APPLICATION FORM **Fall** X / **Spring** ____

Course: Data modeling

Title of presentation/essay:
An Introduction to Simulation Modeling and Its Application in Engineering

Presenters:

Name	Date	Signature	Honor Pledge
wyatt frerichs	12/3/2021		pledged

Wyatt Frerichs
Data Modeling

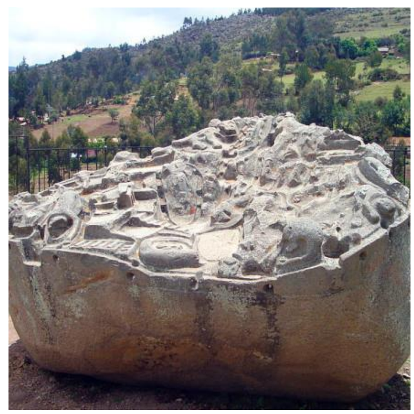
An Introduction to Simulation Modeling and Its Application in Engineering

Abstract

The focus of this paper is simulation modeling and its applications in engineering. It aims to provide a brief introduction to the concept of simulation models and how engineers utilize them and cover the basics of simulation modeling answering the typical what, how, and why questions that would trouble a novice engineer. In order to accomplish this task, the paper covers a variety of examples of simulation models created by engineers for different purposes. For each example a brief overview of the model is given as well as the results obtained from the model.

Introduction

Figure 1: Ancient Model



listed, not. (2019). *History of modeling. making models from antiquity to the present day: Architekton: Kiev, Ukraine*. Architekton. Retrieved December 3, 2021, from

Engineering is a field where accuracy and precision are of the utmost importance. When errors can lead to costly disasters, engineers must utilize every tool to ensure success. One method engineers use to prevent, and in some cases even predict failure is modeling. "A model is an entity that is used to represent some other entity for some defined purpose. In general, models are simplified abstractions, which embrace only the scope and level of detail needed to satisfy specific study objectives."1 An example of a model people use on a daily basis is a map. A map is a two-dimensional model of the earth's surface. Models are often used when the direct investigation of a system is not practical. Investigation into the system can be labeled impractical for a wide variety of reasons: expensive, slow, dangerous, intrusive, or in some cases illegal. These issues have troubled engineers throughout history. In fact, modeling has been around for centuries, with some of the earliest models, like the one pictured above, belonging to ancient civilizations such as the Egyptians or Incas. Over the centuries modeling has become more advanced and an essential tool used by engineers.

Literature Review

Simulation modeling is a practice that has been used by engineers in some form or fashion since before the turn of the millennia. The age and popularity of the method meant that a number of introductory papers had already been written on this Topic.[1] These low level introduction papers were a fantastic resource to draw information from during the early stages of the paper. Many papers had also been written defining methods for creating accurate, or "valid", simulation models. [2] Simulation models have been a mainstay of engineering because of its variety of uses. Simulation models have often been used to measure and compare the efficiency of systems.[3][4] These models can also be used to test systems that are already in place but physical testing can prove very costly.[5] Planning is another important use of simulation models.[6] The validity and credibility of sources referenced were assessed before their inclusion in this paper. Each source included in the paper is either written by an expert in their respective field or published by a respectable academic institution. The papers included were also limited to those published within the last 5 years. However, several exceptions were made to the criteria set for included material. The paper on the creation of simulation models comes from 2008.Another paper is from 1997 it is on the basics of simulation. There were more recent papers published on the topic but from the papers considered this paper seemed to give the most thorough explanations of the process. Several websites were also used for basic definitions of concepts. These sources did not meet the requirements set forth for sources however the information they provided is supported by the validated sources, using this reasoning it was determined that the inclusion of these sources into the paper should not affect its credibility.

What are Simulation models

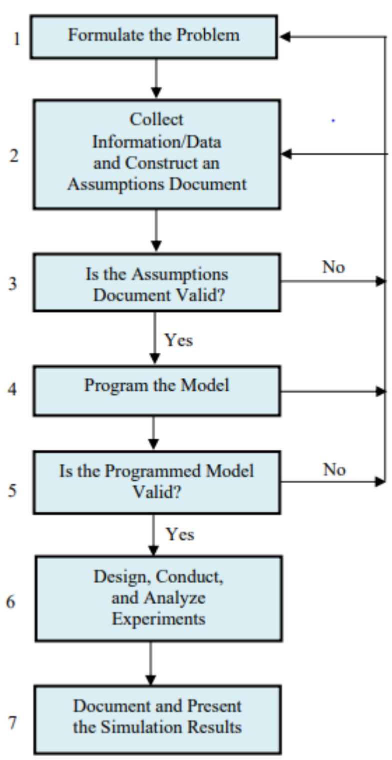
A simulation model is a unique type of model that combines two different types of models: physical models and mathematical models. Physical models are defined as "a material, pictorial, or analogical representation of (at least some part of) an actual system."**2** These models are often used in large scale engineering projects to examine the behavioral aspects of a system. Mathematical models use equations to represent the relationships between the entities or elements of a system. Mathematical models are necessary to run any form of computer simulation. Mathematical models allow mental models to be translated into sets of rules that a computer can read using some form of modeling language or programming. Simulation modeling is still experimental despite being around since before the turn of the millennium. At its root's simulation modeling is very similar to running real tests in the field. However, the key difference is that in simulation the system being studied is replaced by a physical or a computer model. Simulation models can be divided into two categories: human orientated and non-human orientated. Human orientated simulation models are designed for human interaction with a simulated environment. This type of model is often used for training purposes or entertainment. Non-Human orientated models are simulations that deal with the analysis and design of processes and systems. These models are often more technical and are the primary category of simulation the engineers deal with. An example of this type of simulation is wind tunnels.

Discrete Event Simulation

Discrete event simulation, abbreviated DES, is a "method used to model real world systems that can be decomposed into a set of logically separate processes that autonomously progress through time. Each event occurs on a specific process and is assigned a logical time (a timestamp). The result of this event can be an outcome passed to one or more other processes. The content of the outcome may result in the generation of new events to be processed at some specified future logical time."3 Due to its importance in simulation modeling a basic structure for DES has been developed, process-oriented Discrete event simulation. While this is one of the most common methods for DES it is not the only one. Understanding Discrete Event Simulation begins with first understanding the elements of the simulation. DES begins with a system, the status of the internal conditions of this system are known as its state. Changes in the state of the system are measured in order to derive the outputs for the simulation. The outputs of the simulation are essential to answering the questions that simulation was designed for. In order to change the state of the system an input must be introduced. Inputs in a discrete event simulation are introduced via entities. In process orientated DES, Entities flow through a system and are the important structural elements that induce change in the system's state. Entities are essential to the simulation. Without entities no changes would be introduced to the system and it would do nothing. In fact, this is one of the stopping criteria for these models. Each entity has a set of characteristics, the values of these characteristics are specific to that entity. Attributes are critical to performance and function of entities within a system. Resources within the simulation represent anything that has a capacity constraint. These resources are shared by entities, entities that come upon resources that are busy must either que and wait or be diverted elsewhere. Common examples of resources within a simulation would be workers, machines, or traffic intersections. Very complex resources can be modeled, conveyor belts are a very complex resource that can be modeled in discrete event simulations. Within the simulation logic and processes are called Activities. When an entity interacts with an activity it creates an event. Events are the conditions which occur at a point in time, which induce change within the state of the system. There are three major types of events: delays, ques, and logic. A delay activity occurs when the flow of the system is suspended for a definite period of time. Ques, much like delays, occur when the flow of the system is suspended. However, entities are placed into ques for unspecified amounts of time. The most common use of ques is waiting in line for resources. Logic activities are different from the other activities because they don't require a pause in the system. This type of activity allows entities to interact with a system by manipulating state variables or decision logic. The other elements of Discrete event simulation revolve around global variables. Global variables are variables available to the entire simulation. A good example of a global variable is in fact another element of DES, the clock. The clock keeps the time of the simulation. Like the clock the calendar keeps track of all the events scheduled to occur.

Model Validation for Simulation Models

Figure 2: Creating Valid Models

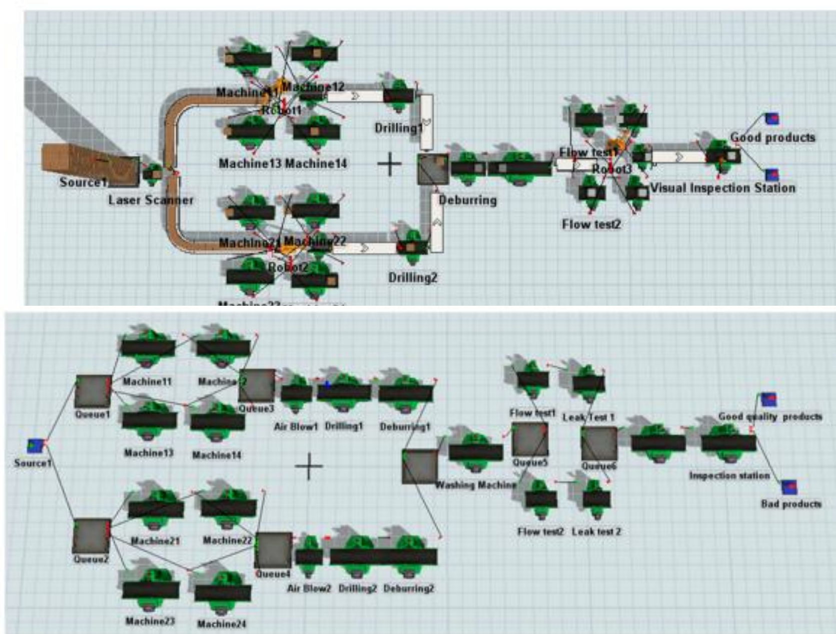


The process of deciding whether a simulation is an accurate representation of the system it represents with respect to the objective of the study it is made for is called validation. Valid models can be used to make decisions in the same fashion as if experimentation on the actual system was performed. The difficulty of this assessment increases with the complexity of the model being evaluated. The creation of valid models can be explained in a seven-step process. The first of which is defining the Problem for which the simulation will be made to solve. During this portion of the process overall objectives, scope, and performance measurements of the model should all be defined during this step. Once the problem is clearly defined an assumption document should be prepared. Data and information should be gathered in order to specify parameters and probability distributions for the simulation. This should all be compiled into a single document. Once completed the third step is to assess the validity of the document. If the document is deemed valid then the creation of the model follows as the fourth step. Once the model is created the next step is to assess the validity of the model itself. The next step is to conduct the experiment with the model. Finally, the last step of creating a valid simulation model is documenting and presenting the results.

Simulation Models in Engineering

One use of simulation models, which is often used by industrial engineers, is to gauge the efficiency of manufacturing or storage systems. A study conducted in 2020 by engineers at the Silesian University of Technology used simulation models in the efficiency analysis of engine head manufacturing lines. The purpose of their study was to compare the efficiency of human operated assembly lines to assembly lines operated by autonomous machines. As shown in the images, two different models were used in this study, one to represent a human controlled assembly line while the other modeled an assembly line with robots. The model used DES to simulate each assembly line running for 5760 hours, three shifts a day for forty-eight weeks per year. The results of the simulations were then judged based on the overall factory efficiency and the overall equipment efficiency. The model was then adjusted to accommodate for both human and machine failure then run for the same amount of time again. The results of the experiment were that a machine line was thirty percent more efficient than a human man. Using two opposing simulations is a very common practice for comparing opposing methods. Another study conducted at the Oklahoma state university used a similar set up to compare different methods for automated warehouses. These would have been massive projects if the physical systems had been observed to gather the data required for this level of analysis but with simulation both studies were significantly easier and cheaper.

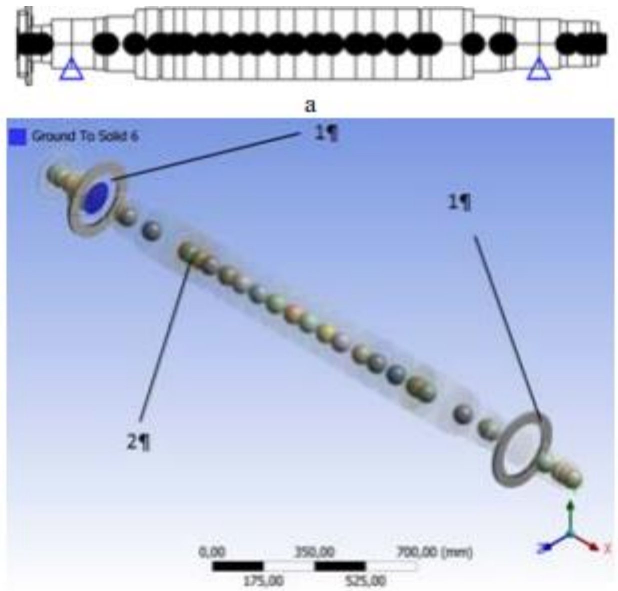
Figure 3: Assembly line simulation



Barosz, P., Gołda, G., & Kampa, A. (2020). Efficiency analysis of manufacturing line with industrial robots and human operators. Applied Sciences, 10(8), 2862.

Another common use of Simulation model is to test physical systems that are either inaccessible or could be damaged by testing. A study done on the vibration reliability of rotors in centrifugal multistage compressors. In order to simulate the vibrations a mathematical model was first constructed for the critical frequencies of the rotor. The calculation of the frequencies

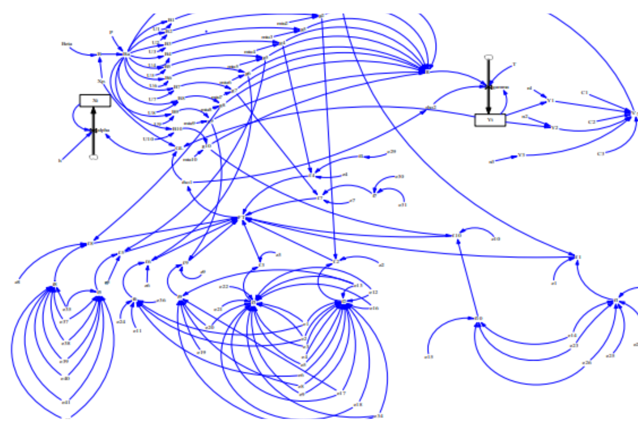
Figure 4: Rotor simulation



Pavlenko, I., Neamtu, C., Verbovyi, A., Pitel, J., Ivanov, V., & Pop, G. (2019). Using Computer Modeling and Artificial Neural Networks for Ensuring the Vibration Reliability of Rotors. In CMIS (pp. 702-716).

allowed for provides the determination of potentially dangerous rotor speeds under its rotation at the operating frequency. The mathematical model was then added to computer software in order to create the simulation. In the end the simulations were successful, the refinement of the mathematical models allowed for engineers to achieve a "significant increase in the preparatory and machine times without loss of the calculation accuracy." The that would need to be done to implement this kind of experiment on the physical rotor could result in damage to the compressor or the rotor. The simulation provided a means of experimentation without risking expensive damages to the machine.

Figure 5



Akinyemi, O., & Adebiyi, K. (2019). Development of system dynamics based simulation models for runway safety planning. *International Journal of Industrial Engineering & Production Research*, *30*(4), 381-403.

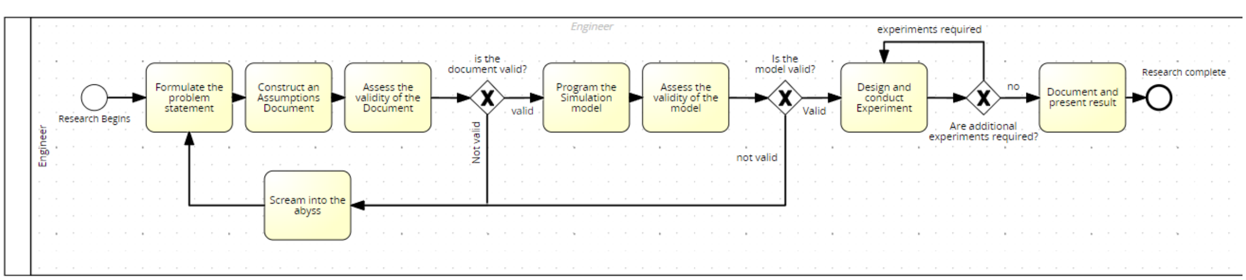
The third use of simulations utilized by engineers is planning or proof of concept. Simulations are incredibly useful when experimenting with untested plans that could be expensive to implement. They also come in handy when trying to prove that untested concepts can even work. This is exactly how it was used by researchers to help in planning safety systems for runways. The study set out to study the overall performance of the aviation system using System Dynamics stock and flow diagram. The diagram was developed to highlight the runway accident hazards. The model was then turned into a computer simulation and ran. In the end the simulation found twenty-nine runway safety system components and forty-four runway accident hazards for runway safety system database. The authors viewed this a huge success.

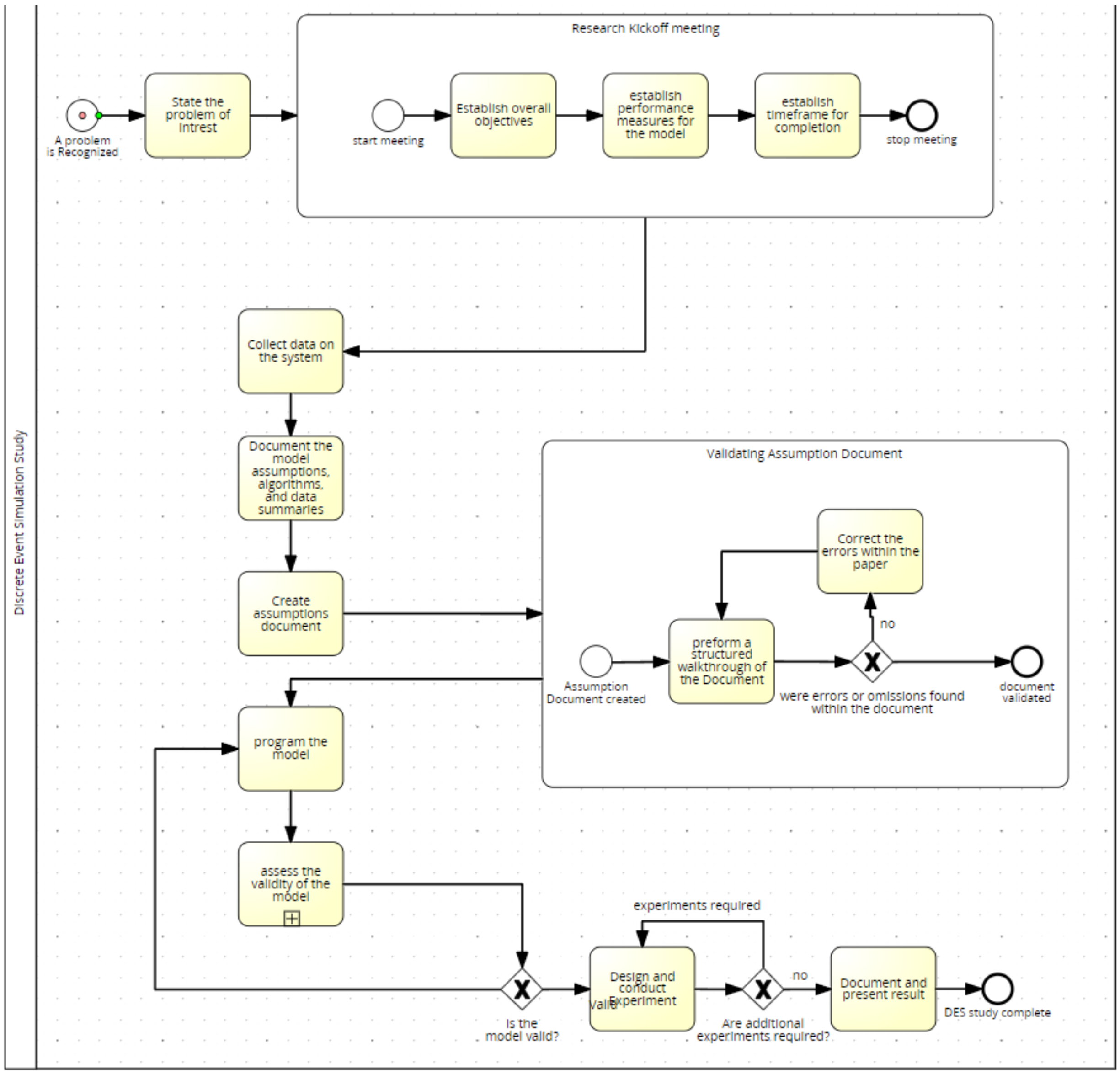
Conclusion and Reflections

Models are incredibly versatile tools that can be utilized by engineers for a multitude of projects. Simulation models are a special type of model that can be incredibly helpful to engineers. These models relate physical and mathematical models in order to represent real systems in virtual environments. and A common method for building these models is called discrete event simulation. Discrete event simulations are made up of elements which interact with one another to create changes in system state which are then measured, and output is derived. Simulation models have increased in popularity because of its numerous benefits. Simulation models are great because they provide visualization as well as a risk-free environment for experimentation. These models are also a cheap and fast alternative to long and expensive studies of physical systems, such as assembly lines or airports. Simulations also allow for higher degrees of accuracy. Computers can perform simulations and calculations constantly with an incredibly small percent error as compared to humans which are known to make errors. It is because of these benefits that engineers employ this modeling for projects. A few examples of projects engineers use simulations for are comparing different systems, conducting tests of physical systems under extreme conditions, and planning. These are not the only problems that simulations can be used to tackle but do serve well as general examples.

These last few words have been reserved for reflections on the paper and reference material. When I finally chose simulation modeling as the topic for this research project, I had no idea how complex some of these models could be. They often included Complex mathematical models and lots of technical jargon. Most of my time was spent attempting to understand the models' inner workings. Time management was a big issue for me with this project as well with most of the work coming from this past month due to procrastination. As a result of this I have spent many late nights reading research papers and screaming at a monitor but to quote the famous aviator Otto Lilienthal said “Opfer müssen gebracht warden.” I have also included a model for the process for creating valid models in BPMN format. I’m glad you recommended making this model. When I took another look at business process models in order to refresh myself on the rules, I noticed that the structure of a BPMN is very similar to how the structure of DES in their set up and I actually had a lot of fun making the second draft of the model.

Figure 6 BPMN 1st draft





Discrete Event Simulation Study
A problem is Recognized
State the problem of intrest
Research Kickoff meeting
start meeting
Establish overall objectives
establish performance measures for the model
establish timeframe for completion
stop meeting
Collect data on the system
Document the model assumptions, algorithms, and data summaries
Create assumptions document
Validating Assumption Document
Assumption Document created
preform a structured walkthrough of the Document
were errors or omissions found within the document
no
Correct the errors within the paper
document validated
program the model
assess the validity of the model
Is the model valid?
Valid
Design and conduct Experiment
experiments required
Are additional experiments required?
no
Document and present result
DES study complete

References

Agrawal, N. K., Heragu, S. S., & Methapatra, C. (2016). Performance Comparison of Automated Warehouses Using Simulation.

Pavlenko, I., Neamtu, C., Verbovyi, A., Pitel, J., Ivanov, V., & Pop, G. (2019). Using Computer Modeling and Artificial Neural Networks for Ensuring the Vibration Reliability of Rotors. In *CMIS* (pp. 702-716).

Akinyemi, O., & Adebiyi, K. (2019). Development of system dynamics-based simulation models for runway safety planning. *International Journal of Industrial Engineering & Production Research*, *30*(4), 381-403.

Barosz, P., Gołda, G., & Kampa, A. (2020). Efficiency analysis of manufacturing line with industrial robots and human operators. *Applied Sciences*, *10*(8), 2862. https://doi.org/10.3390/app10082862

Law, A. M. (2008). How to build valid and credible simulation models. *2008 Winter Simulation Conference*. https://doi.org/10.1109/wsc.2008.4736054

Koperski, J. (n.d.). *Models*. Internet encyclopedia of philosophy. Retrieved December 3, 2021, from https://iep.utm.edu/models/

White, K. P., & Ingalls, R. G. (2018). The Basics of Simulation. *2018 Winter Simulation Conference (WSC)*. https://doi.org/10.1109/wsc.2018.8632271

Maria, A. (1997). Introduction to modeling and Simulation. *Proceedings of the 29th Conference on Winter Simulation - WSC '97*. https://doi.org/10.1145/268437.268440

Barrett, J. S., Jayaraman, B., Patel, D., & Skolnik, J. M. (2008). A SAS-based solution to evaluate study design efficiency of Phase I Pediatric Oncology Trials via discrete event simulation. *Computer Methods and Programs in Biomedicine*, *90*(3), 240–250. https://doi.org/10.1016/j.cmpb.2007.12.008