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STRIVING FOR UBIQUITY OF SIMULATION IN OPERATIONS THROUGH EDUCATIONAL ENHANCEMENTS

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ABSTRACT

The 50th anniversary of WSC provides a good opportunity to reflect on how widely simulation is used in the business world to support problem solving and decision making. This paper posits that, despite the success of the WSC, simulation is not as widely used as it should be and that a major cause is a general lack of understanding of the value of simulation outside of the simulation-specialist community. However, this paper suggests that one way to increase the use of simulation is through changes in education. As part of the review and development of suggested changes, the paper examines the activities related to education at the WSC. It then offers a variety of suggestions for how the simulation education community – including academics, practitioners, and vendors – can help to address this issue.

1 INTRODUCTION

Having been involved in simulation for more than 40 years, beginning with my first simulation course in graduate school in the mid 1970s, I am surprised that simulation is not more ubiquitous in the design and management of operations systems, i.e., it is not the “go-to” tool for engineers. Similarly, I am amazed that managers do not generally require a simulation analysis as part of proposals for significant process-changes or capital investments. After all, no company would release a product without thoroughly testing it first. Similarly, most enterprises would not change their marketing approach without testing. However, few organizations – whether manufacturing, logistics, or service – effectively test their operations processes before initiating or making changes. specification may have changed.

One reason that simulation is not a common tool in process design is that the process design process itself, and its methodologies, are much less defined and respected compared to the product design and software design processes. Process design tends to be more ad hoc and thus its evaluation tends to be ad hoc and extemporary. If the process design process were more formal and rigorous, then simulation would likely be a primary tool to design, review, and evaluate process designs. While this is an important aspect to consider when assessing the use of simulation, further discussion is the topic of another paper.

Another reason that simulation is not as ubiquitous as expected is that there is a general lack of understanding in the business world of the power and value of simulation. In this case, business world means any type of operations, including manufacturing, healthcare, transportation and logistics, etc. If there were a general understanding – comparable to financial analysis, lean thinking, process improvement, etc. – then it would be used more frequently. It is this aspect of the use of simulation, or the lack thereof, that is the subject of this paper.

To address the premise of this paper that the application of simulation can be significantly increased through changes in education, it is organized as follows. Section 2 provides a brief historical summary of the role of education in the WSC over the past 50 years. Section 3 describes the need to develop a broader focus and consider simulation from the “consumer’s” view. Section 4 identifies and defines some means to increase the application of simulation through education. Section 5 provides conclusions and offers some opportunities for future work.

2 WSC AND EDUCATION

The WSC has certainly been a major contributor to the development of simulation methodologies, both through research-related presentations and introductory and advanced tutorials on many aspects of simulation. In recent times it has featured successful applications in its Case Studies track. Finally, it has been a great place to keep up with the latest technologies through the exhibit area and vendor presentations. However, one facet of simulation that has not been featured as much as those just mentioned is teaching simulation.

The 50th Anniversary of the WSC provides an opportunity to reflect on how WSC has contributed to the pedagogy of simulation. One way to assess this is to consider the number of papers and panel discussions that focused on education; this is reflected in Figure 1. Since 2000, the WSC's program has consistently included a Simulation Education track. As shown in the plot, this seems to have sparked dialogue about education and resulted in much more activity related to teaching than in the prior 30 years. However, there is considerable variability from year to year. The 2000 conference had the most papers presented - 14 in five sessions. The fewest papers presented since then has been three; unfortunately, one of those years was 2016, the last conference.

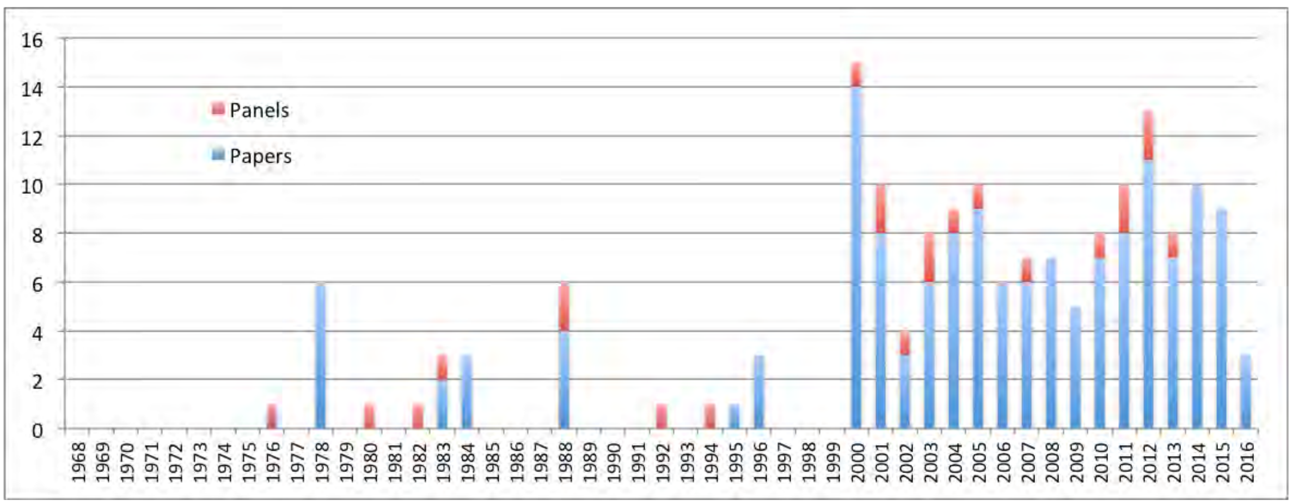


Figure 1: Level of activity related to education at the WSC. Source: Winter Simulation Archive (2017).

The focus, at least at the WSC, has been on the simulation specialist. Of course, this makes sense, most of the attendees are simulation specialists or those who are working toward that goal, whether in academe or practice. Papers in the education tracks tend to address teaching simulation-focused courses in universities, primarily in engineering and business programs. For many years the WSC has offered, and continues to offer, excellent tutorials. These sessions provide great opportunities for both new and seasoned simulation specialists to keep abreast of our changing field. However, we need to address how to ensure a solid understanding of the value of simulation in our simulation-based courses and how to reach a broader audience in terms of their awareness of the value of simulation.

Most of simulation education occurs in academe which develops and disseminates knowledge, both through teaching and research. Since the value of simulation comes from its application, a key aspect of simulation teaching and research should be how to effectively use simulation to solve problems. However, the primary focus on simulation in academe is on developing simulation specialists through ISE and MSci programs. At the undergraduate level, these programs typically require a full semester course in simulation modeling and analysis. This course is typically heavily focused on methodology and not application, where application involves professional practice, project management, and proficiency in simulation software. Today, most simulation software is powerful and sophisticated; therefore, proficiency requires more than a cursory introduction in a few tutorials or laboratory sessions.

Practitioners are those that apply the simulation methodologies and practices through the use of technology, i.e. simulation software. They need to balance the hard and soft aspects of simulation. The hard aspects include knowing how simulations work and being able to: customize software to handle today's system complexities, link simulation with other software systems, and design, analyze, and interpret simulation results. The soft aspects of simulation include knowing how to: formulate problems, set clear objectives, work with, and communicate with, stakeholders from diverse backgrounds, and use project management principles to successfully complete simulations. The WSC offers a practitioner-based case studies track that features many interesting and valuable applications of simulation.

Vendors are a critical link to education since no one does simulation without software. Simulation specialists must understand how the software works and how it can be customized to better represent the system being considered. Vendors can be a major resource for disseminating the value of simulation – they possess a plethora of information about, and models of, successful simulation applications.

A key point is that everyone does not need to be a simulation specialist in order to benefit from simulation. While simulation projects involve many stakeholders, most do not need to be simulation specialists. Similar to the common saying that we do not need to be an automotive engineer and understand the workings of a car in order to effectively use it, simulation stakeholders do not need to understand the details of simulation modeling and analysis. The domain experts are critical for validation, but with the visualization capabilities available in today's simulation software, they can easily view the behavior and results of the logic and data that constitute the simulation model without reviewing the logic and data directly.

To achieve this broader awareness and understanding, a place to start is with education, especially in engineering and business schools. It is imperative that IE and MSci students all understand the value of simulation and not just be aware of methodologies and technologies. Everyone in a simulation course will not be, nor will they necessarily want to be, a simulation specialist, but everyone in a simulation course should be strong proponents for the use of simulation. Therefore, simulation courses must provide extensive examples of the successful application of simulation. This can be done through projects, interactions with practitioners, case studies, etc. They can be individual and group research exercises to identify and describe application of simulation to their classmates. Therefore, time must be allocated in the simulation courses for these types of activities.

Beyond the basic simulation course, other faculty need tools that they can use to show the value of simulation through their courses. For example, simulation is a great way to teach operations, statistics, etc. We must reach managers, and future managers, as well as others in the organizations to expose them to the value of simulation.

We need to cultivate the interactions among key stakeholders in the use of simulation: academics, including teaching and research, practitioners, and vendors. The WSC is a great place to facilitate these interactions because all constituencies attend. However, they typically do not interact; and, if they do interact, the focus is on the simulation specialist, not the occasional user or decision maker.

3 A NEW FOCUS

We commonly use the service of many professionals because we understand and appreciate the needs they serve and we recognize we do not possess the expertise required to perform the service. This is the case for doctors, attorneys, accountants, engineers, architects, etc. To us in the field of simulation, the need for simulation is clear, processes should to be tested and evaluated before instituting change, but there is a general lack of awareness and understanding of this need. Therefore, in addition to developing and supporting the specialist, we need to enlighten potential consumers of simulation and through them stimulate demand.

This requires a proactive approach to reach the real consumers of simulation – those that use simulation to support their problem-solving and decision-making processes and those that are affected by the decisions. Using the "Field of Dreams" analogy, if we build representative models and conduct the right analyses, "they" will come, has not resulted in a more ubiquitous use of simulation in operations analysis. While many have come, and benefited from simulation, many have not. As proposed earlier, a major problem is the lack of a broad and general knowledge of simulation and its power to aid in problem solving and decision making. Generally, the simulation community does not address this broader reach. One exception is the structure of the Beaverstock, Greenwood, and Nordgren (2017) textbook; it is organized around three level of users: occasional, intermediate and advanced.

The premise of this paper is that the simulation community needs to focus more on promoting a clear understanding of value of simulation. One way to accomplish this is to ensure that students in simulation-focused courses have a solid understanding of the basics of simulation, how it is applied, and how it can be used to enhance problem solving and decision making. Of course, in order to develop simulation specialists there still needs to a solid understanding of simulation modeling and analysis. But, as noted earlier, everyone does not need to be a specialist in order to use and advocate the use of simulation. Therefore, an outreach to a broader population is needed. For example, all business students, or at least operations management students, need to fundamentally understand the value of simulation and how it can be used to enhance problem solving and decision making. This understanding will likely need to be developed on multiple fronts.

Much of the focus of WSC and our education is focused on the producer of the simulation, i.e. the simulation specialist, and not the consumer. The consumer is the one that makes use of the simulation – it helps them solve their problem or make a better decision. In this case, consumer is preferred to user since it is more general and implies to a lesser degree direct interaction with a simulation model.

4 MEANS TO INCREASE THE APPLICATION OF SIMULATION VIA EDUCATION

This section describes some of the opportunities and means that are available in higher education to enhance the basic understanding of the value of the use of simulation to support the problem-solving and decision-making processes. Examples of these means are provided from the literature and from the author's experience. There are two basic strategies for enhancing the understanding of the value of simulation value; both strategies take a more consumer focus, as described in the previous section. One strategy focuses on increasing breadth, the other on increasing depth.

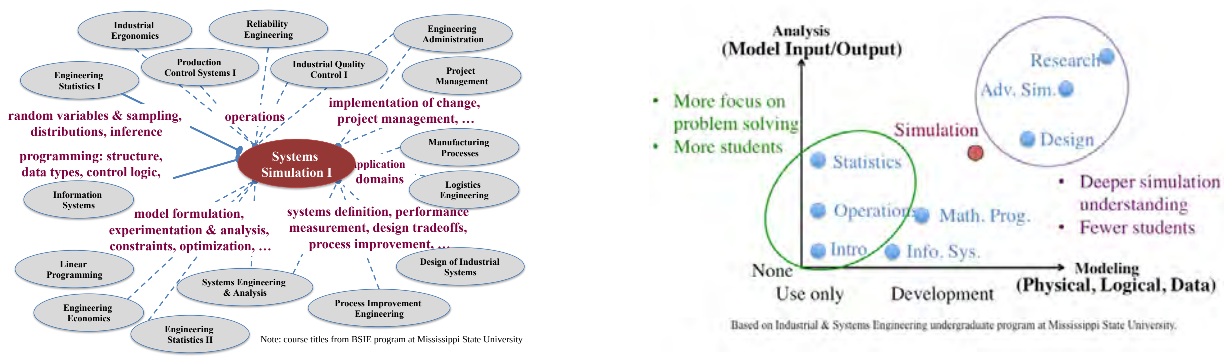
4.1 Breadth strategy

A breadth strategy involves reaching out beyond simulation-focused courses, either within the curriculum or across curricula. Obviously, the first is easier to accomplish.

4.1.1 Intra-curriculum outreach

There are many opportunities within curricula that offer a simulation-focused course to enhance the understanding of the diversity and power of simulation. This is illustrated in two ways in Figure 2, both are based on a typical ISE undergraduate curriculum.

Figure 2a identifies the topical relationships between the simulation course and other courses in the curriculum. Prerequisite courses are linked to the simulation course via solid lines; other courses in the curriculum, that may be taken before or after the simulation course, are linked to the simulation course via dashed lines. The topics that are related between the courses are noted on the link lines. For example, random variables and sampling, distributions, and inference are topics from engineering statistics that are a foundation of simulation. Similarly, operations as a topic is discussed in courses in ergonomics, production control, quality, etc.



a. Topical relationships

b. Modeling/analysis relationships

Figure 2: Examples of intra-curriculum links to simulation. Source: Greenwood and Beaverstock (2012).

Even though courses in engineering statistics and information systems are prerequisites to the simulation course, the use of simulation can be introduced into those courses. For example, in the engineering statistics course, simulation can both be a source of data for statistical analysis and can be the reason for a designed experiment. Romen (1995) notes that while simulation courses make heavy use of statistics, the converse is not true. Examples of the use of simulation to teach statistics is discussed in Chi, Pepper, and Spedding (2004), Romen (1995), and Walker (2004). In the information systems course, algorithms related to simulation can be used for programming exercises and linking applications, such as interfacing a simulation model to spreadsheets or databases.

As shown in Figure 2a, there are many links between non-prerequisite courses in the curriculum and the simulation course. In addition to the broad notion of operations that is noted above, the following topics are all related to simulation: implementing change, project management, application domains (manufacturing, healthcare and other services, transportation and logistics), system definition, performance measurement, design tradeoffs, process improvement, model formulation, experimentation and analyses, constraints, and optimization. Therefore, simulation can be used in these courses as examples (e.g., managing a simulation project) or as a means to illustrate concepts (e.g., the effect of various processing rules on performance).

Figure 2b illustrates the relationships between the simulation course and other courses in the curriculum in terms of the extent of modeling and analysis. In this case, modeling refers to representing the physical, logical, and data aspects of a system and analysis involves using a model to consider alternatives and support decision making. Focusing on the less modeling-intensive courses can emphasize the problem-solving and decision-making power of simulation.

4.1.2 Inter-curriculum outreach

Reaching students outside of programs that contain a simulation-focused course is obviously more challenging. However, some examples are provided below. Simulation faculty can develop and provide materials to faculty in other programs, such as:

- Case studies of how simulation has been used in industry to improve operations. There is an abundance of published examples (e.g. Winter Simulation Conference proceedings, *Interfaces* journal, vendor websites) of how simulation has been used in numerous and diverse industries to improve operations.

However, the information needs to be compiled, summarized, and formatted for effective distribution and use.

- Interactive "games" that use simulation to illustrate operational concepts, etc. These can range from large comprehensive simulations, such as the plant-wide comparisons of traditional production approaches versus lean implementations that was developed by Walden and Hill (2007) to simpler, more narrowly-focused interactive examples such as those included with the Beaverstock, Greenwood, and Nordgren (2017) textbook. One example of a simpler, more narrowly-focused interactive example is shown in Figure 3. The figure shows the one-page system description, screenshot of the simulation model, user interface, form for submitting a recommended solution, and a trade-off of performance measures. In this example, students experiment with several system parameters that affect the operation of a roller coaster (e.g. number of cars, number of passengers per car, and staffing levels) in order to try to maximize the performance of the system. The exercise demonstrates the basic conflicting tradeoff inherent in many simulation projects between the cost of customer waiting and the cost of providing a service. The exercise also illustrates the need for multiple replications. This example has been used to introduce simulation to freshmen in an introduction to ISE course and to high-school students to recruit them into ISE. Students complete to find the best solution.
- Guest lectures by faculty to illustrate and demonstrate the use of simulation in problem solving and decision making.

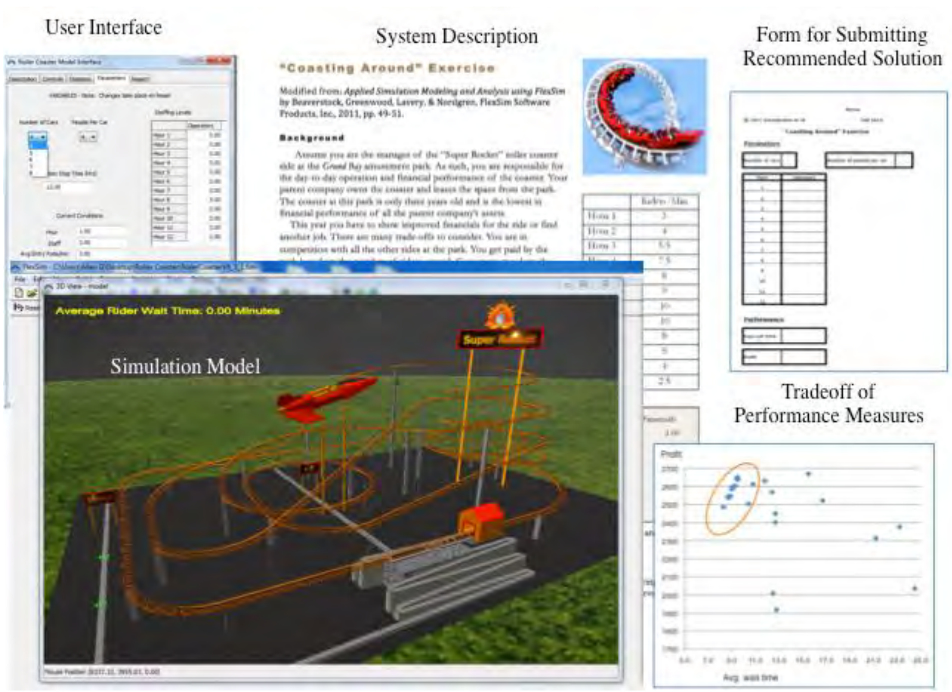


Figure 3: Exercise to introduce simulation. Source: Beaverstock, Greenwood, and Nordgren (2017).

Other possible outreach activities include:

- Demonstration of simulation models and analyses by faculty, students, and industry representatives at college fairs, recruiting events, industry days, departmental open houses, etc.
- Cross-disciplinary student projects such as between mechanical and industrial engineering or operations management and industrial engineering.
- Invitation of a broader audience to select presentations from industry, faculty, students, etc. on successful applications of simulation.

One critical constituency to reach are business-school students since they represent many of the potential decision makers that can demand simulation-supported analyses, if they understand the value of simulation and the risks associated with not simulating before deciding. This has been the topic of discussion at the WSC, especially in terms of operations management, e.g. Born (2003), Chwif and Barretto (2003), Saltzman and Roeder (2013), and Jain (2014). Jain (2014) identifies the importance of simulation to support decision making, but notes that the general trend has been for business schools to reduce the quantitative-course requirements in many business curricula. However, this may be reversing with the increased interest in analytics. The author notes that while business schools use simulations, students are not learning how to develop the simulation. Jain's survey, based on the 49 responses from the top 100 business schools, indicate there is significant interest in teaching discrete-event simulation and system dynamics.

Another prime area for emphasizing the use of simulation is in engineering management programs. As Tolk, Rabadi, and Merino (2009) indicate, engineering managers need to understand the technical aspects associated with simulation design and implementation as well as the administrative and management processes associated with simulation intensive projects. They also point to the 2006 NSF Report on "Simulation-based Engineering Science" as an impetus for an increased focus on the use of simulation in engineering education and practice.

4.2 Depth strategy

There has been considerable discussion of teaching simulation in a full-term course at the WSC. Many of the discussions have been via panel presentations, e.g. Bellas et al. (1980), Roberts et al. (1982), Kachitvichyanukul et al. (1988), Jacobson et al. (1994), Altiok, et al. (2001), and Banks (2001). These sessions provide a range of perspectives – primarily from engineering, business, and industry – on the simulation courses' structures, contents, and approaches, mainly at the undergraduate level. Of course, a number of papers have focused on similar general pedagogical issues, but in more depth, such as: Nance (2000), Nance and Balci (2001), Standridge and Centeno (2005), Garcia and Centeno (2009), and Greenwood and Beaverstock (2011).

A depth-based strategy involves modifying the topics and activities within a basic semester-long simulation course to ensure students have a solid understanding of how simulation is used to support problem solving and decision making. Of course, this involves the classic dilemma of not offering enough fundamentals and having simulation misused, which obviously negatively impacts the use of simulation, versus spending too much time on technical foundations resulting in a very limited ability to apply simulation, also limiting the use of simulation in practice. Setting the dilemma aside, there are two basic approaches to developing a stronger understanding of the use and value of simulation: (1) raising awareness and (2) providing hands-on experience. The former is more passive and requires less time and effort; whereas, the latter is more active and requires more time, both in the course and by the instructor.

4.2.1 Raising awareness of simulation applications

Many of the approaches for raising awareness within a simulation-focused course is similar to those used for inter-curricula outreach. Therefore, the approaches are just listed here since they are described in Section 4.1.2.

- Case studies of how simulation has been used in industry to improve operations.
- Interactive games to illustrate application areas and decision making.
- Demonstration of simulation models and analysis developed to address specific problems.
- Guest speakers from industry – younger speakers and former students are the best spokespersons since students relate better with their peers.

4.2.2 Hands-on experience with simulation applications

The main approach for providing hands-on modeling and analysis experience in a simulation-focused course is through course projects. Adding a project to a course obviously requires the removal of some topical coverage and/or other course activities (tests, assignments, etc.), which always forces hard decisions. Introduction of a course project requires careful planning and management. Some of the definitional factors of a simulation-based course project include:

- Degree of project focus, or how much course time and assessment is allocated to a project. Time needs to be available to discuss the project both in and outside of class time, including project definition, status, results, and feedback.
- Student-defined or faculty-defined, i.e., who identifies and defines the project. Typically, in a faculty-defined project, all students address the same problem in the same application domain; whereas in student-defined projects each group addresses a different problem and likely in a different domain. Student-defined projects provide more diversity of application, but are more difficult to manage. Also, students may spend considerable time on the problem definition, formulation, and scoping aspects, which are good experiences, but may limit the extent of simulation modeling and analysis.
- Number of projects. Related to the item above, but regardless of who defines the projects, the total number of projects in a course. If the entire class addresses the same problem in the same domain, evaluation is easier, and possibly fairer, and competition may increase quality. Also, there is the opportunity for collaborations among groups on some of the more challenging aspects of the project, e.g., modeling the arrival process, representing complex process logic in the system, constructing 3D objects, data collection for analysis.
- Level of customer (system-owner) involvement. Typically, industry-based projects provide better learning experiences; however, they involve more coordination, and thus more time, as well as more risk. For example, company-provided information may be delayed due to shifting priorities; however, course dates have little flexibility. The instructor can play the role of the customer – providing basic system definition supplemented with student research and faculty-supplied information on the system as requested by the students. Typically, a project based on a case study has no customer involvement – all information is supplied or assumed.
- Extent of system definition. As with any simulation project, clarity of system definition can vary greatly in terms of objectives, performance measures, flows, times, sizes and locations, process logic, data availability, etc.
- Composition of groups. Simulation projects are typically done in groups; therefore, there are many group-related issues: who forms the groups and by what means, size, performance evaluation, etc.
- Evaluation of project components. Criteria and weight for model, analysis, documentation, interpretation and presentation (written and oral) of results, status reports, customer interactions, etc. The evaluators for each component must be specified, e.g. faculty, group, industry, external judges. Also, how much of the total project grade is group-based and how much is measured at the individual student level.
- Feedback and discussion. Time should be allowed to discuss the project process and results, identify lessons learned, and provide feedback. Many opportunities for learning are missed when projects are just submitted at the very end of a course.

Figure 4 provides a collage of materials from a project in one of the author's simulation-focused courses. The collage shows example data sources (e.g., layouts, schedules), simulation models, simulation output, and photos from the system definition and presentation to client phases. The project involved modeling and analysis of a surgical suite at a major regional medical center. Approximately 20% of the course time was spent on the project; the remainder involved the foundations of simulation modeling and analysis. Similarly 20% of a student's grade was derived from the project grade. The project was faculty-defined in collaboration with the staff at the medical center, who were heavily engaged in the project. Each student group modeled a different type of surgery area. However, the groups collaborated so that representatives from each group focused on certain modeling and analysis issues, as well as interactions with the hospital. Students presented their work to key members of the hospital staff in a "walk-around" review. The hospital provided an award to the students who, in the judgment, had the best project.

Figure 4: Example project from a simulation-focused course.

Figure 5 provides a collage of project materials from another of the author's courses. The figure provides a sample of the companies involved, poster promoting the project presentations (a major university event), photos showing student immersion in industry and scenes from the presentations event, and a sampling of the simulation models. This course is part of a two-semester course in the logistics degree curriculum offered by the Faculty of Engineering Management at Poznan University of Technology (Poland). The first semester course covers logistics process design and includes an introduction to simulation in the laboratories. The second course involves group projects that take place in local companies and focus on the use of simulation in the design of logistics processes and systems. Course faculty work with students throughout the project semester on simulation modeling and analysis issues. The course was developed by Professor Pawel Pawlewski and is currently in its eighth year; see Pawlewski and Pasek (201, 2012).

The use of projects in simulation-focused courses add greatly to student understanding of how simulation can be applied to support problem solving and decision making. It also adds relevance to the course, which many students want and need. Relevance is important to industry as well – they want graduates who quickly become productive and who can effectively use problem-solving tools. Developing working relationships between faculty and industry result in a win-win situation. Last, but not least, successful projects are satisfying and rewarding.

Of course, there are many challenges to using projects in courses, especially those involving real systems and industry participation. As mentioned earlier, to make room in a course for projects, topics need to be modified or taught more effectively. Since projects involve real problems, they are inherently risky and messy. As a result, they require considerable time, planning, and management, which is challenging to faculty given their other commitments, responsibilities, and priorities. There is additional work for students as well, which will have mixed reactions.

Figure 5: Components of a simulation-focused project course.

5 CONCLUSIONS AND RECOMMENDATIONS

Considerable progress has been made over the past 50 years in terms of the use of simulation, as evidenced by the successful history of the WSC. However, there is still a ways to go to make simulation ubiquitous and the "go-to tool" for engineers and managers to support their problem-solving and decision-making needs.

Hopefully the WSC will encourage and promote the ways and means for realizing a more widespread dissemination of knowledge of the value of the use of simulation. Of course, as with any endeavor, it primarily requires a grassroots effort, among individuals, to make it happen, but hopefully the WSC can be the catalyst and the forum. Below, are few ideas, as starting points, to move the agenda forward.

- Sessions, panels, workshops, papers and case studies that focus on the ways and means to develop a broader appreciation and understanding of simulation's role in the design, testing, and management of organizational processes and systems.
- Keynote/plenary presentations that discuss the broader outreach.
- Recognition of teaching and education through a best education-focused paper or contribution, vendor student awards, promotion and recognition of university-industry collaborations, etc.
- Collaborations among professional societies and conferences to enhance dissemination.
- Faculty, practitioner, vendor collaborations with a focus on a high-level awareness.

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