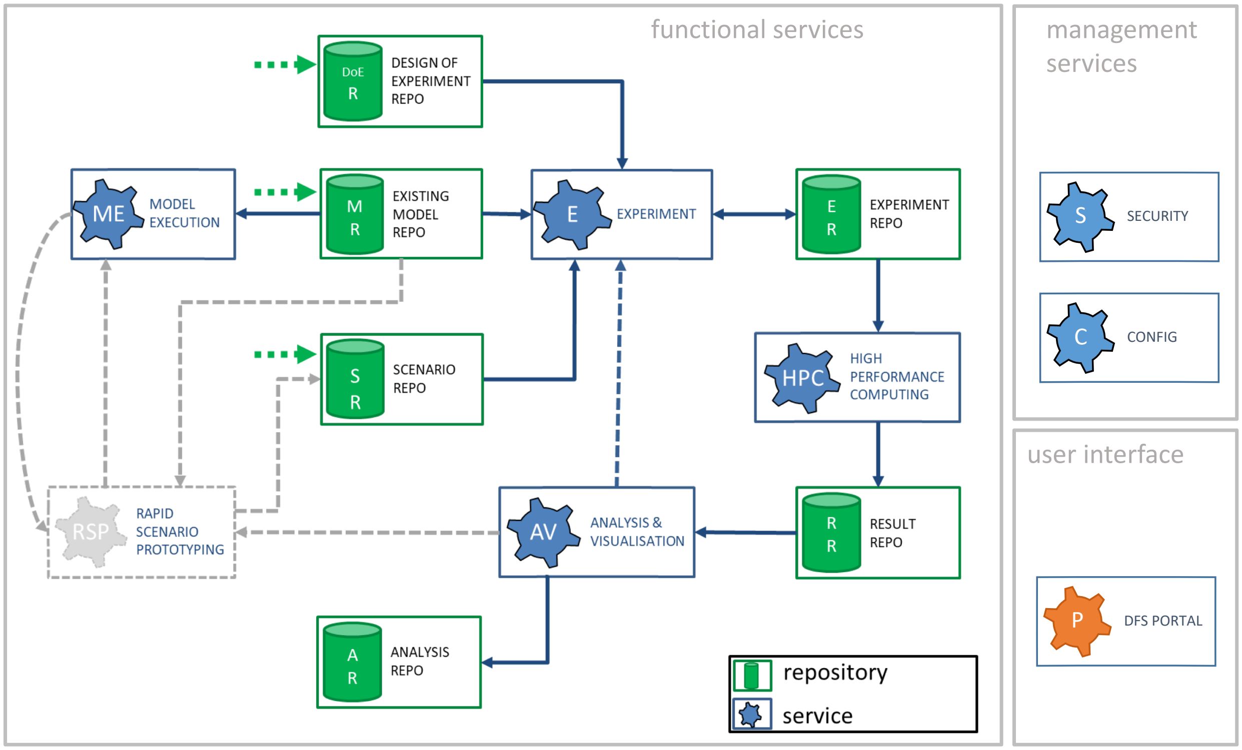

Figure 2: Data Farming Services in detail.

of a simulation tool is integrated, such that in the realm of Rapid Scenario Prototyping the dynamics of the simulated model can be verified. This service must be simulation tool specific, since this tool must be integrated into DFS.

- **Experiment**: Service to create the Design of Experiment (DoE) based on the used model and the specified ranges of the model input factors. Methods used for creating the DoE can be for instance Full Factorial or Nearly Orthogonal Latin Hypercube design.
- **High Performance Computing**: Service to execute all the simulations defined in the DoE on a high performance computing cluster. This service functions as a simulation tool specific wrapper for a standard HPC software or framework. Similarly to the Model Execution Service it has to be simulation tool specific since it must parse the DFS data objects into simulation tool inputs and also has to store the simulation results in DFS.
- **Analysis and Visualization**: Service to analyze and visualize the results created by the HPC in a web application.
- **Repositories**: Services (green in Figure 2) to store all DFS data objects. For optimal service distributability the set of DFS data objects are partitioned into six clusters: model, scenario, design of experiment, experiment, result and analysis. These services function as wrappers for SQL-databases.
- **Security**: Management service to handle user authentication and authorization.
- **Configuration**: Management service to provide a central registry of all services. Since the system can be distributed on several servers and there can be multiple service implementations present per type.
- **Portal**: Web application to provide a GUI to let the user work with the services, provide workflow guidance and visualization of data.

The data structure as presented in Figure 3 is designed to be distributable using specific repository services and handle big data in a web application / microservice architecture.

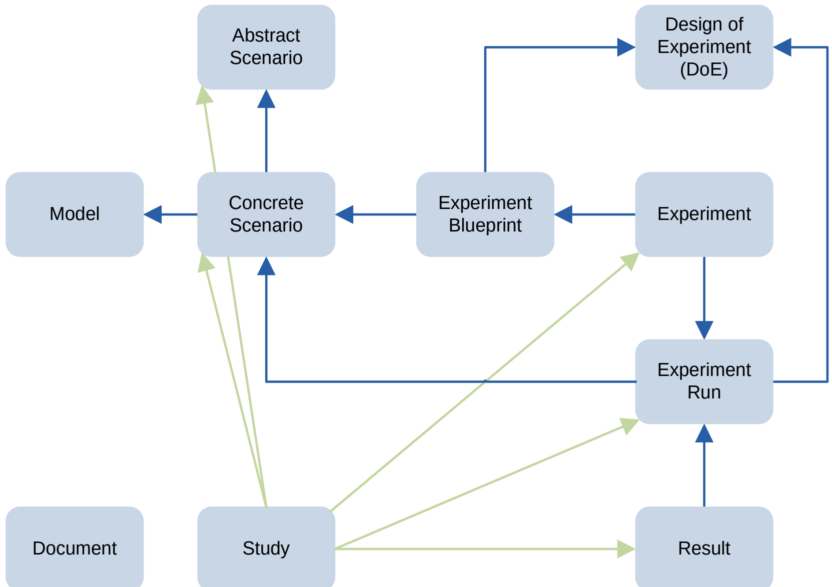

Figure 3: Data structure of DFS.

Following is a short description of all data types:

- **Study**: Encapsulating object to bundle all data belonging to one data farming study. A study is created by a user to answer specific questions in a military scenario.
- **Model**: A simulation model. Currently this is description of a model, defining a description, outputs and inputs. In the future this will also be the actual executable model.
- **Abstract & Concrete Scenario**: An abstract scenario is a textual description of the research question. It is linked to the model and it's inputs and outputs by defining a concrete scenario. The Concrete Scenario also specifies the relevant MoEs and outputs for the study as a subset of all simulation outputs.
- **Design of Experiment**: Currently only a description of algorithms like Full Factorial or Nearly Orthogonal Latin Hypercube Design to create a Design of Experiment (DoE), which is a set of simulation configurations. In the future it will also contain the actual algorithms, such that the Experiment Service will execute these algorithms to create the set of simulation configurations.
- **Experiment, Experiment Blueprint & Experiment Run**: The Experiment Blueprint is the input for the Experiment Service. It is created in the DFS portal to configure the Design of Experiment. The Experiment Services creates a set of Experiment Run objects, which are simulation input configurations. An Experiment Run can be send to the Model Execution or HPC Service to initiate the execution of a simulation. A set of Experiment Runs created by the Experiment Service is bundled in an Experiment, which also keeps the links to the used model, scenarios and results.
- **Result**: The relevant output of a simulation execution, as defined in the Concrete Scenario. Additionally the Result can also contain MoEs which are calculated from simulation output using mathematical functions.
- **Document**: Saved analysis visualizations, including metadata like author, comments, date of creation, etc.

3 Implementation of DFS

3.1 The Architecture

Employing Microservices is a software development technique that structures an application as a collection of loosely coupled services. In a microservices architecture, services are fine-grained, the protocols are lightweight and they communicate over a network using HTTPS. The benefit of decomposing an application into different smaller services is that it improves modularity. Especially in a multi-national environment, where many nations or groups want to participate with specialized services, the development and deployment can be distributed and parallelized. If groups or nations don't want to share services, they can implement their own, but can use the shared services of others.

The current implantation of DFS is basically a service base, with each service type implemented once, in a general manner, such that a comprehensive working base is provided. This base can be easily expanded. As shown in Figure 4, each of the service types defined in Figure 2 was implemented as a REST-web-service. The HTTPS-protocol is used for communication between services. Request information and data are transferred using XML documents, thus data objects must be parsed into XML and vice versa. For advanced security, principally only the http request method POST is used, such that only minimal information is present in the unencrypted part of the messages.

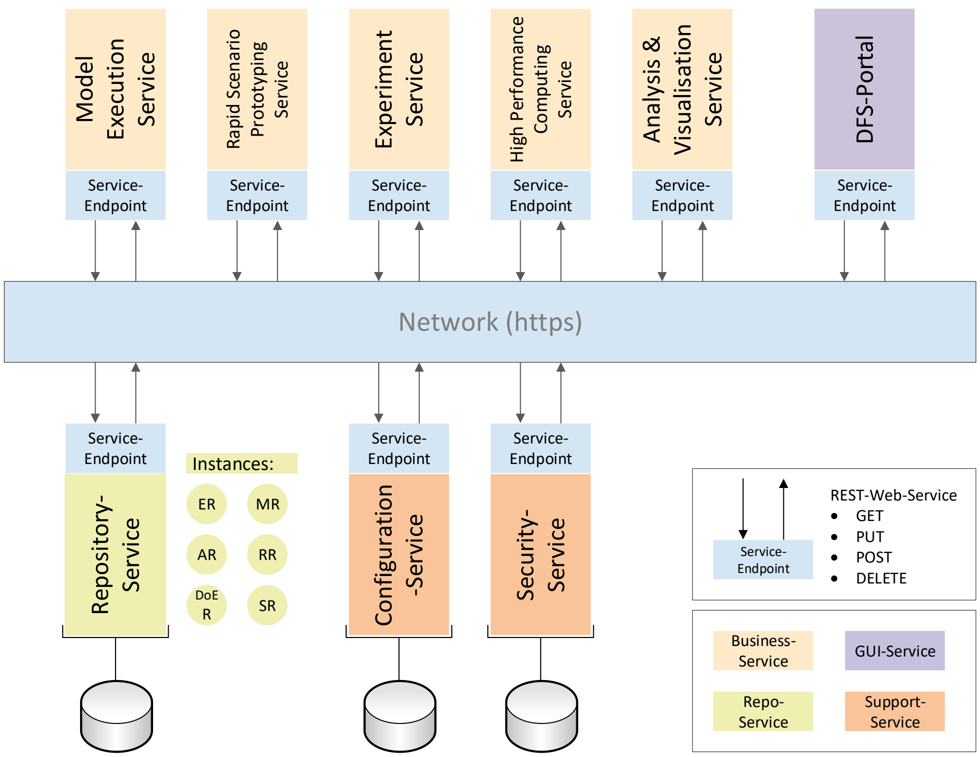

Figure 4: DFS microservice architecture.

For efficient collaboration in the development of services, the API and data structure for each service are documented in each service using the OpenAPI 3.0 specifications (Swagger 2019). The microservices are written in either Java or Python and are containerized, such that each service can be deployed independently on distributed servers using Docker. When working with DFS, there has to be at least one service of each type available in the network. Since there can be more than one service per type, the actual service used must be selected by the user in the web application.

3.2 The Web Application

After the user is logged into the DFS portal, she can select which services she wants to work with. After this selection, a new study can be created or an existent one can be loaded. After loading a study, the application shows a view like presented in Figure 5 (excluding the overlay of arrows and blue boxes, visualizing the design concept of the application). The main view of the portal is organized into swim lanes, each representing a major step in the data farming workflow.

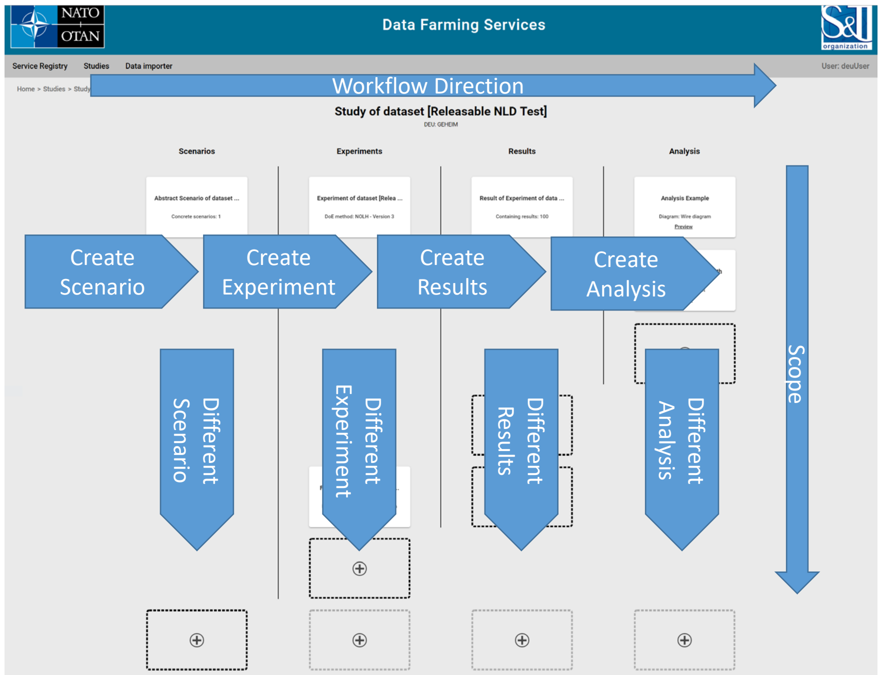

Figure 5: DFS portal: study view plus workflow concept.

The horizontal direction, i.e., working from left to right through the swim lanes, defines the data farming workflow. The vertical direction is used to increase the scope of the study, e.g., by using a different a model, a different DoE or more analysis. Whenever a new step wants to be taken, clicking on the ⊕-squares opens a new view for selecting, creating or modifying data. Each increase in scope creates a new horizontal level in the swim lane table, such that, for example, results can be clearly associated to the used experiment, or analysis to their data basis.

The DFS services can be used with any client, e.g., the NATO TOPFAS application which connects to the Analysis-Repository to include visualizations into TOPFAS created in DFS, but the general concept is that all work with DFS is done using the portal. This facilitates the objective to provide an integrated toolset.

3.3 High Performance Computing

One major part of DFS and data farming in general is the possibility to execute huge numbers of simulations. The concrete number of simulation runs necessary in a study depends of course on the model used and the scenario defined. In MSG-124 the final DoE defined roughly 860,000 simulation runs. Thus there is the objective for DFS to be able to handle studies with one million Experiment Runs and Results. This creates requirements on the data transfer and analysis capabilities, but first calls for the capability to execute these numbers of simulations in an appropriate time frame.

In DFS existing High Performance Computing (HPC) or High Throughput Computing (HTC) frameworks are used, like Microsoft HPC (Microsoft 2019) or HTCondor (HTCondor 2019). The HPC service of DFS acts as a service wrapper of a so called master or head note, which can submit jobs into a cluster. Thus, a traditional HPC/HTC-Cluster is connected to DFS in the backend. The job of the HPC-service is to download all of the Experiment data from the DFS repositories, create simulation tool specific input data and to create and submit jobs to the cluster. After the simulations are finished and result data is collected by the master/head-node, the service has to parse this simulation tool specific data into Result objects and post them to the Result Repository.

This data parsing capability requires, in general, a specific HPC-service implementation for every HPC/HTC framework and simulation tool combination. Also one service instantiation is required for each attached HPC/HTC-cluster.

3.4 Visualization and Analysis

Another major part of DFS and data farming in general is the analysis and visualization capability. Without the ability to create sound problem and audience specific analysis, a data farming study is pointless. The Analysis and Visualization Service in DFS is based on the prototype Data Farming Decision Support Tool for Operation Planning (DFTOP) created in MSG-124 (Schubert et al. 2017). The main aspects were: implementation of best practice analysis workflows, integration of standard mathematics and statistic applications and decision maker specific visualization and interaction possibilities. Since DFTOP was designed as a desktop application and it integrated commercial applications, which created licensing problems, it could not be used as a service in DFS. A new service, based on the main concepts of DFTOP, using the data science capabilities of Python was implemented.

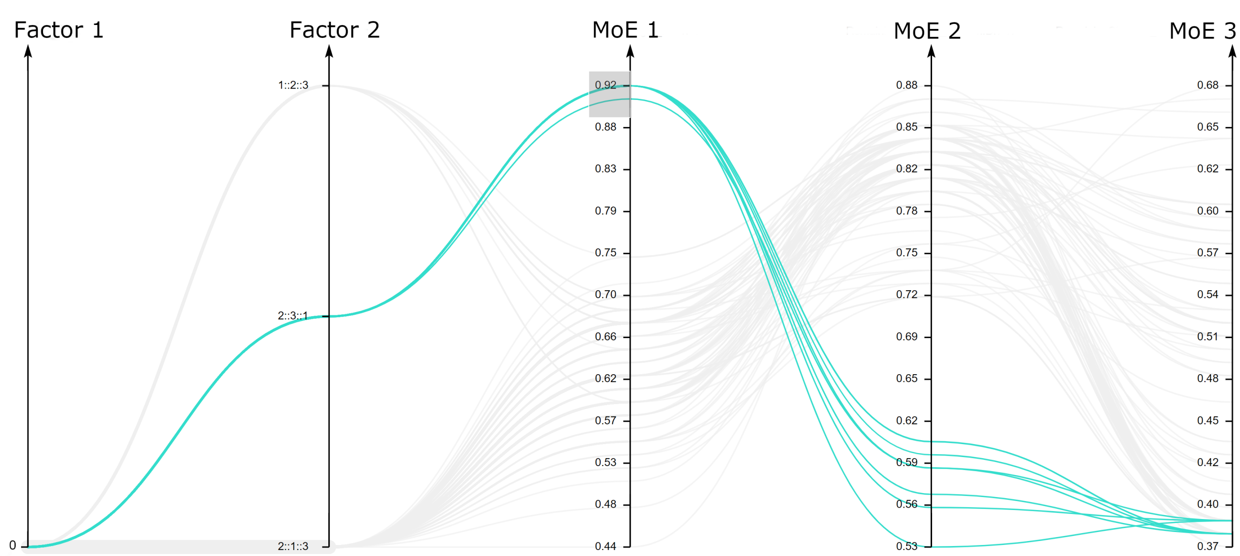

Figure 6: Visual analytics design example: screenshot of parallel coordinates plot

As an example of the capabilities of the current service implementation, a screenshot of a parallel coordinates plot is shown in Figure 6. When presenting DFTOP in various occasions to military decision makers, this kind of plot was very well suited to explore the data and to help develop courses of actions. In a parallel coordinates plot, each axis is one input factor, simulation output or MoE, each line, spanning all axis, is one simulation run. In DFS this is implemented as an interactive visualization, where the user can filter data on axis, which is especially useful to answer questions like ”Which simulations produced especially low casualties?”. After applying this filter, the input factor ranges of these simulations are highlighted (green lines). When disabling the first filter and useing new filters on all simulations with those input ranges, a secondary question can be ”What is my range in casualties when using set input ranges?”

Additionally the service also provides box plots, bar plots, line plots and an analysis to find the most important factors for achieving especially high or low values of one MoE.

4 Application of DFS

To show the applicability and military relevance for DFS in NATO, several use cases are developed in MSG-155. These use cases are based on former or current projects of the partner nations and the objective is to support decision support for these use cases using DFS, either by utilizing the whole data farming workflow or by importing data farming data and utilizing the visualization and analysis capabilities of DFS. The use cases are also used to validate the conceptual scope and implementation of DFS and provide insights into future development potential and operational requirements.

4.1 German Use Case on Future Land Operations

The German use case ”Simulation-based analysis of future combat operations of ground forces” aims to use the agent-based simulation model PAXSEM (Kallfass and Schlaak 2012) to identify and analyze key factors of future land-based combat operations.

The appearance of future ground combat theaters is driven by innovative developments, disruptive technologies and trends such as digitalization, demographic change of industrial societies, robotics and artificial intelligence. Advanced automation of war fighting processes, shared information, handling of big data and artificial intelligence of a certain degree are key to identify and to finally overcome the challenges of future ground combat theaters. This study utilizes innovative modeling and simulation, and data farming techniques to analyze the combat value and effectiveness of present and future combat systems, such as combat tanks, and unmanned ground and aerial platforms based on a certified scenario. Modeled platforms are evaluated in combination with defined degrees of automation and autonomous behavior, elements of swarming techniques, common situational awareness capability, and an automated threat evaluation and fire control system in a quantifiable manner. The outcome provides the opportunity to gain insight into the complex dynamics of an attack operation of heavily armored ground forces and contribute to the digital transformation process of the German Army.

The simulation model PAXSEM, which is used in this use case is a constructive data-farmable analytical agent-based combat simulation that has been developed on behalf of the German Armed forces with the focus of simulating tactical and technical scenarios on a single platform level for the analysis of operational scenarios. Its high resolution 3D visualization allows the simulation of technical-tactical scenarios and plots. Within these, military units are represented as agents in a granularity ranging from single entity to enforced company level (Huber and Kallfass 2015).

4.2 USA & Finland Use Case on Cyber Security

The cyber security use case for MSG-155 is titled: Optimal Placement of Sensors in a Computer Network. Representatives from the nations of FIN and USA are co-leading this use case with the objective to investigate how various network monitoring and detection systems should be deployed in order to effectively protect critical services from a wide range of malicious cyber activity under various conditions.

Under development is a model where a number of different network sensors can be deployed to monitor malicious activity. The goal is to be able to analyze different solutions and find optimal configurations with regard to some user-defined Measures of Effectiveness (MoEs) or desired end states. The model will support the decision-maker in allocating additional resources where they are needed the most. In the acquisition area, one possible result of this use case is to analyze the cost effectiveness of different solutions.

One question concerns defining relevant MoEs for different situations. This question is connected to situational awareness, e.g. do the sensors provide the network administrator with enough information to take timely actions? Sensors include intrusion detection systems (IDS), intrusion prevention systems (IPS), anti-virus software (at each workstation) and firewalls. A number of issues will be considered to include different sensors, network topologies, cyber threats (with different goals), conditions (e.g. peacetime, low intensity, high intensity), objectives (what needs to be protected may change over time), and time scales. The work will also consider sensor placement and situational awareness in general.

This use case will be based on the foundation provided by the aforementioned MSG-124 task group, in which a prototype simulation model, DACDAM (Data-farmable Actionable Cyber Defence Agent-based Model), was developed. DACDAM already contains many of the elements needed and is being adapted in MSG-155 using iterative and incremental model development.

4.3 Czech Use Case on Defence Acquisition

The Czech DFS Use Case is designed to analyze the critical activities in the acquisition cycle. The defense acquisition community uses Modeling and Simulation (M&S) to help define, cost, develop, test, produce, operate, and sustain defense systems and systems-of-systems across the entire acquisition life cycle.

M&S, in general, provides support to better capture operational needs in order to specify a future military system and provides guidance for decision makers to choose from different options to fulfill a future capability. In detail, simulation is an effective tool during the acquisition processes in order to save money and time only if the following is true (Hodicky et al. 2019): the simulation is verified and validated for experimental purposes, the simulation is data farmable, an effective DoE is employed to reduce time and to deliver rigorous results for decision making, the input data regarding platforms is validated by military expertise and the platforms are modeling in the simulation.

The main objective of the use case is to demonstrate the value, applicability and limitation of DFS in the process of comparing three ground platforms that are known candidates for acquisition in the context of operational requirements, cost of systems and maintenance.

The constructive simulation tool used in the use case is MASA SWORD (MASA 2019). The simulation tool enables creating or modifying entities, units, crowds and their behavior including logistics, human factors, information exchange, etc. It is empowered by artificial intelligence functions, which give entities behavior complying doctrines without the need to be controlled by humans.

The scenario is placed in the real operational area in the Czech territory with vignettes likely to happen. Therefore geography and initial military operational status with defined own and enemy forces is given and will remain constant during the experiment. Factors to be varied are composed of three types of ground platforms, three or four type formation of platforms to be acquired and weather. The noise factor is a variation of enemy ground platforms in the scenario. Outputs of the simulation are blue and red losses, operational state and resource consumption. Furthermore, MoEs of the layer above the simulation are captured in cost of platforms used and maintenance cost as the costs of components that were destroyed and need to be replaced.

4.4 Netherlands Use Case on Operational Planning Support

Supporting the military decision making process amongst other things involves supporting the planning process, in specific the Course Of Action selection. Data farming can be used in this selection process, because it gives the decision maker insight into the effectiveness of the many possible actions that can be taken.

This was shown in one of the use cases of NATO MSG-124 (Horne et al. 2018) which involved decision making at the operational (JHQ) level for kinetic operations. In the Netherlands, data farming has been studied for supporting the planning process at the operational level as well, but for comprehensive operations involving more elements than only kinetic. The simulation models that were used for non-kinetic operations typically involve a lot of uncertainty because these are about the modeling of human behavior. In (Veldhuis, G.A. and de Reus, N.M. and Keijser, B.M.J. 2019) a case study is described regarding how

Exploratory Modeling and Analysis can be used to explore plausible futures using system dynamics models in a large scenario analysis combined with an extensive sensitivity analysis taking into account uncertainty. The explored concept has been called Comprehensive Operations Support with Modeling & Simulation (COSMOS).

This concept is currently under development to be extended for the tactical (Brigade) level planning process involving (kinetic) combat operations. The foreseen model to be used will be the VR-Forces CGF simulation package in the aggregate level mode. This mode allows the modeling of Company and Battalion level and doesn't need the details that are required at the non-aggregate level. The simulation package will be extended to make it data farmable and usable in a planning support setting. The application will be developed in a Concept Development & Experimentation approach where, initially ad-hoc solutions will be used for the Data Farming steps. Data farming services will be part of the future roadmap of development of this concept as these will enhance the usability in an operational setting. The initial experiments will deliver requirements to further the development of these services.

5 Conclusion

The NATO MSG-155 was formed to develop Data Farming Services (DFS) to provide decision makers with data farming capability in form of a prototype and a roadmap. DFS is designed to make data farming available and usable to a wide area of NATO users and applications for more efficient and better decision-making. DFS is currently on TRL level 4 and was tested and presented at the CWIX exercises in 2018 and 2019. By using a microservice architecture and relying on container technology, distributed (national, international, mission, ...) deployment and DevOps are optimally supported. The simulation models of the use cases are being integrated and are already showing the general applicability of DFS, but also further development needs, especially in the fields of data analysis capability and service orientation of simulation models for integration in a generalizable HPC service. Until the final MSG-155 presentation at the 2020 CWIX exercise, the development focus will be on providing the use case owners analysis capabilities to effectively and efficiently use DFS for decision support.

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