Chapter 2
Applications

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2.1 Introduction

Modeling and simulation provide a powerful means to understand problems, gain insights into key trade-offs, and inform decisions at all echelons of the domain. Applications of modeling and simulation should be driven by the nature of the problems of interest and the appropriateness of the model or simulation for the problem and domain in which this approach is being considered or applied.

This chapter begins by reviewing five important areas to understand the nature of the problems addressed rather than the approaches to modeling and simulation employed in these instances. This leads to consideration of crosscutting challenges associated with these examples. This chapter concludes with a discussion of specific modeling and simulation challenges identified.

2.2 Five Examples

Five exemplar application areas where modeling and simulation can provide the means to understand problems, gain insights into key trade-offs, and inform decisions include the following:

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- Urban infrastructure
- Health care delivery
- Automated vehicle manufacturing
- Deep space missions
- Acquisitions enterprise

Table 2.1 compares these five examples in terms of the nature of the problem addressed rather than the specific modeling and simulation employed. The five examples are contrasted in terms of top-down forces, bottom-up forces, human phenomena, and the difficulty of the problem.

2.2.1 Top-Down Forces

The top-down forces affecting urban infrastructure include the consequences of climate change, forced migration, and macroeconomic trends. In contrast, health care delivery is being affected by increased demand for services from an aging population, increased prevalence of chronic disease, and changing payment models. Many of these forces are exogenous to the urban and health care enterprises.

Automated vehicle manufacturing is being affected by demands from the Department of Defense for rapid design, development, manufacturing, deployment, and sustainment. This occurs in the broader context of the acquisitions enterprise, which is being affected by congressional and military services' imperatives, mandates, regulations, and budget pressures. These forces are endogenous to the defense enterprise, but exogenous to particular programs.

The top-down forces affecting deep space missions include mission requirements for robustness and flexibility, as well as the magnitude and timing of budgets. These requirements are seen as exogenous to the extent that they are taken as nonnegotiable. There could be, of course, trade-offs between requirements and budgets.

2.2.2 Bottom-Up Forces

Bottom-up forces tend to come from within the enterprise and hence can be seen as endogenous to the system. Such forces are often more amenable to prediction, control, and perhaps design. Thus, they are more likely to be explicitly represented in models and simulations rather than seen as being external to the phenomena being modeled.

The bottom-up forces of increased demands on infrastructure and generation of waste, as well as dealing with waste, affect urban infrastructure. Health care delivery must deal with patients' disease incidence, progression, and preferences, as well as providers' investment decisions. Deep space missions are affected by environmental surprises, technological failures, and public support for space

Table 2.1 Comparison of five applications examples

	Urban infrastructure	Health care delivery	Automated vehicle manufacturing	Deep space missions	Acquisitions enterprise
Top-down forces	Consequences of climate change, forced migration, and macroeconomic trends	Increased demand for services, increased prevalence of chronic disease, and changing payment models	Demands for rapid design, development, manufacturing, deployment, and sustainment	Mission requirements for robustness and flexibility, magnitude, and timing of budgets	Congressional and services' imperatives, mandates, and regulations; budget pressures
Bottom-up forces	Increased demands on infrastructure and generation of waste, dealing with waste	Patients' disease incidence, progression, and preferences; providers investment decisions	State of technology for design, development, and manufacturing; availability of tools, components, and materials	Environmental surprises, technological failures, and public support for space exploration	Asymmetric threats, changing missions, globalization of technology, and declining defense industrial base
Human phenomena	Social and political forces, individual preferences, and decisions regarding consumption and use of infrastructure	Disease dynamics, patient choice, andclinician decisions	Design and development decision making, supervisory control of manufacturing, and operation and maintenance of deployed systems	Design and development decision making, ground operations decision making	Decision making at all levels; sustainment of deployed systems
Difficulty of problem	Fragmented decision making across city, state, and federal agencies; aging infrastructure	Uncertainty of demands for various services, science and technology advances, and stability of payment models	Required pace of rapid automation exceeds state of the art, level of integration of all needed ingredients very demanding	Harsh environment, extreme distances, communications delays of minutes to hours, and infeasibility of maintenance and repair	Plethora of models, methods, and tools; fragmented and siloed decision making

exploration. These three examples concern the magnitudes and uncertainties associated with demands on those systems.

Automated vehicle manufacturing is affected by the state of technology for design, development, and manufacturing, as well as the availability of tools, components, and materials. Acquisitions enterprises must address asymmetric threats, changing missions, globalization of technology and, in some areas, the declining defense industrial base. These two examples are laced with changing requirements and both technological and organizational constraints.

2.2.3 Human Phenomena

Behavioral and social phenomena are much more difficult to model than purely physical systems. The five examples differ significantly in terms of the prevalence of human phenomena.

Social and political forces, as well as individual preferences and decisions regarding consumption and use of infrastructure affect urban infrastructure. Disease dynamics, patient choice, and clinician decisions affect health care delivery. Many of the behavioral and social phenomena associated with these examples are not amenable to design changes.

Automated vehicle manufacturing is laced with design and development decision making, supervisory control of manufacturing, and operation and maintenance of deployed systems. Deep space missions are similarly affected by design and development decision making, as well as ground operations decision making. Acquisitions enterprises are also affected by decision making at all levels, and sustainment of deployed systems. The decision making for these three examples is often amenable to various levels of decision support.

2.2.4 Difficulty of Problem

The difficulty of addressing urban infrastructure is exacerbated by fragmented decision making across city, state, and federal agencies, all in the context of severely aging infrastructure. Health care delivery is difficult due to uncertainty of demands for various services, impacts of science and technology advances, and stability of payment models. These two examples face uncertain demands and organizational difficulties.

For automated vehicle manufacturing, the required pace of rapid automation exceeds the state of the art. The level of integration of all needed ingredients is very demanding. Acquisitions enterprises are beset by a plethora of models, methods, and tools, as well as fragmented and siloed decision making. Deep space missions face harsh environments, extreme distances, communications delays of minutes to hours, and infeasibility of maintenance and repair. These three examples are laced with technological and technical difficulties.

2.2.5 Crosscutting Issues

In all cases, the problem being addressed must be considered within the broader enterprise context of top-down and bottom-up forces that influence the problem and likely constrain the range and nature of solutions, as well as the choice of the model (s) or simulation(s) to be applied. In other words, what phenomena are internal and external to the model and simulation?

Many models and simulations do not incorporate rich representations of the human behavioral and social phenomena associated with the problems of interest. Yet, human operators and maintainers, as well as citizens and consumers, are central to several of the example problems. Humans provide flexible, adaptive information processing capabilities to systems, but also can make risky slips and mistakes. There is much more uncertainty in systems where behavioral and social phenomena are prevalent.

There are also the human users of models and simulations, ranging from direct model-based decision support to use of model-derived evidence to support organizational decision processes. Technology now enables powerful decision support environments that can empower decision makers to immerse themselves in the complexity of their problem spaces. Evidence of this is increasingly immersive interactive visualizations that prompt expressions like "wow," but are not well understood in terms of their impacts on decision making.

All of the examples are plagued, to a greater or lesser extent, by the fragmentation and incompatibilities of the ever-evolving range of available tools. Some areas such as computational fluid dynamics, semiconductor design, and supply chain management have achieved a level of standardization, but this is quite difficult in areas where "one off" solutions are the norm. Investing in developing and refining a model and simulation is easier to justify when one is going to produce thousands or even millions of the system of interest. This is more difficult to justify and accomplish well when the target is, for example, a single mission.

Underlying all five examples are implicit assumptions and questions about the model or simulation of interest. Is the credibility of a model or simulation understood, accepted, or implied? Are the effects of uncertainty understood? Can one trust in the results of the model or simulation? Can truly emergent behavior be elicited by the representation(s) chosen? How can one understand the current configuration as the model or simulation evolves? Does the model or simulation conform to exchange standards that enable valid conjunctions of models or simulations?

There is also an assumed demand for interactivity between the users and the model or simulation environment. This is likely to require more intelligence and resilience in the model or simulation to enable valid responses to the range of external stimuli allowed. At the very least, it requires that developers of models and simulations have deep understanding of the use cases the model is intended to support as well as the likely knowledge and skills of the envisioned users.

Finally, a major challenge concerns the necessary regulatory, statutory and cultural hurdles that must be surmounted to actually use a model or simulation, and of the set of phenomena associated with the problem of interest to support making real decisions. This requires that decision makers both trust the model or simulation and be willing to make the decisions being informed by the visualizations of model outputs for the scenarios explored.

2.3 Modeling and Simulation Challenges

The applications cited above are part of an almost infinite space of uses for models and simulations. There are overlaps in the application of models and simulations; overlaps in the necessary characteristics of the model or simulation for the intended use; overlaps in the methods and processes used to develop models or simulations; and overlaps in the challenges with the application of modeling or simulation.

The development of a model, or a simulation execution of a model, as a representation of reality can only go so far. Most problems are complex, and hence are decomposed to enable a solution. Modularization of a problem so that each part can be modeled or simulated is fairly straightforward. What is not straightforward is the understanding of the interdependencies between the system modules being modeled. In part, this is caused by the loss of understanding of these interdependencies when a system is decomposed, or modularized. You cannot validly model or simulate what you do not understand.

Because of the loss of understanding of important interdependencies, it is very difficult to explicitly and adequately represent the interactions in the models of the decomposed system. Because of this, it is not possible to recompose the models or simulation executions into a representation of the original system. Emergent behaviors as a result of the composition may or may not replicate the unidentified relationships between the modules of the original system. In other words, the emergent behaviors may be artifacts of the decomposition rather than reflections of reality.

The challenges with emergent behavior extend beyond the composition of models or simulation executions. These challenges extend into the relationships which exist between the modeled physical and organizational phenomena, and the simulation of the processes in which the models are to be used. This boundary point can be thought of simply as an interface definition.

The concept of an interface is simple; however, the necessary depth of information needed to express the relationship between the physical and organizational phenomena and the system or process that uses them is not easily identified. Methods for identifying the needed depth of information, based on understanding of the interactions, are an area of significant challenge in efficient use of conceptual modeling or execution of conceptual models in a simulation.

Continuing with issues associated with the interactions between modeled parts of a system, or models within a larger system, challenges exist with automated methods for constructing an operational environment from a hierarchical set of model components, for example, within a product line. Considering the needed depth of information, there are challenges in knowing how much information to include in the operational environment. This multifaceted problem includes identification of the necessary depth of information to properly exercise the model, or gain the necessary data from the simulation execution. There are no known methods for translating between the system and the environment in which it operates. As stated earlier, you cannot validly model what you do not understand.

Other challenges in conceptual modeling exist in translating the descriptive models from their representational format into executable simulations. These challenges exist in both the essence of model content and the computer environment in which the model will execute. For example, some conceptual models exist in text format. The automated translation of a model expressed in a rich language, into an environment which ultimately is expressed in Boolean expressions, is perhaps the largest of the challenges in the translation domain. Less complex, but no less challenging, is the ability to completely describe the model or simulation so that automated methods can, without loss, translate from one representational format to another.

Additional challenges in modeling and simulation exist within the computational environment in which they exist. Just as there are challenges in modeling the relationships between modeled parts of a system, there are dependencies which exist between the model or simulation, and the infrastructure in which it operates or exists. This is especially true for simulations. An improper execution environment will introduce unquantified unknowns into the results. Potentially less known is the impacts to the model from the infrastructure in which it exists. The model, as the basic representation of reality, is assumed to be uncorrupted. The model is usually never assessed for representational accuracy or corruption effects when accessed. It is assumed to be in the same state as when it was last 'touched'. The ability to assure that the model is free from infrastructure-induced defects is a gap existing today.

Once the model is put into use, challenges exist due to the need to match the results to the user's viewpoint. Visualization of the model or visualization of the simulation results can be assessed as correct or incorrect simply because the visualization tools used do not represent the results in a manner that is understandable, or useful to the user. Work remains to be done on characterizing the user needs and preferences, as matching that to the visualization effects of the model, or data set resulting from the simulation execution. These challenges can be extended deeper than the visualization tool. Characterizing the user needs and matching them to the models or simulation execution that fits the problem space in an automated fashion has the potential to significantly increase the efficiency in the use of the model or simulation.

Other challenges exist in the representational format of the underlying phenomena within the model or simulation. There exists a plethora of representational methods for models. Not all of these are known to all model builders or users. Model or simulation users need to be able to assess the applicability of models or simulations to various problems, which exist in formats that are unknown or less known to the users. Methods to translate model or simulation characteristics from one format to another, or represent them in a standard, acceptable format, remain a challenge today.

Challenges existing at the intersection of model and simulation content and the infrastructure in which it exists or executes include the need for methods to identify optimal fidelity or resolution needed for proper application to decision support. Typically, decision makers express their needs in terms of textual or spoken questions. This hides the complexity which exists in matching computational simplicity and rigor to the rich context underlying written or spoken format. Beginning with simple noun–verb comparisons will get us part of the way to the match. However, nouns and verbs are not easily matched to mathematical expressions which exist in the computational environment. Methods are needed both to automatically perform the match and to break down the language question into constituent parts which more easily match the computational component, taking care to allow for variability in the language itself. Early steps include allowing the user to base model or simulation selections on the presentation of computational expressions.

Challenges remain in the representation of the natural environment, both internally and externally. Biological and social processes are not easily expressed using logic constructs. As such, a different tactic may be to express what is known in logical constructs, and to quantify what is not known. This serves to reduce the problem to some extent but leaves unresolved a way to quantify the uncertainty of biological and social systems.

Particularly, challenging is a method to express environments that are driven by human behavior, such as socioeconomic environments. There is a lack of methods to express, or understand, what is not expressed in systems and environments where humans are involved. Human actions can be unscripted, unpredictable, and often not possible to model in ways comparable to physical phenomena. This is partly because of the unknown relationships, but also because human judgement can be quite subtle.

In order to model or simulate interactions involving biological (human, animal, etc.) inputs, or human–human interactions results, the multi-fidelity, multimodal, multi-domain models often constructed involve rather mixed precision. The ability to actually do this, and have a repeatable, predictable result is necessary, but methods do not exist today to accomplish this, or validate the composition or decomposition.

The challenges discussed, thus, far have not included the challenges coming from the application domains themselves. One challenge is with the applicability of the model or simulation beyond the problem space for which it was originally intended. Models and simulations are often reused due to word of mouth, with or without the associated documentation. Challenges exist with models or simulations, built for one purpose being validly used in another domain. Just because it was not built for a particular purpose does not mean that it is inherently not usable for another purpose. The challenge is how to validate a model in a different domain.

Modeling and simulation exist for almost every activity today. However, each activity domain retains its own language. This usually underlies the domain's models and simulations. Challenges exist with integrating the domain language and knowledge, extended into the model or simulation manifested. Integration or interaction between multiple domains is usually accomplished using language. This allows for reasoning and translation of concepts. How can this be extended to facilitate multi-domain model integration?

Many models and simulations are never retired. Such models and simulations evolve through modification. Is it possible to characterize the types of modifications performed to evolve the models? If yes, how? When is it necessary to characterize a model as new? When is it impossible to assume validation due to changes? There exists a need to answer these questions, since evolving models and simulations need to be trusted.

A final challenge remains in understanding and then describing a model or simulation as a complete entity, for future use, for contracting purposes, etc. The methods to completely describe a model or simulation begin with understanding what "complete" means in a domain, as well as use of a model or simulation. The use of a model or simulation within a domain, or ecosystem, needs to be articulated to fully understand the boundary conditions of the model or simulation, the extensibility of the model or simulation, the history of the model or simulation, and the current state of use.

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