**The Inclusion of Simulation Modeling Within a Supply Chain Management Curriculum: Some Considerations**

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**Abstract**

Supply Chain Management (SCM) exists today as a practical and possible management approach because of the exponential growth in information technology (IT) capabilities and the proliferation of their use. From a curricular perspective, U.S. academic programs in supply chain typically focus on traditional business content (economics, accounting, finance, operations management, etc.), with additional content in supply chain structure, governance, strategy, logistics and distribution, inventory management, and information systems, among others. Frequently, these courses incorporate pre-built simulation exercises to illustrate key supply chain strategic managerial concepts. However, when students have the opportunity to build their own simulation models of a unique supply chain, they gain additional insights about that supply chain’s network structure, interrelationships, process behaviors, and everyday operating difficulties by learning how to gather sample process data, describe process behavior with probability distributions, and interpret supply chain performance by evaluating simulation output data. In this paper, the value of teaching SCM students to build their own supply chain simulation models will be explored. The evolution of SCM as a science will be described, the difference between building and using simulation models will be examined, the pros and cons of simulation modeling inclusion within a graduate-level SCM academic program will be discussed, and the effectiveness of this curricular content based on student survey data will be evaluated.

**Key Words:** *Supply Chain Management, Supply Chain Simulation, Supply Chain Management Curriculum*

**The Inclusion of Simulation Modeling Within a Supply Chain Management Curriculum: Some Considerations**

1. **Introduction**

Supply Chain Management (SCM) exists today as a practical and possible business management approach because of the exponential growth in information technology (IT) capabilities and the proliferation of their use. Today’s network technology provides the structural foundation for the information system(s) used within a supply chain, which the American Production and Inventory Control Society (APICS) defines as the “interrelated computer hardware and software along with people and processes designed for the collection, processing, and dissemination of information for planning, decision making, and control” (APICS Dictionary, 2018). Supply chain partners can now communicate critical operations information in real time within their own individual organizations, as well as to and from the other member organizations in the chain. (APICS CSCP, 2018, p. 1-205). The ability of these information systems to automate data collection and business processes, as well as provide additional process control through advanced planning and scheduling (APS) capabilities, also allows supply chain participants to incorporate optimization analysis into their planning and scheduling decisions, whether it be by mathematical modeling of parts (or all) of the supply chain, or by computer simulation models. Specifically, Enterprise Resource Planning (ERP) software platforms, “a modularized suite of business applications that are seamlessly integrated to provide automated interactions and a common source of data” (APICS CSCP, 2018, p. 1-229), provide this capability. ERP systems are characterized by a large database accessible by multiple supply chain partners that incorporate transactional modules related to key business functions, including manufacturing, sales, finance, logistics, and others (APICS CSCP, 2018, p. 1-229), as well as the strategic analysis and planning capabilities found within an APS module.

Because of the advances in network connectivity and ERP software capabilities, supply chain managers now have a wealth of analytical results at their fingertips, a treasure-trove of information that significantly improves their ability to make accurate, strategic management decisions, given that they understand how to interpret these results correctly. Statistical literacy is more important than ever for today’s SC managers, who must, at a minimum, be able to interpret point and confidence interval estimates of key performance indicators (KPIs) and use this knowledge to quantify the risk associated with any of the myriad of decision points along the chain. With system analysis automated within ERP planning modules, SC analysts and managers are less encumbered by computing KPIs themselves and are more able to focus on interpreting results and taking appropriate actions based on them. Moreover, the ready access to supply chain simulation analysis provides these managers with even more powerful tools to evaluate different SC configurations, test what-if scenarios, and pre-test supply chain performance before implementation or without physically altering an existing chain.

To keep pace with the changing roles of supply chain managers, academic supply chain management programs must also recognize the increasing importance of training future SC managers in the quantitative skills of statistical interpretation and risk analysis. Since these managers will also have ready access to simulation tools and the analytical results from them, the question then becomes: Should simulation modeling be taught within a supply chain management academic curriculum?

1. **The Development of Supply Chain Management in Business and Academia**

It could be said that the story of supply chain management, and supply chains themselves, is the story of technological, and analytical, innovation. From Frederick Taylor’s groundbreaking approach to standardizing work, particularly manual loading (as introduced in his *Principles of Scientific Management* (1911), through the unitizing of freight in the 1940’s and 1950’s and the shift to motor carrier freight transportation in the 1960’s, organizations began to embrace the analytical tools, first of transportation management then physical distribution, as a way to optimize the transportation and storage of finished product (Robinson, 2015). Before this time, logistics as a science was encountered primarily in military organizations, the activities now associated with logistics were scattered across multiple business functions, and little academic research was produced that examined cost tradeoffs between such things as transportation, storage, and inventory costs (Ballou, 2006). Likewise, educational courses did not typically focus on logistics and distribution as a subject of study. The first college course in logistics and distribution was introduced at Michigan State in 1960 (Ballou, 2006), and the first textbook on the subject was released soon after (Smykay *et al.,* 1961). Academia and industry practitioners at that time also became aware of the value of considering production, transportation, warehousing, storage, and distribution as a singular system that could be managed and optimized at the highest, strategic management level of an organization.

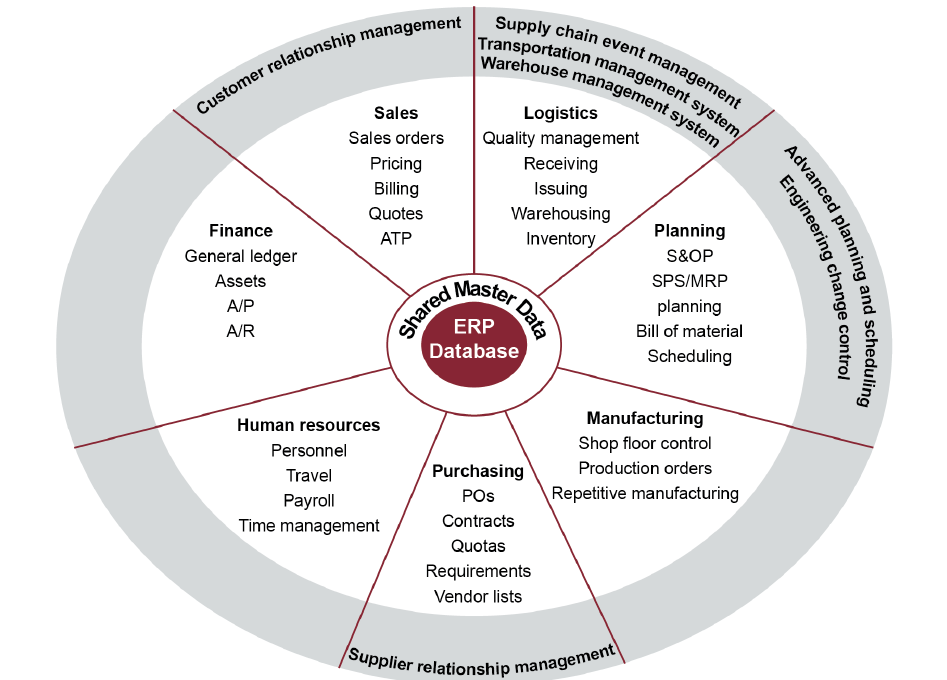
Beginning in the 1960s and 1970s, the introduction of computers facilitated the transition from manual to computerized record-keeping, which in turn opened the door to the possibility of significant innovations in many areas of production and logistics planning: from material requirements planning in production to routing, scheduling, network design, and many more in the distribution end of the supply chain. Furthermore, the availability of personal computers beginning in the 1980s and the introduction of flexible spreadsheet software provided wider, affordable access to logistics planners, which in turn caused the use of these tools to flourish (Robinson, 2015).

In both academic and business organizations, the slow-paced change from Logistics to Supply Chain Management quickened with the emergence of Enterprise Resource Planning (ERP) software platforms in the 1990s, which allowed multiple databases across an enterprise to be integrated with one another and communicate in real time. (Southern, 2011; Robinson, 2015). Furthermore, real-time collaboration through data sharing between all entities in what was now called a supply chain – from the supplier’s supplier to the customer’s customer – became possible. With this extended network of supply chain partners now connected digitally in real time, the productivity and cost gains experienced earlier within the logistics and distribution were now possible across the supply chain as a whole. This capability fits with the contemporary view of supply chain management as the management of business *processes* rather than individual business functions (Ballou, 2006). The Global Supply Chain Framework (GSCF) defines these business processes as Customer Relationship Management, Supplier Relationship Management, Customer Service Management, Demand Management, Order Fulfillment, Manufacturing Flow Management, Production Development and Commercialization, and Returns Management (Lambert, 2014), each of which involve multiple business functions either within an organization or across multiple supply chain nodes. Now, because the databases of the individual functions could be linked and the resulting data “set” was more accurate and available, optimization and planning analysis could be performed at the strategic level of an organization across multiple functions, rather than focusing on best performance for each individual business function. By the 2000’s, Advanced Planning and Scheduling software emerged as the latest advance in ERP capabilities (Robinson, 2015). The APICS dictionary, 16th edition, defines Advanced Planning and Scheduling (APS) as

“techniques that deal with analysis and planning of logistics and manufacturing over the short, intermediate, and long-term time periods. APS describes any computer program that uses advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling, sourcing, capital planning, resource planning, forecasting, demand management, and others.” (APICS Dictionary, 2017)

Figure 1, below, highlights the types of data and analyses that are available from a typical ERP configuration.

**Figure 1: ERP System Functionality**



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SC managers have a wealth of real-time, data-rich SC analytical results at their fingertips thanks to the proliferation of advanced ERP IT capabilities available to them. This in turn changes the expectations of academic supply chain management programs, which must prepare future SC managers to utilize these readily-available performance tools to make strategic management decisions in their future workplaces.

**SCM: A specialization within an academic business management program**

As supply chain management IT capabilities grew, academic researchers began to recognize the value of the integrated SC databases for improved analytical techniques related to production planning and scheduling. A wealth of research in supply chain planning and mathematical optimization algorithms has been produced in recent years as a result of this expanded capability (Chen and Ji, 2007; Sindi and Roe, 2017; Jonsson and Mattsson, 2016; Ozturk and Ornek, 2016; Peng and Chen, 2014; Giglio and Paolucci, 2014; Juan and Peng, 2014; Zhong *et al.,* 2014). Similarly, a significant body of work has also been produced related to the use of simulation modeling for advanced planning and scheduling purposes (Musselman *et al.,* 2016*;* Santa-Eulalia and D’Amours, 2012; Terzi and Cavalieri, 2004; Ingalls, 1998).

Academic institutions in the United States, particularly Colleges of Business, have kept pace with the transformation of business models made possible by these IT advances and the resultant research made possible by them. Along with their business counterparts, collegiate academic programs in this field have also morphed from their sole focus on logistics and transportation in the early years through a broadened view of the extended enterprise embraced in the supply chain philosophy today (Smeal, 2019). From a curricular perspective, the U.S. academic business programs in supply chain management have focused on traditional business content (economics, accounting, finance, operations management, etc.) with additional content in supply chain structure, governance, strategy, logistics and distribution, and inventory management, among others (Athens State Undergraduate Catalog, 2019; Athens State Graduate Catalog, 2019). The current trend is to create a broad curriculum that exposes students to the three focal points of SCM: procurement, manufacturing (operations), and logistics (Kaplan, 2017). No matter the focus, business analytics courses included within a SCM program (including statistics) introduce students to the analytical skills needed to evaluate these core SC activities. Frequently, SC and general management courses incorporate pre-built simulation exercises to illustrate key managerial concepts and allow practice in the analytical skills needed for effective decision-making. For example, products such as CAPSIM© allow students to practice business strategy development in a simulated business environment (Forsyth and Anastasia, 2016), and approximately 95% of AACSB-accredited business schools use them for measuring learning outcomes (Ahn, 2008).

1. **The Difference Between Building and Using Simulation Models**

At this point, the distinction between using pre-built simulations to model business scenarios and *building* the simulation models themselves should be made. Pre-built business simulation games, a subset of Digital Game-Based Learning (DGBL) tools, are used in an academic setting to enhance learning effectiveness and visually illustrate the dynamic impacts of business decisions upon many functions within an organization as well as overall business success (Ellahi *et al*., 2017). In a typical business simulation game, the players are provided a description of an imagined business and the environment within which it operates. Players then input decisions regarding how the business is to operate (resource allocation, pricing, business goals, etc.) (Elgood, 1996). These games are readily available for classroom use and allow students to input business decision parameters into the model, run the model, then observe the simulated business results. Programs such as CAPSIM©, Simbound©, and the MIT LearningEdge Initiative provide a wide variety of business simulation games to mimic anything from team management decisions and strategy to sales and marketing. (Capsim, 2019; Simbound, 2019; MIT LearningEdge, 2019).

In contrast to DGBL tools, simulation *modeling* of business processes (including entire supply chains) involves the creation of the model itself. Saxena (1996, p. 702) defines a business process as “a set of interrelated work activities characterized by specific inputs and value-added tasks that produce specific outputs”. At the most fundamental level, a simulation model of a business process should define the static resources (equipment, manpower, and facilities) of the system to be modeled and their relational and behavioral characteristics, as well as the dynamic entities that flow through, are transformed by, and interact with, the static components of the system. The model “usually takes the form of a set of assumptions concerning the operation of the system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the objects of the system” (Banks *et al.,* 2010). There are three basic methods of simulation modeling which vary according to the level of abstraction of the system. The Systems Dynamic approach takes a high-level, managerial/strategic view of the system being modeled, whereas discrete-event simulation (the most popular approach at present), embodies a low to medium level of system detail. The third method, Agent-Based, describes a system in terms of interacting objects with defined behavior characteristics and is capable of the widest range of modeling abstraction (AnyLogic, 2019). Readily available general-purpose simulation software packages include Arena©, Witness©, AnyLogic© , Flexsim©, and many others (Capterra, 2019).

The use of DGBL tools for learning enhancement within collegiate business programs is quite common, but simulation modeling at the undergraduate level is typically taught within an engineering or computer science curriculum, although the content is also applicable within a management program (Banks *et al.,* 2010). However, with the advent of graphical-interface, user-friendly software packages, simulation modeling becomes a realistic choice for business academic programs to enhance student learning and increase students’ understanding of the impact of complex, multi-dimensional process variability on overall business process performance. With these new, easier-to-use software tools, collegiate business programs, specifically Supply Chain Management academic programs, could include simulation modeling and analysis as a key skill to be taught within their curriculum.

1. **The Addition of Simulation Modeling to a Supply Chain Management Curriculum: Pros and Cons**

**Advantages to adding simulation modeling to an SCM curriculum**

Accredited baccalaureate business programs within the U.S. are required to incorporate quantitative methods within their core professional curricular components. For ACBSP accreditation, baccalaureate programs in business must incorporate Quantitative Techniques/Statistics within the Undergraduate Common Professional Component (CPC) of Technical Skills and demonstrate compliance by identifying where these skills are taught within their required course selections (ACBSP, 2019). Beyond this, candidate programs are free to incorporate the quantitative techniques/statistics they identify as critical within their course structure and as they see fit in order to meet the mission and objectives of their particular program. For AACSB accreditation, candidate programs should consider content within several general skill areas, including Technology Agility, which should include “evidence-based decision-making that integrates current and emerging technologies, including the application of statistical tools and techniques, data management, data analytics and information technology throughout the curriculum as appropriate” (AACSB, 2019, p. 35). Business statistics courses are often used as the primary quantitative course series to meet this requirement, with topics included within the broad scope of “business analytics” increasingly considered a necessary skillset as well, given the prevalence of big data and readily available data mining capabilities. However, with the advent of user-friendly simulation modeling software, simulation modeling could also be used to meet the technical skills/analytics requirements for both accrediting organizations.

Given its improved ease-of-use and its value in meeting accreditation technical skills requirements, simulation modeling should be considered as a potential addition to a supply chain management curriculum for several reasons:

1. Simulation modeling provides experience with process mapping tools.

A process map, one of the Seven Tools of Quality, is “a diagram of the flow of a production process or service process through the production system. Standardized symbols are used to designate processing, flow directions, branching decisions, input/output, and other aspects of the process” (APICS dictionary, 2017). This continuous improvement tool allows a process to be described in high detail and be analyzed to determine sources of process weaknesses. The graphical flow chart modules in Arena © simulation software, as well as many others, allows the simulation model itself to be built in this process map format.

1. Students gain a higher level of appreciation for the random nature of system components.

Business statistics courses introduce basic probability distributions: their parameters, characteristics, shape, common uses, etc., but typically do not delve into sampling from these distributions or observing the behavior patterns of a stream of sampled datapoints (Lind *et al.,* 2018; Anderson *et al.,* 2014*)*. With simulation modeling, students are afforded the opportunity to study these probability distributions at a deeper level with tasks such as generating streams of random observations from a specified distribution or fitting a probability distribution to data the students have collected. Built-in distribution fitting tools common within today’s simulation software options make this a straightforward task (Kelton *et al.,* 2015).

In addition, standard inventory costing word problems (and other, similar word problems) assume static inputs and base decisions on averages alone (Chapman *et al.,* 2017). These types of inventory analysis problems can be solved more realistically using simulation by recognizing and describing the real-world variability patterns of cost inputs.

1. Students can visually witness bottlenecks in a simulated system, hypothesize the reasons for a bottleneck based on their deeper understanding of the random inputs of the system, and strategically change system characteristics in order to alleviate the bottleneck. Simulation gives them the tool to address a critical issue in supply chain management: continuous flow of product through the chain, where supply patterns match demand patterns.

In his landmark book, *The Goal,* Eli Goldratt introduced the world to the Theory of Constraints and how to use this understanding of system constraints to resolve bottlenecks in a system. Students can easily apply lessons learned from this concept to resolve system bottlenecks within a simulation model (Goldratt, 2014).

1. Student can experiment with process structure.

As supply chain managers, students will one day be tasked with optimizing a process within their organization: determining optimal staffing levels or the number of resources, minimizing inventory levels, reducing costs, etc. Simulation modeling provides the student with the opportunity to do more than adjust accounting measures on a spreadsheet. They can change key components of a business process (resources, transport times, input costs) within its simulated model, watch the simulated system “run”, and observe the impact upon key performance measures (Campuzano and Mula 2).

1. Students are provided the opportunity to understand the nature of a business process at a deeper level.

Business processes cannot be managed well from an office, or tracked well with spreadsheets, if the structure and behavior of the process is not thoroughly understood. Analytical techniques taught within a supply chain curriculum (finance, accounting, statistics, and others) provide significant value, but the effectiveness of these analytical skills is enhanced when the processes to which they are applied are well understood. Simulation models, built by the students themselves, affords the opportunity for students to gain this deeper understanding of process behavior (Campuzano and Mula, 2011).

**Drawbacks to incorporating simulation modeling into a SCM curriculum**

Despite the many advantages to incorporating simulation modeling within a SCM curriculum, the change would not be without its challenges. Some of the drawbacks include the following:

1. Fear of the unfamiliar.

Computer coding, even when attempted using an easy-to-use graphical interface, can be intimidating to many students, especially for those whose strongest academic skills are not in analytics. Students who have little experience in the use of computer software for analysis (spreadsheets, databases, coding software) may be wary of delving into unfamiliar territory. This can slow down their progress in the course.

1. Weak statistical analysis skills

Students who viewed their statistics courses as an obstacle to be overcome and forgotten rather than as a valuable source of critical business skills may not have mastered the necessary skills in confidence interval creation, probability distribution comprehension, and hypothesis test execution to take advantage of the decision-support information provided by simulation models. This may be particularly true at the undergraduate level.

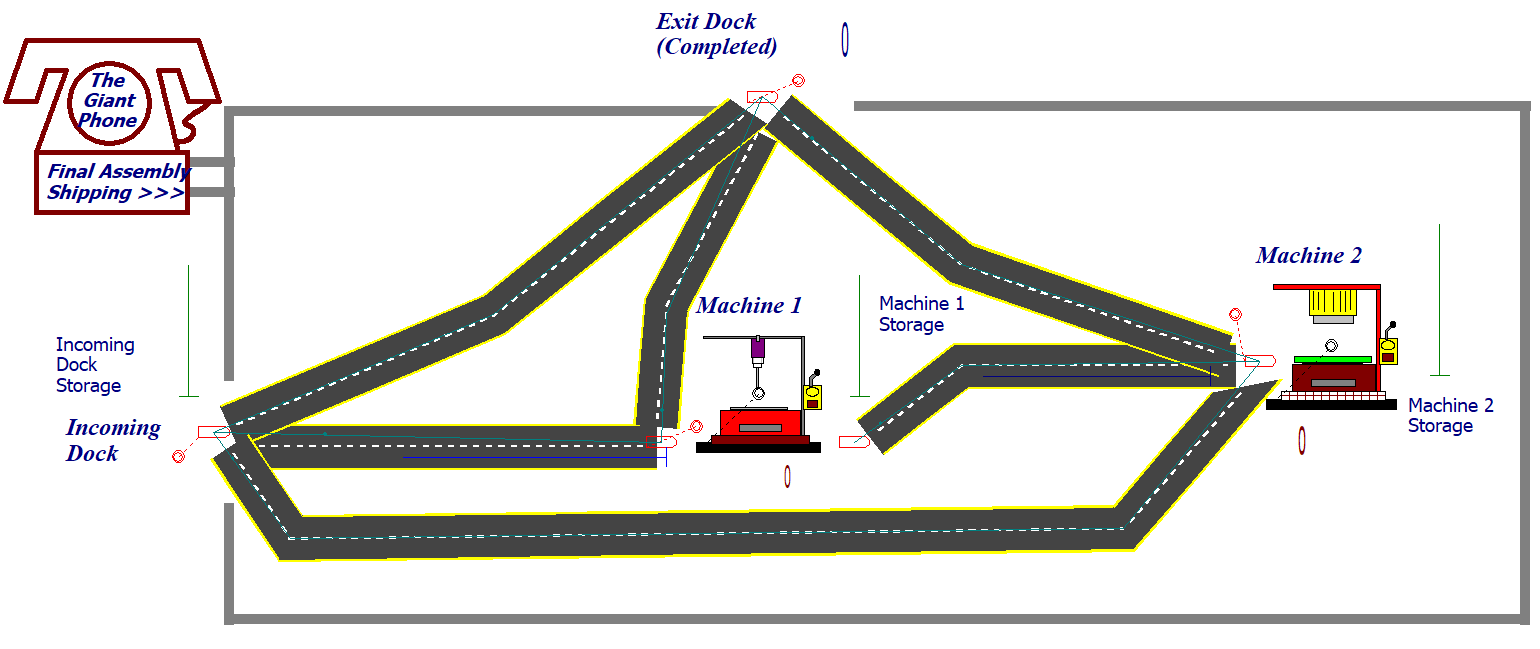
1. Unwillingness to devote time to modeling

Building a simulation model from scratch, just like writing a computer program, takes time and patience. Time must be allotted to learning how to use the simulation software, debugging programs that won’t run, and improving models once additional modeling skills are attained (although this disadvantage has been significantly reduced with newer, easier-to-use modeling tools). Time is also needed to learn and practice new data analysis skills, including proper data sampling skills, so that simulation results can be used meaningfully for business decisions.

1. **A Practical Example**

The Master of Science program in Global Logistics and Supply Chain Management at Athens State University includes LSM 604 (Supply Chain Simulation Modeling and Analysis) as one of its core academic courses. This course includes “advanced techniques and methodology for logistics, transportation and supply chain system design, customer service, and policy formulation. [The] methodological focus [is on] simulation and analytical techniques to develop empirical results that document current and anticipated system performance” (Athens State Graduate Catalog, 2019). At present, the course uses Arena © discrete-event simulation software for modeling basic supply chain structures, with business process performance tracked by global variables (built-in and user-defined). The course content centers around three objectives: learning the basics of general simulation modeling with Arena, developing strong stochastic model input and output analysis skills for decision-making purposes, and investigating real-world implementations of supply chain simulation models for optimization purposes.

Below is an example of the graphical description of a small manufacturing operation built by a student in the LSM 604 course using Arena© simulation software. (Information concerning resources, entities, delay times for processing and transport, and other details of the system are entered in associated data modules). During the course of a simulation run, the animation illustrates resources (busy or idle), the number of entities waiting at a particular resource, part transfers via material handling equipment, and counts of the number of entities that have passed through a particular module of the model at any given time. For each component of the model, stochastic inputs are described via pop-up windows, and stochastic performance measures are documented in an Output Report following the simulation run.



The above example illustrates a student’s model of a production node in the supply chain. Later in the course, the students model an inventory system using global variables to track total inventory costs, with stochastic inputs for customer demand and order delivery lag. In this exercise, students attempt to minimize total ordering costs by adjusting their choices of *s, S,* and inventory evaluation interval length.

Near the end of the semester, the students take what they’ve learned about modeling small systems and apply those skills to modeling a small supply chain. This case study requires them to model customer demand, supply patterns and transportation, production, and distribution and transport to final customers. In the offerings of this course so far, students have been asked to track statistics on total cycle time, resource utilization, queue characteristics, total operating costs, and general observations concerning bottlenecks as part of their case study evaluation. The case study for the Fall 2018 offering of LSM 604 is included in Appendix A.

1. **A Study Comparing the Effectiveness of DGBL Games and SC Simulation Modeling for Supply Chain Performance Evaluation**

To test the effectiveness of supply chain simulation modeling education upon a student’s ability to analyze and optimize supply chain operations, a survey of the Fall 2019 LSM 604 graduate students was conducted. These students had also used CAPSIM© Core the previous semester in LSM 601 (Procurement and Materials Management) to practice their SCM strategic management skills. The purpose of this survey was to compare and contrast the supply chain management knowledge and skills acquired through the use of these two simulation tools. Eight of the 12 students enrolled in the course participated in the survey. The survey questions, along with the student responses, are detailed in Tables 1 through 20.

Tables 1 through 20: CAPSIM© / Arena© Survey Results

Fall 2019 LSM 604 Students

Table 1: Survey Question 1 Results

|  |  |
| --- | --- |
| **Question 1: CAPSIM© Core provides realistic practice in managing a business at the higher, strategic level** | |
| Strongly Agree | 12.5% |
| Agree | 75.0% |
| Neither Agree nor Disagree | 12.5% |
| Disagree | 0% |
| Strongly Disagree | 0% |

Table 2: Survey Question 2 Results

|  |  |
| --- | --- |
| **Question 2: Arena© simulation modeling provides realistic practice in managing a business at the higher, strategic level.** | |
| Strongly Agree | 62.5% |
| Agree | 25.0% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 12.5% |
| Strongly Disagree | 0% |

Table 3: Survey Question 3 Results

|  |  |
| --- | --- |
| **Question 3: CAPSIM© Core provides realistic practice in managing a business at the lower, operational level.** | |
| Strongly Agree | 12.5% |
| Agree | 50.0% |
| Neither Agree nor Disagree | 12.5% |
| Disagree | 25.0% |
| Strongly Disagree | 0% |

Table 4: Survey Question 4

|  |  |
| --- | --- |
| **Question 4: Arena© simulation modeling provides realistic practice in managing a business at the lower, operational level.** | |
| Strongly Agree | 25.0% |
| Agree | 62.5% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 12.5% |
| Strongly Disagree | 0% |

Table 5: Survey Question 5 Results

|  |  |
| --- | --- |
| **Question 5: The inputs and outputs to a CAPSIM© Core business simulation are static: They are constant values that do not recognize process variability.** | |
| Strongly Agree | 25.0% |
| Agree | 0.0% |
| Neither Agree nor Disagree | 50.0% |
| Disagree | 12.5% |
| Strongly Disagree | 12.5% |

Table 6: Survey Question 6 Results

|  |  |
| --- | --- |
| **Question 6: The inputs and outputs to an Arena© business simulation are static: They are constant values that do not recognize process variability.** | |
| Strongly Agree | 0.0% |
| Agree | 12.5% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 37.50% |
| Strongly Disagree | 50.0% |

Table 7: Survey Question 7 Results

|  |  |
| --- | --- |
| **Question 7: CAPSIM© Core business simulation games allow students to practice business management skills by controlling key financial inputs to a simulated business operation and observing the resulting financial performance of the firm.** | |
| Strongly Agree | 62.5% |
| Agree | 37.5% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 0.0% |
| Strongly Disagree | 0.0% |

Table 8: Survey Question 8 Results

|  |  |
| --- | --- |
| **Question 8: Arena© simulation models allow students to practice business management skills by controlling key financial inputs to a simulated business operation and observing the resulting financial performance of the firm.** | |
| Strongly Agree | 12.5% |
| Agree | 25.0% |
| Neither Agree nor Disagree | 12.5% |
| Disagree | 25.0% |
| Strongly Disagree | 25.0% |

Table 9: Survey Question 9 Results

|  |  |
| --- | --- |
| **Question 9: CAPSIM© Core business simulation games allow students to practice business management skills by controlling the logic of procurement, manufacturing, transportation, and storage of the finished product within the business operation, including details of resource availability and condition as well as product routing.** | |
| Strongly Agree | 0.0% |
| Agree | 25.0% |
| Neither Agree nor Disagree | 25.0% |
| Disagree | 25.0% |
| Strongly Disagree | 25.0% |

Table 10: Survey Question 10 Results

|  |  |
| --- | --- |
| **Question 10: Arena© simulation models allow students to practice business management skills by controlling the logic of procurement, manufacturing, transportation, and storage of the finished product within the business operation, including details of resource availability and condition as well as product routing.** | |
| Strongly Agree | 50.0% |
| Agree | 37.5% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 12.5% |
| Strongly Disagree | 0.0% |

Table 11: Survey Question 11 Results

|  |  |
| --- | --- |
| **Question 11: Skills gained by using CAPSIM© Core business simulation can later be used to build simulation models of the student’s own workplace.** | |
| Strongly Agree | 0.0% |
| Agree | 37.5% |
| Neither Agree nor Disagree | 25.0% |
| Disagree | 37.5% |
| Strongly Disagree | 0.0% |

Table 12: Survey Question 12 Results

|  |  |
| --- | --- |
| **Question 12: Skills gained by using Arena© simulation models can later be used to build simulation models of the student’s own workplace.** | |
| Strongly Agree | 75.0% |
| Agree | 25.0% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 0.0% |
| Strongly Disagree | 0.0% |

Table 13: Survey Question 13 Results

|  |  |
| --- | --- |
| **Question 13: In CAPSIM© Core business simulations, students can custom-build performance metrics for the simulated firm.** | |
| Strongly Agree | 12.5% |
| Agree | 62.5% |
| Neither Agree nor Disagree | 12.5% |
| Disagree | 12.5% |
| Strongly Disagree | 0.0% |

Table 14: Survey Question 14 Results

|  |  |
| --- | --- |
| **Question 14: In Arena© simulation software, students can custom-build performance metrics for the simulated firm.** | |
| Strongly Agree | 25.0% |
| Agree | 75.0% |
| Neither Agree nor Disagree | 0.0% |
| Disagree | 0.0% |
| Strongly Disagree | 0.0% |

Table 15: Survey Question 15 Results

|  |  |
| --- | --- |
| **Question 15: Which business simulation approach is best for practicing business financial management skills?** | |
| CAPSIM© Core | 100.0% |
| Arena© | 0.0% |

Table 16: Survey Question 16 Results

|  |  |
| --- | --- |
| **Question 16: Which business simulation approach is best for evaluating an existing business or supply chain?** | |
| CAPSIM© Core | 12.5% |
| Arena© | 87.5% |

Table 17: Survey Question 17 Results

|  |  |
| --- | --- |
| **Question 17: Which business simulation approach gives the user the most control over simulation structure, inputs, and outputs?** | |
| CAPSIM© Core | 12.5% |
| Arena© | 87.5% |

Table 18: Survey Question 18 Results

|  |  |
| --- | --- |
| **Question 18: Which business simulation approach is best for identifying potential opportunities for business and/or supply chain improvement?** | |
| CAPSIM© Core | 25.0% |
| Arena© | 75.0% |

Table 19: Survey Question 19 Results

|  |  |
| --- | --- |
| **Question 19: Which business simulation approach is best for understanding the variable nature of business?** | |
| CAPSIM© Core | 62.5% |
| Arena© | 37.5% |

Table 20: Survey Question 20 Results

|  |  |
| --- | --- |
| **Question 20: If you could list only one of these two programs within the Skill/Competencies section of your resume’, which would it be?** | |
| CAPSIM© Core | 12.5% |
| Arena© | 87.5% |

**General observations from survey study**

The small sample size (8) used in the study, coupled with the lack of independence between populations sampled for CAPSIM© Core vs. Arena©, inhibited the use of statistical hypothesis testing to analyze the survey results. However, general observations and conclusions can be drawn. Questions 1 through 14 were designed as 7 pairs of core questions asked of both CAPSIM© Core and Arena© users. When weights are assigned to the Likert scale categories (with 5 = strongly agree down to 1 = strongly disagree), weighted means can be calculated and used to compare paired questions. The comparison of weighted means for the 7 paired survey questions is provided in Table 21.

Table 21: Comparison of Weighted Mean Likert Scores

For Paired Survey Questions (7 paired questions, 14 survey questions total)

|  |  |  |
| --- | --- | --- |
| **Survey Question** | **CAPSIM© Core** | **Arena©** |
| Paired question 1: Simulation approach provides realistic practice in managing a business at the higher, strategic level | 4.0 | 4.375 |
| Paired question 2: Simulation approach provides realistic practice in managing a business at the lower, operational level. | 3.5 | 4.0 |
| Paired question 3: The inputs and outputs for the simulation approach are static: They are constant values that do not recognize process variability. | 4.125 | 1.75 |
| Paired question 4: Simulation approach allows students to practice business management skills by controlling key financial inputs to a simulated business operation and observing the resulting financial performance of the firm. | 4.625 | 2.75 |
| Paired question 5: Simulation approach allows students to practice business management skills by controlling the logic of procurement, manufacturing, transportation, and storage of the finished product within the business operation, including details of resource availability and condition as well as product routing. | 2.50 | 4.25 |
| Paired question 6: Skills gained by using simulation approach can later be used to build simulation models of the student’s own workplace. | 3.0 | 4.75 |
| Paired question 7: With this simulation approach, students can custom-build performance metrics for the simulated firm. | 3.75 | 4.25 |

Based on the results presented in Table 21, the data collected for this study indicates that Arena© simulations provide slightly more effective management practice at both the strategic and operational levels. Paired question 3 indicates that CAPSIM© Core inputs are generally static in nature, whereas Arena© inputs are not. Practice in managing business financials and evaluating business structure with same is better in CAPSIM© Core, but students can control the logic and system structure of a modeled organization more effectively with Arena©. Most importantly, students are better able to use Arena© models to model their own workplace as opposed to CAPSIM© Core, where students only access pre-built business models. Finally, Arena© holds a slight edge over CAPSIM© Core in terms of custom-built performance metrics.

The last 6 questions of the survey compared CAPSIM© Core and Arena© directly. The results of these questions, provided above in Tables 15 through 20, show that CAPSIM© Core is better for practicing financial management skills, but Arena© is preferred for evaluating an existing business or supply chain. The students surveyed also felt that Arena© provided them more control over model structure and the ability to describe a real supply chain, and it was also best for identifying opportunities for improvement – something that a game based on managing financials would not necessarily reveal. Question 20 of the survey showed that students strongly preferred listing Arena© modeling as a skill over experience with CAPSIM© Core on their resume’ if given a choice, which indicates that the value of the simulation model building experience extends beyond the classroom and into the workplace.

The survey results from Question 19, showing that students felt that CAPSIM© Core was better for understanding the variable nature of business, was surprising given the student responses to Question 5. It could be deduced from this result that their CAPSIM © Core experience illustrated to them the effect of multiple interacting factors upon the varying financial performance of a firm.

The survey results presented here can serve as an initial indicator of the value, and unique roles, of these two approaches to simulation use within a supply chain academic program. Future research to compare these two alternatives should involve larger, independent samples so that appropriate hypothesis testing can be conducted.

In addition, future research might also focus on the modeling aptitude of undergraduate vs. graduate students, or between students in the various business disciplines, in order to determine where a simulation modeling course might be placed within the various plans of study in an academic business curriculum.

1. **Summary**

Beyond learning the analytical techniques themselves, the value for supply chain management students in learning simulation modeling lies in the experience of the physical gathering and stochastic description of system input data. The students are afforded the opportunity to become intimately familiar with the behavior of the different components of the supply chain, which in turn results in a deeper understanding of the interplay between product velocities at different points in the chain. For example, they can examine the final dynamic of cycle time affected by supply input velocity and behavior vs. production process velocity and behavior, and well as logistics/transportation velocity and behavior. This experience is not readily available to them when using pre-built simulations via DGBL tools. Once an original supply chain simulation is built, however, simulation modeling software provides data-based decision support for predicting overall stochastic system performance and quantifying risk associated with a supply chain business decision, similar to the DGBL tools. The experience of building a simulation model of a supply chain is one that students do not forget, and it provides them the opportunity to view a supply chain from an entirely different perspective.

**References**

AACSB. (2018). *2013 Eligibility procedures and accreditation standards for business accreditation”, Standard 9*. Revised July 1, 2018. Retrieved from <https://www.aacsb.edu/-/media/aacsb/docs/accreditation/business/standards-and-tables/2018-business-standards.ashx?la=en&hash=B9AF18F3FA0DF19B352B605CBCE17959E32445D9>. .

ACBSP. “Unified Standards: Standards and Criteria for Demonstrating Excellence in Business Degree programs”, Criterion 6.4a, p. 49. Retrieved from <https://cdn.ymaws.com/www.acbsp.org/resource/collection/EB5F486D-441E-4156-9991-00D6C3A44ED1/ACBSP_Unified_Standards_and_Criteria_for_Accreditation.pdf>).

Ahn, J.H. (2008). Application of experiential learning cycle in learning with a business simulation game. *E-Learning, 5(2)*, pp. 146 – 156.

Anderson, D.R., Sweeney, D.J., Williams, T.A., Camm, J.D., and Cochran, J.J. (2014). *Statistics for Business and Economics, 12th Edition.* Stamford, CT: Cengage Learning.

AnyLogic Corp. (2019) Multimethod Simulation Modeling for Business Applications. Retrieved 6 March 2019 from [*https://www.anylogic.com/resources/white-papers/multimethod-simulation-modeling-for-business-applications/*](https://www.anylogic.com/resources/white-papers/multimethod-simulation-modeling-for-business-applications/)*.*

APICS CSCP (2018). *APICS CSCP Exam Content Manual, Version 4.2*.Chicago, IL: American Production and Inventory Control Society.

APICS Dictionary (2017). *APICS Dictionary, 16th Edition.* Chicago, IL: American Production and Inventory Control Society.

Athens State University. *2018–2019 Undergraduate Catalog.* Retrieved 6 March 2019 from <http://www.athens.edu/academics/catalogs/undergraduate/17-18-catalog/>.

Athens State University. *2018-2019 Graduate Catalog.* Retrieved 7 March 2019 from [*http://www.athens.edu/academics/catalogs/graduate/18-19-catalog/*](http://www.athens.edu/academics/catalogs/graduate/18-19-catalog/).

Ballou, Ronald H. (2006). The Evolution and Future of Logistics and Supply Chain Management. *Production, 16(3),* pp. 375 – 386.

Banks, J., Carson, J.S., Nelson, B.L., and Nicol, D.M. (2010). *Discrete-Event System Simulation, 5th Edition.* New York: Pearson Publishers.

Banks, J. and Carson, J. (1984). *Discrete-Event System Simulation.* Englewood Cliffs, NJ: Prentice-Hall.

Campuzano, F. and Mula, J. (2011). *Supply Chain Simulation.* London, Springer-Verlag.

Capsim website. [www.capsim.com](http://www.capsim.com). Accessed 6 March 2019.

Capterra. (2019). Simulation Software. Retrieved 6 March 2019 from <https://www.capterra.com/simulation-software/>.

Chapman, S., Arnold, T., Gatewood, A. and Clive, L. (2017). *Introduction to Materials Management, 8th Edition.* New York: Pearson Publishing.

Chen, K. and Ji, P. (2007). A mixed integer programming model for advanced planning and scheduling (APS). *European Journal of Operational Research, 181(1).*  pp. 515 – 522.

Elgood, Chris. (1996). *Using Management Games,* 2nd Edition. Aldershot Hampshire, England: Gower Press.

Ellahi, A., Zaka, B., and Sultan, F. (2017). A Study of Supplementing Conventional Business Education with Digital Games. *Educational Technology & Society, 20(3),*  pp. 195 – 206.

Forsyth, B. and Anastasia, C. (2016). The Business Simulation Paradigm: Tracking Effectiveness in MBA Programs. *Journal of Management Policy and Practice, 17(2)*, pp. 85 – 100.

Giglio, D.; Paolucci, M. (2014). A mixed-integer mathematical programming model for integrated planning of manufacturing and remanufacturing activities. *ICINCO 2014 – Proceedings of the 11th International Conference on Information in Control, Automation, and Robotics.*

Goldratt, E. (2014). *The Goal: A Process of Ongoing Improvement.* Great Barrington, MA: North River Press.

Ingalls, R.G. (1998). The value of simulation in modeling supply chains. *1998 Winter Simulation Conference Proceedings.*

Jonsson, P., Mattsson, S.-A. (2016). Advanced material planning performance: a contextual examination and research agenda. *International Journal of Physical Distribution and Logistics Management, 46(9)*, pp. 836 – 858.

Juan, Y.-C.; Peng, Y.-R. (2014). A constraint satisfaction coordination approach for distributed supply chain production planning. *Asia-Pacific Journal for Operations Research, 31(6).*

Kaplan, D.A. (2017). The supply chain curriculum: How universities are preparing the next generation of leaders. *Industry Dive,* April 18, 2017. Retrieved from <https://www.supplychaindive.com/news/supply-chain-education-curriculum-talent-crisis/440394/>

Kelton, W.D., Sadowski, RP., and Zupick, N.B. (2015). *Simulation with Arena, 6th Edition.* New York, NY: McGraw-Hill Publishing.

Lambert, Douglas M. (2014). *Supply Chain Management: Processes, Partnerships, and Performance, 4th Edition.* Supply Chain Management Institute.

Lind, D.A., Marchal, W.G., and Wathen, S.A. (2018). *Statistical Techniques in Business and Economics, 17th Edition.* New York, NY: McGraw-Hill Education.

MIT LearningEdge website. Retrieved 6 March 2019 from <https://mitsloan.mit.edu/LearningEdge/simulations/Pages/Overview.aspx>.

Musselman, K., O’Reilly, J., Duket, S. Forsyth, B. and Anastasia, C. (2016). The Business Simulation Paradigm: Tracking Effectiveness in MBA Programs. *Journal of Management Policy and Practice, 17(2),* pp. 85 – 100.

Ozturk, C., and Ornek, M.A. (2016). Optimization and constraint based heuristic methods for advanced planning and scheduling systems. *International Journal of Industrial Engineering: Theory Applications and Practice, 23(1).*

Peng, Y; Lu, D.; and Chen, Y. (2014). A constraint programming method for advanced planning and scheduling system with multilevel structured products. *Discrete Dynamics in Nature and Society, Vol. 2014*, Article ID 917685.

Robinson, Adam. (2015). The Evolution and History of SCM. *Cerasis, 23 Jan. 2015*. Retrieved 6 March 2019 from <https://cerasis.com/2015./01/23/history-of-supply-chain-management/>.

Santa–Eulalia, L. A., and D’Amours, S. (2012. Agent-based simulations for advanced supply chain planning and scheduling: the FAMASS methodological framework for requirements analysis. *International Journal of Computer Integrated Manufacturing 25(10): Special Issue on Collaborative Manufacturing and Supply Chain.*

Saxena, K.B.C. (1996). Reengineering public administration in developing countries. *Long-Range Planning, 29(5),*pp. 703 – 711.

Simbound business simulation website. [www.simbound.com](http://www.simbound.com). Accessed 6 March 2019.

Sindi, S., and Roe, M. (2017). *Strategic Supply Chain Management: The Development of a Diagnostic Model.* New York, NY: Springer International.

Smeal College of Business, Pennsylvania State University. (2019). *A Look Back … Penn State Smeal College of Business*. Retrieved 6 March 2019 from <https://www.smeal.psu.edu/cscr/documents/a-look-back-penn-state-smeal-supply-chain-program/>.

Smykay, Edward W., Bowersox, Donald J., and Mossman, Frank H. (1961). *Physical Distribution Management: Logistics Problems of the Firm.* New York, Macmillan.

Southern, R. Neil. (2011). Historical Perspective of the Logistics and Supply Chain Management Discipline. *Transportation Journal, 50(1),* pp. 53 – 64.

Terzi, S. and Cavalieri, S. (2004). Simulation in the supply chain context: a survey. *Computers in Industry, 53(1)*, pp. 3 – 16.

Zhong, R.Y.; Huang, G.Q.; Lan, S.; and Dai, Q. (2014). A real-time RFID-driven model for two-level production decision-making. *Proceedings of the 11th IEEE International Conference on Networking, Sensing, and Control ICNSC.*

**Appendix A: LSM 604 Fall 2018 Case Study**

Margaritaville Skimboard Company (MSC)

Skimboarding is a beachside sport that started among the lifeguards of Laguna Beach, CA, in the late 1920s. This sport has enjoyed increasing popularity in recent years with the advent of professional tours and the manufacture of professional-quality skimboards. The Margaritaville Skimboard Company produces both wooden and plastic boards for amateur through professional use for beachgoers all over the U.S. Their manufacturing facility in Conway, SC ships their finished products to specialized skimboard and surf shops in Myrtle Beach, SC, Venice Beach, FL, and Destin, FL.

Although MSC has enjoyed success in recent years with their skimboard product lines, they have experienced difficulty in adhering to promised delivery schedules for their 48” fiberglass coated wooden Hammerhead skimboard. The result has been lost business to other manufacturers for this high-profit product.

1. Supply Chain and Manufacturing Details

Three different surfshops serve as the primary customers for MSC’s Hammerhead boards. Demand from Riptide Skimboards in Venice Beach is constant and predictable; they order 20 boards every four days. The orders from Gnarly SkimShop in Myrtle Beach and Ono Surf Shop in Destin are more variable; Gnarly orders 4 boards at a time, with time between orders that is NORM(1, 0.5) days, and the Ono Shop orders 10 boards at a time, with time between orders that is TRIA(5, 6, 8) days.

When any order is received, the MSC onsite warehouse is first checked to determine if they have enough boards in stock to fill the order. If so, they reduce the warehouse inventory by the order amount and ship the order. The warehouse manager uses an (s, S) inventory system for the 48” skimboards, with parameters (20, 40). At the beginning of each 8-hour day, he checks to see if the inventory is below 20, If it is, he can “magically” and instantaneously cause the inventory to go back up to S = 40.

If an order arrives and there is not enough inventory in the warehouse to fill it, the already-available raw wood is loaded onto the first part of their production process to begin manufacture of the order. If there is enough inventory to fill some but not all of the order, the factory goes ahead and builds the entire order, then uses the leftover to replenish the warehouse.

To manufacture the boards, 50” x 30” x “1” thick wooden blanks are trimmed with a jigsaw to the shape of the finished skimboard, then sanded and edged with a nearby belt sander. After a brief wipedown, the sanded and cleaned boards are sprayed with a fiberglass coating and allowed to dry and cure. Following fiberglass coating, the boards are decoratively painted, then sealed with a final coat of clear polyurethane. The two jigsaws on site take NORM(15, 3) minutes to trim the board blanks, then one of three belt sanders takes (TRIA(8, 9, 12) minutes to sand them down. The single fiberglass paint booth spends UNIF(7, 9) minutes coating the boards. The boards then move to the curing area, which takes a constant 2 hours, the curing area can hold 15 boards. The decorative painting process is performed by 1 of 4 local artists, who each take EXPO(45) minutes to paint and dry the fiberglass-coated boards, then 1 of 2 employees apply the final coat of poly to the finished product, with a paint time that is TRIA(17, 18, 20) minutes. As soon as a board is finished, the warehouse inventory is increased.

The skimboard industry is booming, resulting in business success for the small skimboard shops that dot the U.S. coast. Gnarly picks up its orders in Conway with its own parcel delivery van, since it is only 16 miles from the Margaritaville factory, but Ono Surf Shop and Riptide Skimboards each have their own Cessna 414 aircraft that they use to pick up and deliver their orders. The Margaritaville factory batches a full order together for each customer and has the batches waiting when the transport equipment arrives at its facility. The distance from Conway to Venice Beach is 605 miles, while the distance from Conway to Destin is 667 miles; each of the Cessnas travels at 270 mph.

1. Simulation Tasks
2. **Base Model:** Build a simulation model of this SC as its described above and run 4 reps of 40 8-hour days each. Assume an initial inventory of 35 completed boards. **Statistics to be reported**:
3. Order cycle time, point and confidence interval estimate. Report cycle time for each customer.
4. Resource utilization, point and confidence interval estimates, for each of the manufacturing resources (jigsaw, paint booth, artists, and final poly painters).
5. Queue length, point and confidence interval estimates, for the queues at each resource.
6. Wait time, point, and confidence interval estimates for the queues at each resource.
7. Resource utilization for the transport equipment (1 truck and two airplanes).
8. Identified bottlenecks of the system: provide a description of the bottleneck, along with its key characteristics.
9. General observations: What did you notice about this system? Is it efficiently using resources? Are there bottlenecks? Comments on specific characteristics of this supply chain.

**Simulation Suggestions:**

1. A particular order from a particular customer could result in the creation of skimboard blanks into the system.
2. All three customers shouldn’t have orders at time 0. Stagger the “first creation” of the orders so that the system isn’t flooded with blanks at the very beginning.
3. Blanks should be identified by which customer they are associated with.
4. After an order comes in via a Create module, the inventory level should be checked before beginning production. If you’ve got enough in inventory, you’ve still got to ship the order to the customer. In that case, the created order entities just skip the production process.
5. Have a separate shipping dock for each customer, whether the created order entities went through the full production or if they “skipped” production and technically were taken off the warehouse shelves. Route the finished boards to the appropriate dock before shipment.
6. Batch a full order together before shipment, then ship one batch at a time. There’s no need to use a Hold and Signal loop to do this. That way, a transporter will carry a full order when it travels.
7. When the batches of skimboards arrive to a customer, the batch should be separated for individual sale.
8. Don’t forget about the Inventory Evaluator’s daily checks of the inventory levels, and his/her adjustment to inventory if it’s low.
9. Put all time measurements in minutes. However, travel velocities can be in miles per hour, as long as distances are in miles and velocities are set in “per hour” units.
10. **Conversion to a Lean Supply Chain**

For Part B of the Case Study, you are to develop several alternative supply configurations by adjusting key parameters of the model so that (1) all resources are used at the highest utilization possible, (2) in-process inventory is minimized, and (3) total time in the system is minimized. **In particular, develop three alternative versions of the skimboard supply chain.** You may adjust:

* Number of available units of a particular resource or resources
* Number of available units of a transporter
* Batch size for transport
* *Demand patterns for individual customers. As long as an individual customer orders the same number of boards per week, you may change the interarrival times of the orders and the individual order sizes.*

This part of the case study is more art than science: show your creativity in possible alternative model configurations. In this activity, there is no one “right” solution.

1. **Case Study Deliverables**

The deliverables for the Case Study assignment should include two files:

1. The Arena file for the base model of the Margaritaville Skimboard Company supply chain.
2. A full report of the work done in the case, presented in a Word file. This report should contain the following sections:
   1. An introduction to the case, which includes a brief synopsis of the details of the case.
   2. A narrative describing your personal modeling approach to the case. This narrative should demonstrate your personal creativity and original, authentic approach to modeling this supply chain.
   3. A Results of the Base Model section, which includes in a Word table the statistics to be reported. Do NOT paste the Output Report from Arena here: include ONLY the statistics requested.
   4. Presentation of Alternative, Lean Versions of the Skimboard Supply Chain. Briefly describe **each** model change attempted. In a Word table, present the “Statistics to be Reported” for each alternative version, along with the results for the base model. Explain your results after the table.
   5. Conclusions section. What did you learn about this supply chain by building both the base model and the alternative models? What parts of the supply chain could be changed in order to improve performance? Can this factory support more business? Which manufacturing steps should be improved/changed in order to reduce in-process inventory?
3. **Bonus Points**

Bonus points will be awarded to those who demonstrate interesting and detailed animation in their models.