2010

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Repository Citation

Tolk, Andreas, "Using Simulation Systems for Decision Support" (2010). *Computational Modeling and Simulation Engineering Faculty Publications*. 53.
https://digitalcommons.odu.edu/msve_fac_pubs/53

Original Publication Citation

Tolk, A. (2010). Using simulation systems for decision support. In B. Nag (Ed.), *Intelligent systems in operations: Methods, models, and applications in the supply chain* (pp. 253-272). Hershey, PA: Business Science Reference (an Imprint of IGI Global).

Chapter 13

Using Simulation Systems for Decision Support

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ABSTRACT

This chapter describes the use of simulation systems for decision support in support of real operations, which is the most challenging application domain in the discipline of modeling and simulation. To this end, the systems must be integrated as services into the operational infrastructure. To support discovery, selection, and composition of services, they need to be annotated regarding technical, syntactic, semantic, pragmatic, dynamic, and conceptual categories. The systems themselves must be complete and validated. The data must be obtainable, preferably via common protocols shared with the operational infrastructure. Agents and automated forces must produce situation adequate behavior. If these requirements for simulation systems and their annotations are fulfilled, decision support simulation can contribute significantly to the situational awareness up to cognitive levels of the decision maker.

INTRODUCTION

Modeling and simulation (M&S) systems are applied in various domains, such as

- supporting the analysis of alternatives,
- supporting the procurement of new systems by simulating them long before first prototypes are available,
- supporting the testing and evaluation of new equipment by providing the necessary stimuli for the system being tested,
- training of new personnel working with the system, and many more.

The topic of this chapter is one of the most challenging applications for simulation systems, namely the use of simulation systems for decision support in general, and particularly in direct support of operational processes. In other words, the

DOI: 10.4018/978-1-60566-774-4.ch014

decision maker is directly supported by M&S applications, helping with

- "what-if" analysis for alternatives,
- plausibility evaluation for assumptions of other party activities,
- consistency checks of plans for future operations,
- simulation of expected behavior based on the plan and trigger the real world observations for continuous comparison (are we still on track),
- manage uncertainty by simulating several runs faster than real time and display variances and connected risks,
- trend simulation to identify potentially interesting developments in the future based on current operational developments, and additional applications that support the meaningful interpretation of current data.

While current decision support systems are focused on data mining and data presentation, which is the display of snap-shot information and historical developments are captured in most cases in the form of static trend analyses and display curves (creating a common operating picture), simulation systems display the behavior of the observed system (creating a common executable model). This model can be used by the decision maker to manipulate the observed system "on the fly" and use it not only for analysis, but also to communicate the results very effectively to and with partners, customers, and supporters of his efforts. As stated by van Dam (1999) during his lecture at Stanford: *"If a picture is worth a 1000 words, a moving picture is worth a 1000 static ones, and a truly interactive, user-controlled dynamic picture is worth 1000 ones that you watch passively."* That makes simulation very interesting for managers and decision makers, encouraging the use of decision support simulation systems. Another aspect is that of complex systems: non-linearity and multiple connections. In order to understand and evaluate such system, traditional tools of operational research and mathematics have to be increasingly supported by the means of modeling and simulation. The same is true for decisions in complex environments, such as the battlefield of a military decision maker or the stock market for an international investment broker.

To this end, the simulation system must be integrated into operational systems as a decision support service. In order to be successful, not only the technical challenges of integration, discrete and other simulation technologies, into operational IT systems must be solved. It is also required that the simulation system fulfills additional operational and conceptual requirements as well. Simulation systems are more than software. Simulation systems are executable models, and models are purposeful abstractions of reality. In order to understand if a simulation system can be used for decision support, the concepts and assumptions derived to represent real world objects and effects in a simplified form must be understood. The conceptualization of the model's artifacts is as important as the implementation details of the simulation. As stated in Tolk (2006): *interoperability of systems requires composability of models!*

The author gained most of his experience in the military sector, integrating combat M&S into Command and Control (C2) systems. The development of the Levels of Conceptual Interoperability Model (LCIM) capturing the requirement for alignment on various levels to support decision support is a direct result of the experiences of integrating M&S services as web-services into service-oriented C2 systems (Tolk et al., 2006). It is directly related to the recommendations found in the North Atlantic Treaty Organization (NATO) Code of Best Practice for C2 Assessment (NATO, 2002) that was compiled by a group of international operational research experts in support of complex C2 analysis. It was also influenced by the recommendations of the National Research Council (2002, 2006), as using simulation for procurement decision or for analysis and using this analysis for decision support are closely related topics.

Furthermore, the growing discipline of agent-directed simulation (ADS) is very helpful in providing new insights and methods (Oren et al, 2000). ADS consists of three distinct yet related areas that can be grouped under two categories. First, *agent simulation* (or simulation for agents), that is simulation of systems that can be modeled by agents in engineering, human and social dynamics, military applications, and so on. Second, agents for simulation can be grouped under two sub-categories, namely *agent-based simulation*, which focuses on the use of agents for the generation of model behavior in a simulation study; and *agent-supported simulation*, which deals with the use of agents as a support facility to enable computer assistance by enhancing cognitive capabilities in problem specification and solving.

The vision of using simulation systems in general, and discrete event simulation systems in particular, for decision support is that a decision maker or manager can utilize an *orchestrated set of tools* to support his decision using reliable simulation systems implementing agreed concepts using the best currently available data. It does not matter if the decision support system is used in the finance market, where the stock market is simulated on a continuous basis, always being adjusted and calibrated by the real stock data, or if it used to support a traffic manager in guiding a convoy through a traffic jam during rush hour to the airport while constantly being updated by the recent traffic news. The technologies described here support the military commander in making decisions based on the best intelligence and surveillance data available by a sensor, as well as to the surgeon using a detailed model of the human body in preparation of a risky surgery. While the application fields are significantly different, the underlying engineering methods are not.

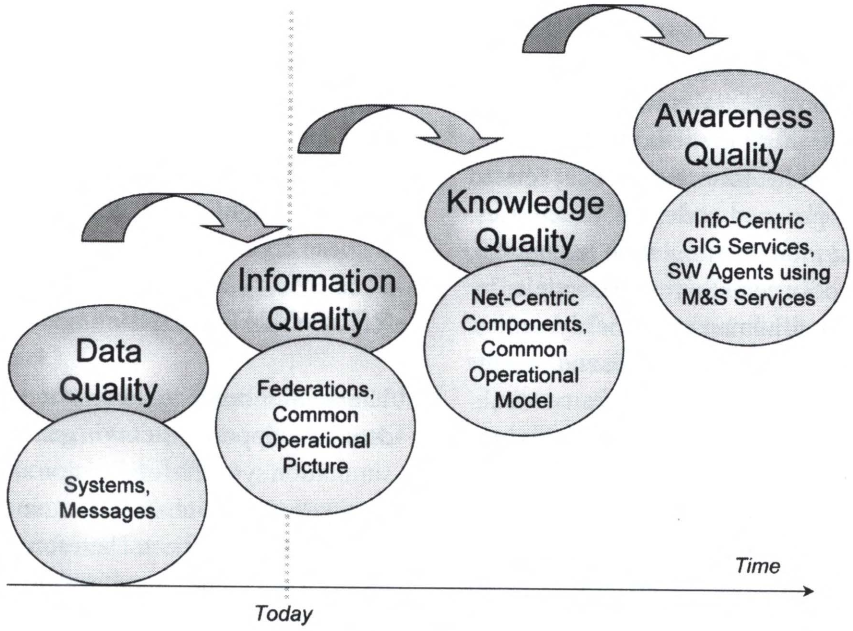
The section will start by presenting the relevant work, focusing on the special insights from the military domains before generalizing them for other applications. The main part is built by enumerating and motivating the requirements for simulation systems when being used for decision support, as identified by the National Science Foundation and related organizations. Finally, some examples are given and current developments are highlighted.

RELEVANT WORK

The area of related and relevant work regarding decision support systems in general and the use of simulation systems for decision support in general is huge. A book chapter can never suffice for a complete explanation. Therefore, the focus of this section is to highlight some of the most influencing works leading to formulation of the requirements for simulation systems. Additional information is contained in the section giving examples of decision support simulations in this chapter.

The need for using simulation systems in addition to traditional decision support systems is best derived from the work documented in the NATO Code of Best Practice for C2 Assessment (NATO, 2002). After having operated under more or less fixed strategic and doctrinal constraints for several decades, in which NATO and the Warsaw Pact faced each other in a perpetual lurking position, NATO suddenly faced a new operational environment for their decisions when the Warsaw Pact broke apart. While in the old order the enemy was well known – down to the equipment, strategy, and tactics – the new so-called “operations other than war” and “asymmetric operations” were characterized by uncertainty, incompleteness, and vagueness. At the same time, developments in information technology allowed the efficient distribution of computing power in the form of loosely coupled services. Consequently, the idea was to use an orchestrated set of operational tools – all implemented as services that can be loosely coupled in case of need – to support the decision

Figure 1. Command and Control Improvements



maker with analysis and evaluation means in an area defined by uncertainty, incompleteness, and vagueness regarding the available information. In order to measure improvement in this domain, the value chain of Net Centric Warfare was introduced; see among others (Alberts and Hayes, 2003):

- *Data* is factual information. The value chain starts with *Data* Quality describing the information within the underlying C2 systems.
- *Information* is data placed into context. *Information* Quality tracks the completeness, correctness, currency, consistency, and precision of the data items and information statements available.
- *Knowledge* is procedural application of information. *Knowledge* Quality deals with procedural knowledge and information embedded in the C2 system such as templates for adversary forces, assumptions about entities such as ranges and weapons, and doctrinal assumptions, often coded as rules.
- Finally, *Awareness* Quality measures the degree of using the information and knowledge embedded within the C2 system. Awareness is explicitly placed in the cognitive domain.

C2 quality is improved by an order of magnitude when a new level of quality is reached in this value chain. Figure 1 depicts this. C2 quality is improved by these developments as follows:

- Data quality is characterized by standalone developed systems exchanging data via text messages as used in most C2 systems. Having the same data available at the distributed locations was the first goal to reach.
- By the introduction of a common operational picture, data is put into context, which evolves the data into information. The collaborating systems using this common operational picture result in an order of magnitude of improvement of the Command and Control quality, as decision

makers share this common information. As stated before: a picture is worth a 1,000 words.
- The next step, which is enabled by service-oriented web-based infrastructures, is the use of simulation services for decision support. Simulation systems are the prototype for procedural knowledge, which is the basis for knowledge quality. Instead of just having a picture, an executable simulation system can be used.
- Finally, using intelligent software agents to continually observe the battle sphere, apply simulations to analyze what is going on, to monitor the execution of a plan, and to do all the tasks necessary to make the decision maker aware of what is going on, C2 systems can even support situational awareness, the level in the value chain traditionally limited to pure cognitive methods.

Traditional decision support systems enable information quality, but they need the agile component of simulation in order to support knowledge quality as well. In other words, numerical insight into the behavior of complex systems as provided by simulations is needed in order to understand them.

In order to support the integration of decision support simulations, it is necessary to provide them as services. However, this task is not limited to technical challenges of providing a web service or a grid service, but the documentation of the service and the provided functionality is essential to enable the *discovery*, *selection*, and *composition* of this service in support of an operational need. The papers (Tosic et al., 2001) and (Srivastava and Koehler, 2003) summarize the state of the art of service composition. Pullen et al. (2005) show the applicability for M&S services. Additionally, what is needed are annotations. Annotations give meaning to services by changing them into semantic web services. The reader is referred to (Agarwal et al., 2005) and (Alesso and Smith, 2005) for more information on this topic.

In order to identify what information is needed to annotate operational M&S services, the Levels of Conceptual Interoperability Model (LCIM) was developed. The closest application to the topic of this book chapter is documented by Tolk et al. (2006). The LCIM exposes layers of abstractions that are often hidden: the conceptualization layer leading to the model, the implementation layer leading to the simulation, and technical questions of the underlying network. Each layer is tightly connected with different aspects of interoperation. We are following the recommendation given by Page and colleagues (Page et al., 2004), who suggested defining composability as the realm of the model and interoperability as the realm of the software implementation of the model. Included in the technical challenge of integrating networks and protocols, the following three categories for annotations emerge:

- *Integratability* contends with the physical/technical realms of connections between systems, which include hardware and firmware, protocols, networks, etc.
- *Interoperability* contends with the software and implementation details of interoperations; this includes exchange of data elements via interfaces, the use of middleware, mapping to common information exchange models, etc.
- *Composability* contends with the alignment of issues on the modeling level. The underlying models are purposeful abstractions of reality used for the conceptualization being implemented by the resulting systems.

The LCIM increases the resolution by adding additional sub-layers of interoperation. The layer of integratability is represented by the *technical layer*, which ensures that bits and bytes can be exchanged and correctly interpreted. The *syntactic* *layer* allows mapping all protocols to a common structure. The *semantic layer* defines the meaning of information exchange elements. Syntax and semantics belong to the interoperability realm. In the *pragmatic layer*, the information exchange elements are grouped into business objects with a common context. Annotations on the *dynamic layer* capture the processes invoked and the system state changes taking place when business objects are exchanged between systems. Finally, the relevant constraints and assumptions are captured in the *conceptual layer*, which completes the composability realm.

The LCIM supports a structured way to annotate M&S services. Dobrev et al. (2007) show how this model can be used to support interoperation in general applications. Zeigler and Hammonds (2007) use it to compare it with their ideas on using ontological means in support of interoperation. It was furthermore applied for the Department of Defense, the Department for Homeland Security, The Department of Energy, and NATO. These annotations are necessary requirements to allow *discovery*, *selection*, and *composition* of services.

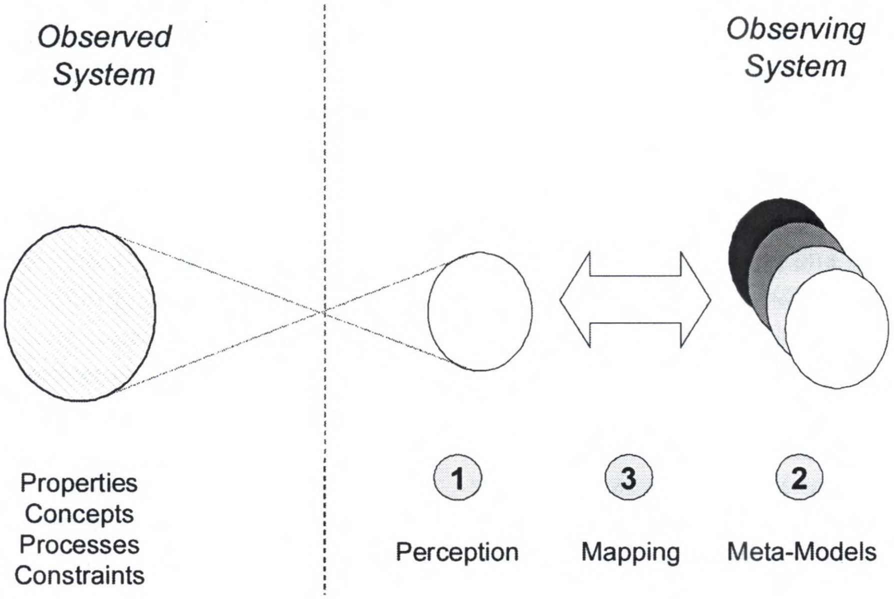
These annotations should be interpreted as a machine understandable version of the underlying conceptual model of the M&S service. Robinson (2008) defines the conceptual model as *"a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions, and simplifications of the model."* He furthermore points out that there is a significant need to agree on how to do develop conceptual models and capture information formally. What is needed in support of composable services is therefore to capture *objectives, inputs, outputs, content, assumptions, and simplifications* of the model in the *technical, syntactical, semantic, pragmatic, dynamic, and conceptual* category. The discipline of model-based data engineering (Tolk and Diallo, 2008) is a first step into this direction.

To understand why these annotations are so important, it is necessary to understand how machines gain understanding. Zeigler (1986) introduced a model for understanding a system within another observing system. Figure 2 shows the three premises that need to be supported by the annotations describing the M&S services. The system – or the M&S service – is herein described by its *properties* that are grouped into propertied *concepts* (the basic simulated entities and attributes), the *processes* (the behavior of simulated entities and how their attributes change), and *constraints* (assumptions constraining the values of the attributes and the behavior of the system).

- The first premise is that the observing system has a *perception* of the system to be understood. This means that the properties and processes must be observable and perceivable by the observing system. The properties used for the perception should not significantly differ in scope and resolution from the properties exposed by the system under observation.
- The second premise is that the observing system needs to have a *meta-model* of the observed system. The meta-model is a description of properties, processes, and constraints of the expected behavior of the observed system. Without such a model of the system, understanding is not possible.
- The third premise is the *mapping* between observations resulting in the perception and meta-models explaining the observed properties, processes, and constraints.

In other words, machine understanding is the selection process of the appropriate meta-model to explain the observed properties, processes, and constraints. This corresponds to the selection of appropriate M&S services to support a decision. The properties and propertied concepts are described by syntax, semantic, and pragmatic annotations, processes by dynamic annotations, and

Figure 2. Premises for System's Understanding



constraints by conceptual annotations capturing objectives, inputs, outputs, content, assumptions, and simplifications in addition to implementation details and technical specifications. No matter if these annotations are used to discover, select, and orchestrate M&S functionality as operational services or if they are used by intelligent agents to communicate their use, they are necessary for every application beyond the traditional system developments that are often intentionally not reused in their requirements. This section can therefore also serve as a guideline for what is needed to annotate legacy systems that shall be integrated into a net-centric and service-oriented environment to contribute to a system of systems.

Table 1 can be used as a checklist to ensure that all information is captured or obtainable for a candidate simulation system for decision support.

All this related work sets the frame for describing M&S services to support their discovery and orchestration for integration as an orchestrated set of tools into the operational infrastructure used by the decision maker. The following section will describe the requirements for the simulation systems themselves in more detail.

Table 1. Checklist points for decision support simulation annotations

Annotation Categories	Levels of Interoperation	System Characteristics	Conceptual Model Characteristics
• Integratability	• Technical	• Properties	• Objectives
• Interoperability	• Syntactic	• Concepts	• Inputs
• Composability	• Semantic	• Processes	• Outputs
	• Pragmatic	• Constraints	• Content
	• Dynamic		• Assumptions
	• Conceptual		• Simplifications

REQUIREMENTS FOR SIMULATION SYSTEMS

This section will explain the necessary requirements for simulation systems when they are to be used as decision support systems. These requirements may not be sufficient for all application domains, so additional application domain expertise is needed for informed selection. While the focus in the last section was annotation, the focus here will be the content and completeness of the simulation system.

This section will start with general requirements for all simulation systems to be applied to decision support and will finish with additional requirements in the case a federation of simulation systems is to be applied, which is the more likely scenario. As the NATO Code of Best Practice (NATO, 2002) points out: it is highly unlikely that one tool or simulation system will be able to deal with all questions describing the sponsor's problem; the use of an orchestrated set of tools should be the rule.

This section extends and generalizes the findings documented in Tolk (1999) and referenced in NRC (2002). While the principle results are still valid, the development in the recent years, in particular in the domain of agent-based models in support of behavior modeling and of computer generated forces contributed significantly to solutions in challenging areas that need to be incorporated. The section on current developments in this chapter will focus on these developments in more detail.

Modeling of Relevant System Characteristics

Models are purposeful abstractions from reality. This means that they simplify some things, leave others out, use assumptions, etc. When using a simulation system as a decision support simulation, it is crucial that all relevant system characteristics are captured. This includes all aspects of the system: modeled entities (properties and concepts), modeled behavior and interactions (processes), and modeled constraints. The reason is trivial: if something important is not part of the model, it cannot be considered for the analysis, nor can it be part of the recommended solution.

The artifacts used for documentation of the system (and annotation) during the conceptualization phase should capture the necessary information. As defined by Robinson (2008) in his overview work on conceptual modeling, the characteristics of a conceptual model are *objectives, inputs, outputs, content, assumptions, and simplifications.* A practical way to accomplish this task has been captured in the contributions of Brade (2000), which will be addressed in the section on verification and validation.

Example: A simulation system shall be used to support the decision of where to install additional gas stations in a town. It models the cars used in this town, the behavior of the car drivers, and the gas stations already in use within this town. The idea is to use simulation based optimization to find out how many new gas stations should be built and where.

In order to be able to use the simulation system, additional system characteristics may have to be captured, such as

- Under which circumstances are drivers willing to go to neighboring towns to buy gas to fill up their cars? (Assumption that drivers in the town will use gas stations in this town)
- How will the competition react? Will they build new stations? Will they close down stations? (Assumption that only the company conducting the study actively changes the gas supply infrastructure)
- Are there additional influences that are relevant, such as the overall driving behavior based on current average oil prices? (Assumption that decision rules used by simulated entities follow a closed world assumption)

Even if this is not implemented, the simulation can still be used in support of analysis, but the expert must be very well aware of what the simulation systems simulates and how. In other words, an awareness of the assumptions and constraints affecting the validity of the simulation results is necessary.

In summary, it is essential that the simulation system can support the decision to be made by ensuring that all concepts, properties, processes, and constraints identified to be relevant in the problem specification process are implemented. The NATO Code of Best Practice (NATO, 2002) gives guidance for the problem specification process. The conceptual models used for the simulation development document the respective characteristics of the simulation.

Ability to Obtain All Relevant Data

Closely related is the second premise that must be fulfilled: the relevant data needed for the simulation system initialization and execution must be obtainable. Even if a simulation system is complete in describing all concepts, properties, processes, and constraints, the model can be practically useless if the necessary data to drive these models cannot be provided. The quality of the solution is driven by the quality of the model and the quality of the data.

The NATO Code of Best Practice (NATO, 2002) gives guidance with respect to obtaining data and ensuring the necessary quality of data. Among the identified factors for good data are the reliability of sources and the accuracy of data. Additional factors are the costs to obtain data, how well the data is documented, if and how the data have been modified, etc.

Another aspect that increases in importance in the area of net centricity and service- oriented architectures is the alignment of protocols for data storage and exchange in operational systems and decision support simulation systems. The optimal case is that decision support simulation systems and the embedded operational system use the same data representation. If this is not the case, data mediation may be a possible solution to mapping the existent operationally available data to the required initialization and input data. However, it must be pointed out that data mediation requires the mapping of data is complete, unambiguous, and precise. To this extent, Model-based Data Engineering was developed and successfully applied (Tolk and Diallo, 2008).

An aspect unique to M&S services is the need that modeled data are conceptually connected to operationally available data. As models are abstractions of reality, some data may be "academic" abstractions that theoretically are constructible, but are difficult to observe or to obtain. In particular statistical measure of higher order, such as using a negative polynomial bivariate intensity probability distribution function to model the movement of entities as a fluid, often make perfectly sense when developing the model, but may be very hard to feed with real world data.

Example: A simulation system shall be used to support a decision maker with evacuation decisions during a catastrophic event (Muhdi, 2006). Most evaluation models currently used are flow-based models. The data available in a real emergency, however, is discrete, describing exit obstacles, individuals, and other data that need to be converted into this model (and potentially mapped back in support of creating elements of a plan that needs to be shared using the operational infrastructure).

In summary, it is essential that data needed by the model can be obtained and mediated. The data will be used to initialize the simulation systems and as input data during execution.

Validation and Verification of Model, Simulation, and Data

Validation and verification are processes to determine the simulation's credibility. They deal with answering questions such as "Does the simulation system satisfy its intended use? Can the simulation system be used to evaluate specific questions? How close does the simulation system come to reality?" In other words, validation and verification are the processes of determining if a simulation is correct and usable to solve a given problem.

The US Department of Defense defined validation and verification for military use in their M&S instruction (DoD, 1996). Validation is the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses. Verification is the process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specifications. In other words, validation determines if the right thing is coded while verification determines if the thing is coded right. Validation determines the behavioral and representational accuracy; verification determines the accuracy of transformation processes.

There are many papers available dealing with the necessity to validate and verify models and simulation before using them for decision making. The interested reader is pointed to the overview of methods and tools provided by Balci (1998) and several specific papers by Sargent (1999, 2000, 2007). The work of Brade (2000) making practical recommendations regarding artifacts was already mentioned in a previous section.

It seems to be obvious that simulation systems designed to be used as decision support simulation systems must be validated and verified. This is true for the models, the simulations, and the data. If this is not the case, the results will not be credible and reliable and as such not applicable to support decisions.

It is not trivial but is at least possible to accomplish verification and validation for physical processes and models. However, the simulated entities and processes are not limited to such physical processes. Cognitive processes and decision models need to be modeled as well. Moya and Weisel (2008) point out the resulting challenges.

Example: To show the necessity of verification and validation, two examples of simulation failures in operational environments are given that are directly applicable to decision support simulation systems as well.

Simulation in Testing: During Operation Iraqi Freedom, Patriot missiles shot down two allied aircraft & targeted another. On March 23, 2003, the pilot and co-pilot aboard a British Tornado GR4 aircraft that was shot down by a U.S. Patriot missile died. On April 2, 2003, another Patriot missile downed a U.S. Navy F/A-18C Hornet which was flying a mission over Central Iraq. The evaluation report identified one of the causes of these failures stemmed from using an invalid simulation to stimulate the Patriot's fire control system during its testing.

Simulation in Engineering: Another catastrophic event in spring 2003 was the Columbia disaster. The space shuttle had been damaged by foam debris during takeoff. NASA engineers decided, based on their professional judgment, that the damage would not endanger the shuttle when returning to earth. They were wrong and the shuttle broke apart when entering the atmosphere, killing the crew and throwing the shuttle program significantly back. What is of interest for the readers of this chapter is that the simulation available to the experts predicted the disaster, but the results were not deemed reliable and credible by the experts. Obviously they were mistaken.

In summary, it is necessary to only make use of validated and verified models and data for decision support simulation systems. It is essential that the decision maker is supported with reliable and credible information.

Creating Situation Adequate Behavior

One of the most challenging premises is to fulfill the requirement for situation adequate behavior.

This premise addresses the behavior of simulated entities, which is represented by the processes of the system characteristics. The premise has a very practical side and a resulting challenge. Many simulation systems used in other application domains, in particular for training and testing, also require that the simulated entities behave as they would in the real world. If this behavior is connected with human decision making, it is quite often humans in the loop making the decision.

A typical military computer assisted exercise comprises not only the training audience, but also soldiers representing the subordinates, partners, and superior commands, as well as the opposing forces. To ensure that soldiers "train as they fight," the units are commanded by military experts. The simulation computes the movement, the attrition, the reconnaissance, and other processes that are based on physical aspects. It is more the rule than the exception that more soldiers are needed to support the simulation system than are trained in an event. The use of agents to generate the orders is mandatory for decision support; otherwise the manpower would increase to the point of no longer being practical or feasible.

Example: If training on the brigade level is conducted, approximately 800 orders have to be created in order to drive a simulation model. Taking into account that not only the orders for the brigade are needed, but also for the neighbored units and – last but not least – the orders for the enemy increases this number by the factor of four to six resulting in the number of 3,000 to 5,000 orders to be created for just one alternative. This is accomplished by a group of 500 to 600 soldiers. As this many personnel can never be supported by a brigade headquarter that wants to use the simulation for decision support, the majority of these orders must be generated by means of behavioral representation in modeling and simulation.

In summary, intelligent software agents representing human behavior in simulation systems must ensure that the simulated entities behave correctly. Scripted and rule driven approaches are not sufficient. The conference on behavioral representation in modeling and simulation (BRIMS) is a good source of current research and proposed solutions. Yilmaz et al. (2006) are giving a good overview of such use of agents in serious games as well as in simulation systems.

Additional Issues When Using Federations of Simulation Systems

The first four premises must be fulfilled by every simulation system that will be used for decision support. However, as pointed out several times in this chapter, the application of an orchestrated set of tools in order to evaluate all relevant aspects of a model is the rule. If several simulation systems need to be used to provide the required functionality, some concerns need to be addressed that are unique to federations of simulation systems.

The main challenge is to orchestrate simulations not only regarding their execution, but also to conceptually align them to ensure that the federation delivers a consistent view to the decision maker fulfilling all requirements that have been captured. The LCIM can support this challenge. A simulation federation in itself is a complex system of systems. Current simulation interoperability standards are not sufficient to support the necessary consistency. Besides several publications by the author in this domain, this view is shared by many other experts in the field, such as Zeigler and Hammonds (2007) show in their survey. Yilmaz (2007) proposed the use of meta-level ontology relations to measure conceptual alignment.

The objective of these alignments is to harmonize the three elements essential for simulation result consistency, which are the concepts underlying the simulated entities (resolution and structure), the internal decision logic used to generate the behavior of the simulated entities, and the external measure of performance used to evaluate the accomplishment. If this is not the case, the results will be counter-intuitive at best, and inconsistent and wrong at worst. As shown in Muguira and Tolk (2006), even if all federates are validated and correct, the federation may still expose structural variances, making the result unusable for decision support.

Example: The triangle of concepts, internal decision logic, and external evaluation logic must be harmonized regarding all three aspects, or structural variance can result in non-credible results.

- *Concepts and decision logic:* Simulation *A* represents a fish swarm as a cubicle; simulation *B* uses a statistical distribution within a bowl. If the decision logic of simulation *A* is used to support a decision in simulation *B*, the decision is based on the wrong assumptions and is likely to be wrong.
- *Concepts and evaluation logic:* If the measure of merit requires inputs not exposed by the federation, or if the structure and resolution are significantly different in the federated simulation systems, the evaluation is wrong.
- *Decision and evaluation logic:* One of the most observed reasons for strange behavior in the results of federations is that the measure of merit used for the evaluation and the measure of merit used to optimize the decisions internally are not harmonized. If the decision logic targets to maximize the amount of fish captured in each event and the evaluation logic checks if the overall regeneration of fish is ensured as well, it is likely that structural variances will occur.

In summary, it must be ensured that the simulation systems are not only coupled and technically correct (based on currently available simulation interoperability standards), but that they are aligned regarding concepts, internal decision logic, and external evaluation logic as well.

Summarizing all five premises dealt with in this chapter, the following enumeration lists the questions that need to be answered to ensure that the requirements are fulfilled:

- Are all concepts having a role in solving the problem identified and simulated in the simulation?
- Are the properties used to model the propertied concepts in the necessary resolution and the necessary structure?
- Are all identified processes (entity behavior and overarching processes) modeled?
- Are the assumptions and constraints identified for the operational challenge to be decided upon reflected appropriately by the simulation system?
- Can operational data and author authoritative data sources provide all data needed for the initialization of the simulation system?
- Can operational data provide all data needed as input data during the execution of the simulation system?
- Do the operational infrastructure and the decision support simulation system share the same data model, or – if this is not the case – can model-based data engineering be applied to derive the necessary mediation functions? Are possible semantic losses resulting from the mapping acceptable?
- Is the data obtainable in the structure and resolution (and accuracy) needed, or – if this is not the case – can the data be transformed into the required format?
- Are all potential M&S services and simulation systems validated and verified?
- Are the data validated and verified?
- Is the behavior of all simulated entities situation adequate?
- In case of personnel intensive simulation systems, can the human component be replaced with intelligent software agents to produce the required decisions (or can it be ensured that always enough persons are available to support the application)?

- Are the represented concepts (simulated entities) sufficient to produce the properties needed for the measures of merit of the decision logic and the evaluation logic?
- Are the measures of merit used for the internal decision logic aligned with the external evaluation logic?

This list builds the core of questions the developer of decision support simulation systems must be able to answer positively. Additional application specific questions are likely and need to be captured for respective development or integration projects as requirements.

EXAMPLES OF DECISION SUPPORT SIMULATION APPLICATIONS

The previous sections dealt with the necessary annotation for M&S services and the requirements for simulation systems when being used for decision support. This section gives some selected references to examples of using simulation for decision support. While these examples are neither complete nor exclusive, they do show that decision support simulation is already applied in various fields.

Kvaale (1988) describes the use of simulation systems in support of design decisions for a new generation of fast patrol boats. This application is the traditional use of simulation in support of the procurement process: alternatives are simulated and compared using a set of agreed to measures of merit. Although this application is not driving the support using operational data directly obtained from operational systems, it is one of the first journal papers describing the use of simulation systems for decision support.

Everett (2002) describes the design of a simulation model to provide decision support for the scheduling of patients waiting for elective surgery in the public hospital system. The simulation model presented in this work can be used as an operational tool to match hospital availability with patient need. To this end, patients nominated for surgery by doctors are categorized by urgency and type of operation. The model is then used to simulate necessary procedures, available resources, resulting waiting time, and other decision parameters that are displayed for further evaluation. Therefore, the model can also be used to report upon the performance of the system and as a planning tool to compare the effectiveness of alternative policies in this multi-criteria decision health-care environment.

Truong et al. (2005) present another application domain for decision supporting use of simulation: fisheries policy and management decisions in support of optimizing a harvesting plan for the fishing industry. As in many application areas, the behavior of fish and the effects of harvesting are not fully understood, but can be captured to sufficient detail to build a simulation that reflects the known facts in sufficient detail. This enables simulation-based optimization using the simulation to obtain quasi-objective function values of possible alternatives, in the example particular fishing schedules. This idea is applicable in similar environments with uncertain and imprecise data that exposes some trends that can be captured in simulations.

Power and Sharda (2007) summarized related ideas recently in their work on model-driven decision support systems. Following their definition, model-driven decision support systems use algebraic, decision analytic, financial, simulation, and optimization models to provide decision support. Like this chapter, they use optimization models, decision theory, and other means of operational analysis and research as an orchestrated set of tools in which simulation is embedded in an aligned way.

Decision support systems, as well as the use of simulation systems, have a relatively long history in the military domain. An example is given by Pohl et al. (1999) who present the results of a project sponsored by the Defense Advance Project

Research Agency (DARPA). The Integrated Marine Multi-Agent Command and Control System (IMMACCS) is a multi-agent, distributed system. It is designed to provide a common tactical picture as discussed earlier in this chapter and an early adapter of the agent-based paradigm for decision support. Between 1999 and 2004, the Office for Naval Research (ONR) sponsored a series of workshops on decision support systems in the United States. Furthermore, Wilton (2001) presented an overview of decision support simulation ideas integrated with C2 devices for the training of soldiers.

Management related military applications are regularly discussed at the annual International Command and Control Research and Technology Symposia (ICCRTS), which features a special track on decision support. The work presented here is often focused on cognitive aspects of sense-making and aims more at increasing the shared situational awareness than on a common technical framework. Many principles are not limited to the military domain but are applicable to all forms of agile organizations without fixed external structures. An example is the analysis of requirements of cognitive analysis to support C2 decision support system design by Potter et al. (2006).

The books edited by Tonfoni and Jain (2002), Phillips-Wren and Jain (2005), and Phillips-Wren et al. (2008) are valuable references for examples of using means of artificial intelligence and intelligent software agents in support of decision making using simulation systems. The use of ontological means to ensure composability of models and interoperability of simulations is the topic of several additional publications.

CURRENT DEVELOPMENTS

As with the previous section of this chapter, it is extremely difficult to decide which of the current developments should be highlighted, as every development in the discipline of M&S improves the usability of resulting systems for decision support. The focus of contributions in this section is therefore relatively small. As before, the idea is not to be restrictive but to give examples.

The military community used the Simulation Interoperability Workshops to work on the development of a technical reference model (TRM) for coupling of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) with M&S systems (Griffin et al., 2002). Figure 3 shows a generalization of the model, as already recommended by Tolk et al. (2008).

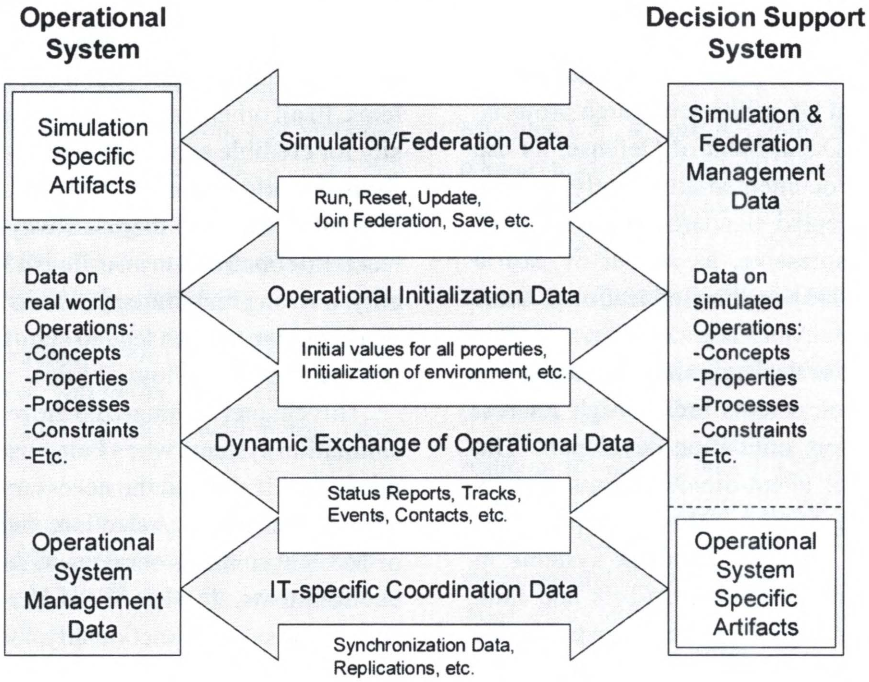
The model focuses on data exchange requirements and categories. The data is categorized as:

- simulation specific management data unique to the decision support simulation system,
- operational initialization data describing the data needed for initialization of both systems describing concepts, properties, processes, and constraints,
- dynamic exchange of operational data describing information that captures the input and output data of both worlds during execution, and
- operational system specific management data unique to the IT infrastructure used by the decision maker.

Unfortunately, the standardization work on the TRM was never completed, so that besides the final report of the study group and several contributing workshop papers no standard in support of embedding decision support simulations into operational IT infrastructures exists. Work in this domain would be very helpful to the M&S community.

As pointed out before, the US Department of Defense is working on a series of strategies and standards to enable net-centric operations. Another

Figure 3. Generalization of the C4ISR Technical Reference Model



standard developed under the roof of the Simulation Interoperability Standardization Organization (SISO), the Base Object Model (BOM) Standard, is currently being evaluated to be used for the registration of M&S services. The standard is defined in two documents, the "Base Object Model (BOM) Template Standard" and the "Guide for Base Object Model (BOM) Use and Implementation" (SISO, 2006). The first document provides the essential details regarding the makeup and ontology of a BOM, the companion document gives examples and best practice guidelines for using and implementing the new standard. In summary, the BOM standard provides a standard to capture the artifacts of a conceptual model. Furthermore, it can be used to design new simulation systems as well as integrating legacy simulations. The conceptual model elements defined by the BOM standard contain descriptions of concepts, properties, and processes. The description is not only static, but the interplay is captured in the form of state machines as well. The BOM template is divided in five categories and reuses successful ideas of the current simulation interoperability standard "High Level Architecture" (IEEE 1516) and supports:

- Model Identification by associating important metadata with the BOM. Examples include the author of the BOM, the responsible organization, security constraints, etc.
- Conceptual Model Definition by describing patterns of interplay, state machines representing the aspects of the conceptual model, entity types, and event types.
- Modeling Mapping by defining what simulated entities and processes represent what elements of the conceptual model.
- Object Model Definition by recording the necessary implementation details (objects, interactions, attributes, parameter, and data types as defined by IEEE 1516)

- Additional Supporting Tables in the form of notes and lexicon definitions.

The BOM standard has successfully been applied in several US military research projects. Outside the US Department of Defense, its use has not yet been documented sufficiently to speak of a broadly accepted standard. The potentials, however, are impressive, as shown by Searle and Brennan (2006) in their educational notes for NATO.

As mentioned at the beginning of this section, many other developments are of high interest to decision support simulation developers. The increasing use of agent-directed simulation is one aspect. The human behavior representation in M&S is another. Complex systems in knowledge-based environments (Tolk and Jain, 2008) are another domain of interest, in particular how to cope with uncertainties or how to apply ontological means in support of complex system interoperation. Enumerating all interesting fields lies beyond the scope of this chapter.

In summary, the developer of decision support simulation systems or the engineer tasked with the integration of simulation systems for operational decision support must follow developments in all levels of interoperation: from technical innovations enabling better connectivity (such as optical memories or satellite based internet communications) via improvement in the interoperability domain (such as new developments in the domain of semantic web services) to conceptual questions (including standardizing artifacts in machine understandable form). As systems developed for this domain need to be highly reliable and credible, the engineer needs not only to be highly technically competent, but also needs to follow the code of ethics of the profession, as wealth – and sometimes even survival – will depend on the work and efforts produced.

SUMMARY

Decision support of operational processes is the most challenging application for simulation systems. In all other application domains, the necessity for credible and reliable results is lower than for real world operation decision support. While in all other domains there is always the chance to react and counteract to insufficient M&S functionality, a wrong recommendation in support of real world operations can lead to significant financial trouble or even the loss of lives.

This chapter summarized the requirements for simulation systems when being used for such applications. It showed the necessary annotation to allow the discovery, selection, and orchestration of M&S systems as services in service-oriented environments. It also listed the premises for simulation system functionality, focusing on completeness of concepts, properties, processes, and constraints, obtainability of data, validation and verification, and the use of means of knowledge management. The current developments continue to close gaps so that the use of simulation in the context of operational decision support will soon enable support to even the cognitive levels of group decision making and common situational awareness.

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KEY TERMS AND DEFINITIONS

Decision Support Systems: Are information systems supporting operational (business and organizational) decision-making activities of a human decision maker. The DSS shall help decision makers to compile useful information from raw data and documents that are distributed in a potentially heterogeneous IT infrastructure, personal or educational knowledge that can be static or procedural, and business models and strategies to identify and solve problems and make decisions.

Decision Support Simulation Systems: Are simulation systems supporting operational (business and organizational) decision-making activities of a human decision maker by means of modeling and simulation. They use decision support system means to obtain, display and evaluate operationally relevant data in agile contexts by executing models using operational data exploiting the full potential of M&S and producing numerical insight into the behavior of complex systems.

Integratability: Contends with the physical/technical realms of connections between systems, which include hardware and firmware, protocols, networks, etc. If two systems can exchange physical data with each other in a way that the target system receives and decoded the submitted data from the sending system the two systems are *integrated.*

Interoperability: Contends with the software and implementation details of interoperations; this includes exchange of data elements via interfaces, the use of middleware, and mapping to common information exchange models. If two systems are integrated and the receiving system can not only decode but understand the data in a way that is meaningful to the receiving system, the systems are *interoperable*.

Composability: Contends with the alignment of issues on the modeling level. The underlying models are purposeful abstractions of reality used for the conceptualization being implemented by the resulting systems. If two systems are interoperable and share assumptions and constraints in a way that the axioms of the receiving system are not violated by the sending system, the systems are *composable*.

Conceptual Modeling: Is the process of defining a non-software specific formal specification of a conceptualization building the basis for the implementation of a simulation system (or another model-based implementation) describing the objectives, inputs, outputs, content, assumptions, and simplifications of the model. The conceptual model conceptual model is a bridge between the real world observations and the high-level implementation artifacts.

Validation and Verification: Are processes to determine the simulation credibility. *Validation* is the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses. Validation determines the behavioral and representational accuracy. *Verification* is the process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specifications. Verification determines the accuracy of transformation processes.

Model-Based Data Engineering: Is the process of applying documented and repeatable engineering methods for *data administration* – i.e. managing the information exchange needs including source, format, context of validity, fidelity, and credibility –, *data management* – i.e. planning, organizing and managing of data, including defining and standardizing the meaning of data and of their relations -, *data alignment* – i.e. ensuring that data to be exchanged exist in all participating systems, focusing a data provider /data consumer relations -, and *data transformation* – i.e. the technical process of mapping different representations of the same data elements to each other – supported by a common reference model.

This work was previously published in Handbook of Research on Discrete Event Simulation Environments: Technologies and Applications edited by E. Abu-Taieh & A. El Sheikh, pp. 317-336, copyright 2010 by Information Science Reference (an imprint of IGI Global).