Proceedings of the 2019 Winter Simulation Conference
N. Mustafee, K.-H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.-J. Son, eds.

TOPICS IN DISCRETE EVENTS SIMULATION FOR BUSINESS STUDENTS

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ABSTRACT

This paper is focused on the issue of how one can get Discrete Events Simulation (DES) more used in Business Schools, since this type of simulation allows students to do interesting simulation projects in companies. We list a great number of project topics that we in four countries have given our business students and which they have been able to carry out successfully as part of an introductory course, requiring one month of work. This list of topics can hopefully give also other students ideas for project work. For some of these topics we also bring out some interesting details.

1 INTRODUCTION

In business courses there is a great focus on being able to estimate and handle the uncertainty inherent in many business situations. One of the methods that is suitable for this is simulation. The use of simulation for this purpose is quite in line with the conference theme *Simulation for Risk Management.* In order to be able to estimate the uncertainty, one has to do a great many simulation runs and have a clear strategy as regards the experimental use of these runs.

This has been a main focus of the simulation courses that my collaborators and I have been teaching to over 10,000 business students since the mid-1970s in Sweden, USA, Norway and Latvia. The teaching has been done, besides by myself at the Stockholm School of Economics (SSE) and at Hofstra University, NY, by Rich Born, at the Business School of Northern Illinois University, and Endre Bjørndal at the Norwegian School of Economics and Business in Bergen and by Edgars Jakobssons and Nicolas Gavoille at the Stockholm School of Economics in Riga.

In many of the courses that have corresponded to a month of full-time work, e.g. one of five courses during a semester, the course has had the focus that the students should do a simulation study out in reality, preferably in a company and resulting in a report of interest to decision makers in this company. We have over the years been involved in almost 1000 such student projects.

All the projects have been carried out in some version of GPSS. We started using an IBM GPSS version, but we have since the end of the 1970's developed our own stream-lined version, after 1998 with a GUI for input and output, lately called aGPSS. The projects listed below could also have been done in some other simulation system, but we believe that in a course with such limited time for the students as a one-month course, aGPSS is a preferable alternative (Born and Ståhl 2013). Most other simulation systems have over the years become more and more sophisticated and complex, but we have instead kept simplifying aGPSS even further, for example making the input dialogs simpler.

Against this background, this paper has several purposes: One is to provide ideas for business oriented projects. We have in our courses for many years provided a list of ideas for suitable projects. The list in this paper is mainly a compilation of these lists. This can hopefully also give new business students, at other schools and universities, ideas for simulation projects.

The reason for such a list is that many students have asked for suggestions for project topics. Even for those students that bring their own ideas for a project, this list of topics has proved helpful by indicating what is a feasible size of a student project. One of the main problems of the original student project idea is that they often tend to be initially too ambitious and too time consuming. Sometimes the students have switched from their original idea, or modified it, on the basis of our list of suggested topics. This list of topics is partly influenced by what earlier student projects have proved successful. The list of topics is hence constantly updated.

Our hope is that this list of topics can be of interest not only for the WSC'19 participants, but also for the many other students who access the WSC Archive (https://informs-sim.org/). As I have learnt from Research gate, business students in many countries, especially in Asia, have read my earlier WSC papers on the use of simulation in education.

Another purpose of this paper is to show the great variability and broadness of business areas that can be covered by a general purpose simulation system and is of interest to business students. I have found that DES (Discrete Events Simulation) can be very useful for a great many subject areas covered in a business school, in particular in business oriented courses of Management Science and Operations Research. It can replace many analytical/optimization methods, for example queuing theory, inventory theory, project planning methods (like PERT/CPM), and decision theory. It has also proved advantageous to cover many problem areas with one single easy-to-use method instead of many complex methods. This has allowed us to focus more on modeling the studied problems and allowed more time for the project work in companies.

Simulation furthermore plays a significant role in the teaching of production and service management, as well as forecasting. Simulation involving production has allowed our business students to get a better understanding of the physical processes in a firm and to see the connection between the physical activities and the financial flows. Simulation based costing, as a special version of ABC (activity based costing), has furthermore been useful when studying cost accounting.

It is against this background surprising that DES is not taught more at business schools. This is discussed in Jain (2014). It is my belief that the relative limited use of DES in business schools is due to two factors. The first of these factors is the lack of information about DES software that can be learnt by business students in a limited time, like a one-month course. I have discussed this first factor, e.g. regarding easy-to-learn software in an earlier paper (Ståhl 2007). The second of these factors is the lack of information about the many business areas in which DES is a superior tool. My focus in the paper is hence on giving our students, as well as teachers, ideas for topics for a DES project in a one-month simulation course at a business school that will cover these interesting areas, and which have proved possible to carry out in such a short one-work-month course.

2 WHY DES AND NOT ONLY EXCEL AT A BUSINESS SCHOOL

As regards the use of DES in business courses, one question then arises: Why should business students not be content with using only Excel? The most important reason is that for many projects it is not at all possible to give a fair representation of the problem in a spreadsheet. Although it is fairly straightforward to represent stochastic uncertainty in a spreadsheet, in particular if one has an add-on like @Risk or Crystal Ball, it is very difficult to give a fair representation of the dynamic aspects of the problem, so that one can follow the development of the simulated process over time.

One factor is of course that a spreadsheet has a limited number of columns to be used for dates. In reality it is seldom practical to have a spreadsheet with more than 50 - 100 columns, since the model otherwise becomes too large to see on the screen or to print on paper. This implies that one has to limit the number of time-points included in the model to a small number. The effect of this limitation can have severe repercussions of how the models represent reality. We can exemplify this lack of number of time points for events with the two diagrams on the next page, regarding the development of cash held by a firm over time.

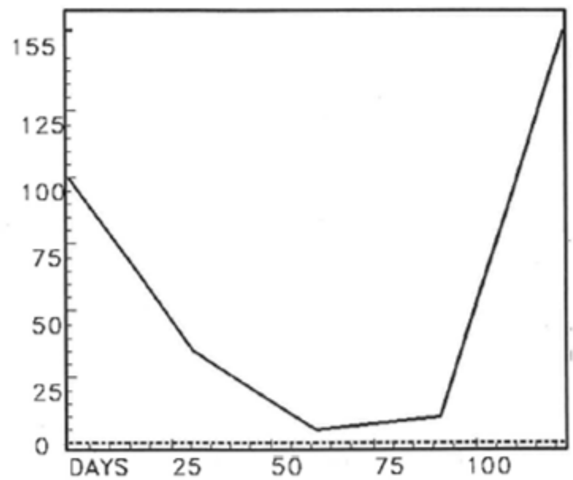

Figure 1: End of the month cash graph.

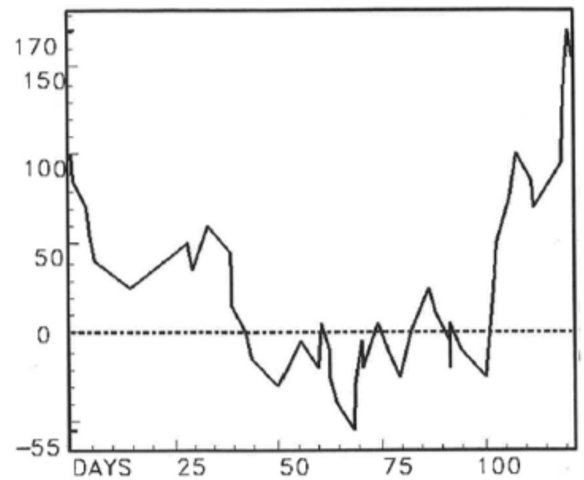

Figure 2: Dynamic cash graph.

We see that the two figures lead to completely different conclusions. In Figure 1 there is no seen risk of running out of cash, but in Figure 2 one sees clearly that the company will run out of cash several times, although it will have a positive cash balance at the end of each month.

These diagrams have been produced by a simple aGPSS simulation program for cash forecasting, presented in Born and Ståhl (2013). The program deals with an importer who buys and sells certain machines. It pays the producer in cash directly for each unit, but provides the customers with credit. Orders arrive according to an exponential distribution, while customers' payment times vary according to an Erlang distribution. Our students can write this program after a few hours of study.

An even more serious limitation with Excel is that one cannot correctly model conditional effects involving time. We can illustrate this problem of Excel with a very simple example that is easy to solve in a DES system, but virtually impossible to solve in Excel. A company has sales of $100 in month 1, $200 in month 2, and generally *j**100 in month *j*. The customers pay after either one month or two months. We want to print out the sales and the payments for each month. The determination of the payments is then problematic. The "nearest" solution in Excel is to have a formula =IF (RAND()<0.5,B2,C2) for the payment in March in cell D3 and then copy this formula to cell E3. This formula implies that if we sample a uniform random value RAND() < 0.5, the payment in March in D3 will be fetched from the sales in January in B2, otherwise from the sales in February in C2. That this solution is incorrect can be seen from the two tables in Table 1 below, obtained after clicking in a sequence. As seen to the right in this table, the February sales are paid twice, while as seen to the left in the table, February sales are never paid.

Table 1: Excel tables for the problem with payment after one or two months.

	A	B	C	D	E
1		Jan.	Feb	March	April
2	Sales	100	200	300	400
3	Payment			100	300

	A	B	C	D	E
1		Jan.	Feb	March	April
2	Sales	100	200	300	400
3	Payment			200	200

The cause of these errors is a fundamental limitation of a spreadsheet like Excel, namely that the formulas are located in the cells. In a spread-sheet we can only pull data from another cell, not send data to another cell. Hence in cell B2 for January sales, we cannot write "Send this value to cell D3 if RAND() < 0.5, else to E3" (Born and Ståhl 2013, pp. 327-328).

Among other problems with Excel, compared to some DES software, is that a model in Excel tends to be very large and hence difficult for the teacher to read and correct. On the other hand, for a teacher, DES systems like ARENA and aGPSS have the advantage of automatically giving a clear code of the whole model, which makes it easier to see if a model is correct and to help debug models that give an erroneous result. We shall below give a few examples of projects that were first modelled in Excel and then in aGPSS with a much smaller and a much more readable model.

3 STUDENT PROJECTS IN GPSS

We shall below present a great number of project topics. For most of these we shall be very brief and only present the main idea. In a few cases we have, however, found it suitable to present some details, which we regard as especially interesting.

It is in this context important to first discuss the main difference between our business students and the main part of simulation students with an engineering background, e.g. in production engineering.

There are two main differences. The first one concerns the type of projects that are of are interest to the students. For production engineering students, the production process, especially dealing with plant lay-out, is of highest interest. It is then often enough to run the simulation a few times, studying the production flow in the plant. For this reason animation of the production process is of great interest.

In contrast, our business students are most often interested in the end results, often measured in monetary terms, of a great number of simulation runs. Although not all topics are strictly limited to business issues, they will in general involve many repeated runs to evaluate the stochastic feature of the problem. As mentioned earlier, the focus in here on dealing with the uncertainty involved in business process, often due to a very complex environment, mainly outside of the control of the studied company. Animation is of less interest. Out of our nearly 1000 projects, only a dozen have involved animation, although aGPSS has a special interface to Proof Animation of Wolverine Software. One reason for this lack of animation is that learning to build a nice-looking layout and make nice drawings of the objects has often seemed too time-consuming when at most a month of work is expected for the whole project work. Another reason is that running an animation is time consuming and one can only make a very limited number of runs, which means that one cannot study the variability in results.

Another difference is that our business students in general have a much weaker background in computer science subjects. While most engineering students have some background in a computer programming language, like C++, out students have at best had a short course in Excel.

It should also be mentioned that some of the project models exist both as the original student project model and in a simplified version, done by us teachers, with especially the data changed, e.g. simplified and with changed numbers to protect companies, and sometimes available in the publications mentioned in the references. Many of the projects are covered in a new booklet (Ståhl 2018), which can be downloaded, free for charge, from http://agpss.com/books.html. Some projects or exercises have, on the contrary, started as teaching material, which the students have used and expanded in their project work. Some projects were extensions of cases in Schriber's 1974 "Red book". Although the booklet is accompanied by commented solutions in aGPSS, most of these project exercises are suitable for use also with other DES software, like ARENA. It should be noted that no animation is involved, but the focus is on repeated runs.

It should also, as a general observation, be noted that we prior to the start of the project work have told our students that it is suitable that the project should utilize the strong sides of a DES system, i.e. that it can handle problems that involve most of the following factors:

A. Stochastic, e.g. with uncertainty.
B. Dynamic: Every time-point must be possible.
C. Waiting is included.
D. Earlier states of system must be remembered.
E. Attributes of individual transactions must be possible to follow.

3.1 Service and Office Projects

The largest group of topics dealt with in our student projects have been service activities, partly due to the fact that many business students have personal experience in this area. Many of our students, in particular when I was teaching in NY, came from families owning restaurants, all the way from fancy ones to fast food restaurants, where topics have included e.g. the location of the various drive-in services. Restaurant management is dealt with in Case 94 in Ståhl (2018).

In particular in Sweden, projects have been dealing with government service office, like tax offices and post office service. In these cases there has often been a focus on waiting times and waiting lines. This also applies to numerous supermarket projects. Some years ago, before the wide use of the web, several projects also dealt with travel agency activities.

In Sweden students of mine made an extensive simulation of a major government liquor store, involving also some animation, which, when presented to top management, led to immediate changes in the waiting line system. The projects involving retailing and wholesaling have often involved inventory planning, i.e. determining optimal levels of replacement and order quantity under uncertainty. We have in our teaching of DES also dealt with inventory simulation models to compare the results with those of the most common analytic inventory models. We have also had a large project with inventory models that were used as training tools for retail managers in a large Swedish retail chain. Other models have dealt with how to represent reneging in the simplest way. Several projects have furthermore dealt with gas stations, often dealing with manning during peak hours.

A special retail simulation project has dealt with the stocking of perishable products in a supermarket. How shall one place new cans of e.g. cottage cheese on the shelf to minimize the loss of getting the cans spoilt from being too old (Born 2004). In later years, some projects have dealt with E-shop systems, e.g. regarding the ways to compose ready-made shopping bags.

Many service projects have dealt with hospital planning. Most of the projects have been part of the mentioned one-month projects in the bachelor program, but we have also had a few people writing Masters theses based on simulation of hospital care, concerning e.g. heart operations in England and hospital porter service in Norway, dealing mainly with patient transport. Some projects have dealt with dentist office management, among other things gold inventories held by dental technicians.

Several projects have dealt with emergency ambulances with a focus on providing service in time. One project has dealt with decease development over time, where Markov chain similar probabilities for transmission of the decease play a major role.

Other service simulation projects have dealt with the planning of new museums and exhibitions (Case 81 in Ståhl 2018), library operations, music studios, amusement parks, golf course management, ski lifts and betting booths at a horse racing arena.

Several projects have dealt with problems that are common in most offices. One example is the administration of secretarial service, e.g. the question if a company president should have his own secretary or if he should share her with a pool of secretaries. Another problem is copying service: How many copying machines are necessary in a company, and who should have priority? Some projects have dealt with the planning of the moving out of medium sized office to another building.

Other projects have dealt with personnel and pension planning in a medium sized company or college. This involves simulation over many years, where one follows a limited number of people, e.g. a couple of hundred, over the years, one by one, with for each person a certain probability each year of leaving the company. New persons are then brought into the model. One also samples the function for the salary development of each employee. One can by simulation follow the personnel situation and the total retirement debt. Other personnel projects have dealt with the handling of cases of stochastic absenteeism.

3.2 Computer and Telephone Systems

Many of our simulations have dealt with computer and telephone systems, but from a non-technical, business operations point of view. How many servers are needed from a certain service level point of view?

How much money is lost if there is a lack of service? How many computers are needed in a college PC lab, so that business courses can be well run? Several projects have dealt with electronic banking systems. What computer capacity is needed to provide for a profitable system?

One important student project dealt with the Stockholm Stock Exchange electronic system (SAX). Another project dealt with a special back-up central system company, which provided temporary computer service to other companies which ran the risk of suffering badly from a breakdown of their ordinary computers. The project involved a model that could be used to get new clients. The simulation model was hence aimed at simulating the operations of the potential customer in order to estimate how much this customer would loose from a temporary breakdown of its computer system and hence how much it would be worth signing up with the back-up company.

Simulation projects have also dealt with a new computer company, involving repeated sales and the effect of launching new models (Case 84 in Ståhl 2018). Software development has also been the focus of some projects. How many programmers should one use in a team for developing a certain software product within a given time (Case 93 in Ståhl 2018)? Other projects have dealt with the manning of help desks for computer users, e.g. in very large Swedish and Norwegian banks.

Several projects have dealt with telephone systems. In particular, during several years we had students working on simulation models for the Ericsson MD 110 switch board. The models were meant for sales support to be used on a lap top by salesmen when selling this switch board, e.g. to insurance companies. The models would test the result for various combinations of number of trunk-lines and number of insurance agents (Case 98 in Ståhl 2018). Some of the models would also, based on input from the client company, calculate the economic loss suffered when a customer could not reach an agent in proper time. It is of interest to note that simulation on a lap top was initially too slow so that the salesmen had to use an analytic model instead. Since the results of the analytic model could be wrong with up to 20 percent, simulation would be better, if it could be fast enough. With the doubling of calculation speed every two years (in line with Moore's law), a simulation model was after some years fast enough to replace the analytic model.

3.3 Logistic and Traffic Systems

Logistics is an important field of study within Management Science. We have had several projects within the logistics area. Some have dealt with the use of trucks on European roads, studying the effect of various stochastic delays on car production in three European countries (Case 100 in Ståhl 2018). Others have dealt with repairs of trucks and cars, systems for preventive maintenance in companies or government agencies with many cars and the planning of activities on marshalling yards. Some projects have dealt with the location of warehouses within a supply chain system. Other projects have dealt with package handling at DHL and trailers for deliveries of gas.

We have had several simulations of bus traffic, in particular in Bergen, Norway. Models have proceeded from single simulations of a single bus line to more complicated systems with several bus lines, finally comparing these with the traffic on the new tramway, Bybanen. In Bergen we have also had several projects regarding the funicular system at Fløyen.

We have had simulation of subway systems in other countries, like England and Switzerland, mostly limited to traffic on a few specific lines. As regards ordinary trains we have had projects regarding car trains, in particular focused on the driving on and off the trains.

There have also been many projects regarding shipping, especially in Norway. Some have dealt with tankers on international routes, other with ferries between islands and the main land (Ståhl 2018 - Case 53). Several have dealt with harbors and decisions on the number of quay places to be built or used. A large project concerned icebreaking operations in the Northern Baltic. A simple prototype was first built in GPSS, and then a larger and more detailed model was built in Simula (Jennergren 1995).

There have also been projects on air traffic. One has dealt with the boarding order for passengers on airplanes. Others have dealt with the choice to be made in an airline between using several smaller or using fewer larger planes for traffic on specific domestic routes traffic. We have also had projects on an airline's decision regarding over-booking and price differentiation (Ståhl 2018 - Case 66). Others have dealt with activities at airports, like gates assignment, luggage handling, check in procedures and air traffic control. Other projects have dealt with air plane maintenance. One project dealt with the decision to be made by SAS between having certain activities at Kastrup or at Arlanda.

Quite a few projects have dealt with road traffic systems, mainly short time decisions concerning timing of red and green lights in a street crossing and the decision on how many booths to keep open at a toll plaza. Others have dealt with more long term decision, like between investing in traffic lights or building roundabouts. Traffic light and toll plaza simulations have been popular with our students. The reason for this popularity among our business students has often been that the students have not been able to find a suitable company for their project and these traffic simulations do not require any contacts.

Although we would have preferred that the students do work in a company, these traffic system simulations have at least the benefit that it is easy for the students to do actual measurement of e.g. arrival rates and drive through times, and preferably do a statistical analysis to see if standard time distributions might be suitable replacements for the input of empirical data pairs. Some traffic light simulation projects have also involved optimization with regard to minimizing the total time that cars have to wait at the traffic light. We have also had several projects regarding taxi systems; in particular we have had one Master's thesis project concerning the total taxi system in Bergen, the second largest city in Norway.

3.4 Finance

Several projects have dealt with banking services, all from the handling of ATM machines to decisions on the number of tellers and the choice between separate waiting lines at each teller and a number ticket system for a joint waiting line. A few projects have involved the administration of loan applications.

Some projects have dealt with how much cash a local bank office, located a some distance from the central office, should have in the morning in order to have a low risk of running out of cash during the day and yet not lose too much interest from having cash instead of interest bearing loans. Several similar projects have been more advanced in that they have not been limited to only one currency, but have dealt with inventories of up to a dozen foreign currencies. Other projects have dealt with portfolios of different types of short loans.

Among projects in finance we should mention the valuation of European stocks with changing volatility. We deal with a call option where the buyer (owner) of the option can buy the stock at a pre-set price, the so-called exercise price, after one year, if she wants to. We have for the model chosen the following formula for estimating the value of the stock at the end of a period:

$$y\text{*exp}((r-s^2/2)\text{*}t+s\text{*sqrt}(t)\text{*fn\$snorm}),$$

where y is the value of the stock at the start of the period, r is the annual interest rate as a fraction, s is the annual volatility of the stock, also given as a fraction, and t the time in months after which the new value is reached. We can then in e.g. 12 steps calculate the value of the stock after one year. Next we calculate the difference between this value and the exercise price. The value of the option at the end of the year is then the maximum of this difference and 0, since the option owner will only use her option, if the difference is positive. The value is then the present value of this, at the start of the year.

We input the starting price, the exercise price, the annual volatility and the interest rate. For the case that we have constant volatility, we can compare the value obtained from the simulation with that obtained from the Black and Scholes formula. The interesting thing with simulation is in this case, however, to obtain option values also for the case when volatility changes during the year, a case not covered by the Black and Scholes formula. We can e.g. study the case when volatility changes from an initial volatility by a monthly constant. We can allow this change in volatility to be stochastic, e.g. that this change follows the normal distribution. To obtain a correct value, we need to run the simulation a great many times. (Ståhl 2018 – Case 97)

3.5 Production

In contrast to engineering student projects, production has not played a paramount role in our business student projects; in particular virtual none have dealt with the detailed layout of the production facility, using animation. Production planning has more been seen as integrated with other activities such sales, packaging and logistics. We have had several projects, both in larger and smaller, companies, dealing with e.g. processes in the food industry, in particular the fishing industry in Norway.

Some other projects, with a focus on planned profitability, have been on a new steel plant and a new iron ore mine, both in northern Sweden. Several cases have dealt with machine part failure and the decisions on the most economical way of dealing with this problem: additional reserve machines or additional repairers.

A very important project involved the IBM automatic printer manufacturing plant in Järfälla outside of Stockholm. This was a new Flexible Manufacturing System. The study was an advanced application of simulation based costing. This was the main part of a doctoral thesis at SSE and is the largest aGPSS model this far, with around 1000 blocks (Nielsen 1996). An interesting aspect is that the cost of one product is dependent not only on the number of units produced of this product, but also on the number of units of another product, which competes for time in the same machine with the first product. The picture below, from this thesis, shows how the costs of the two products vary with the number of units of both the own product and the competing one, as shown in Figure 3.

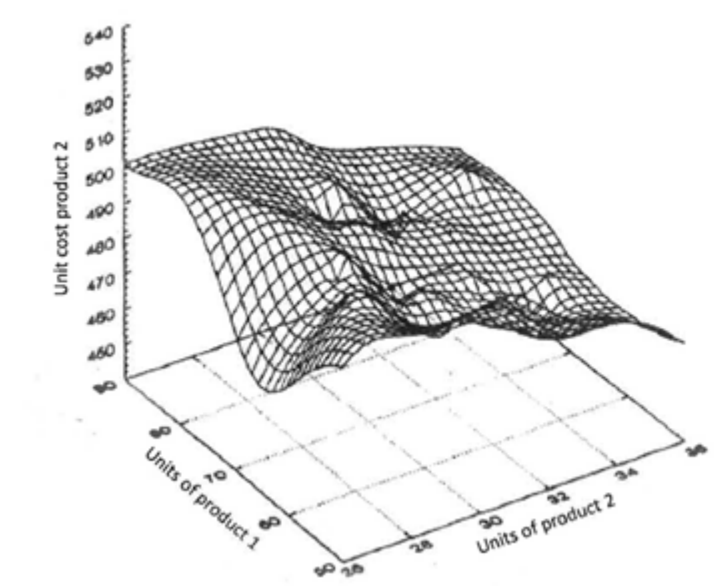

Figure 3: Unit cost of two products using same machine.

A simple, but more fundamental model of simulation based costing, is given in Case 65 in Ståhl (2018), on how stochastic variations, in e.g. machine times, determine the costs of products that compete for time in a machine.

Some production projects have dealt with production on demand, e.g. of furniture, delivered from a store in a Stockholm suburb.

3.6 Energy

An important area for some of our business students has been energy systems. During the last few years the simulation course with aGPSS at the Norwegian School of Economics and Business has to a great extent been followed by students focusing on energy. The course is mainly handled by E. Bjørndal, but I have each year had a few hours of teaching in this course. Some of the topics I have talked about have been simulations of wind mill parks, oil depots and oligopoly models for the pricing of oil. More details are given in Ståhl (2010), which has an extensive list of references on simulation projects in the energy area.

3.7 Construction and Building Design

Although few of our business students have a construction background, we have had some interesting projects in this area. Some have involved simulation as substitutes or complements to CPM/PERT methods (Born and Ståhl 2013). We have also had a project on sales of construction equipment.

An exciting project regarding design was carried out by two SSE students in 2000. Stockholm was at that time applying for getting the Olympic summer games, which involved the building of a completely new Olympic stadium, the Victoria stadium, digging out the Hammarby ski hill. The question was if the three paths leading from this Stadium, in Figure 4 below, to the nearby subway station would be broad enough so that 28,000 spectators could go from stadium to this subway station in 30 minutes. The problem lay in the fact that these spectators would walk at quite different speeds and that those walking faster must have room to overtake those walking more slowly. In the simulation model the movement of each of the 28,000 walkers was followed and there was a check every 10 meters to determine if the walker could overpass the one walking in front or if she had to wait until this other person had left this 10 meter segment.

Repeated simulation of the 28,000 people required long computer run times, but our students could determine that with 95 percent probability the spectators could get out of the stadium in the stipulated time. This was reported to the IOC in Lausanne, but other factors had the games go to Athens and not Stockholm. The Victoria stadium was therefore never built and the Hammarby ski hill still remains as it was in 2000 and could in 2019 still be used for the World Cup competition in parallel slalom.

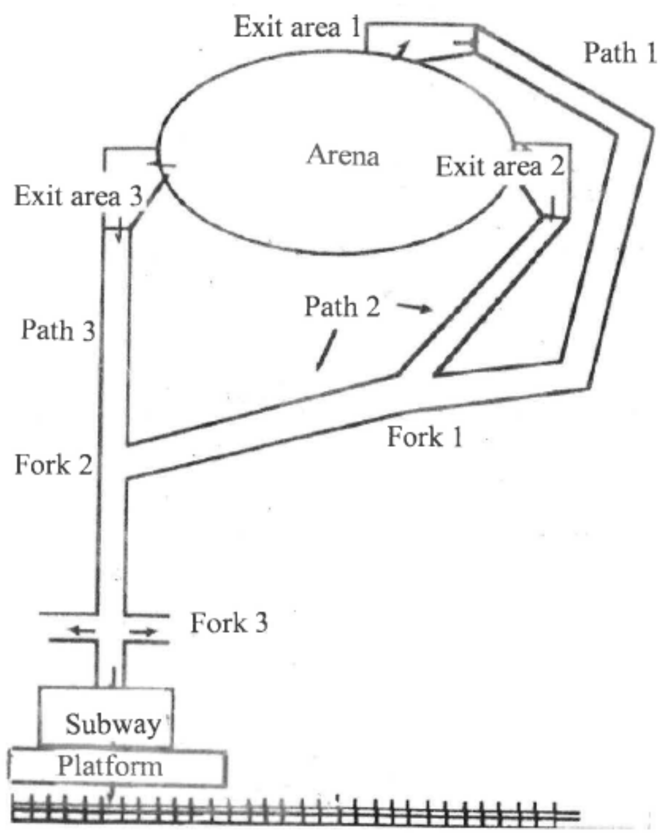

Figure 4: Victoria Olympic stadium with three paths.

3.8 Theory for Education

Some of the project models are based on theoretical papers made available to the students. One such a project is variation of probability calculations, based on an original example by R. Barton (2002). It refers to a case where manual probability calculations by students generally fail, but the students can easily find the correct answer by DES.

Other projects have dealt with the explicit testing of analytical methods taught within OR. This involves first of all tests of queueing theory, where we compare the values on e.g. waiting lines and waiting times obtained analytically with those obtained by DES. One can study the effect of different assumptions about the total time the system is open. Other models tested are simple inventory models, first of all those based on the Wilson formula, but also extended forms of this with assumptions about lead time and back orders.

Other projects have dealt with tests of LP solutions, studying e.g. the effect of stochastic machine times and different machine sequencing decisions. In other models, as in Case 92 in Ståhl (2018), we have compared the values of perfect information, as obtained by the traditional models for EVPI (Expected value of perfect information), with values obtained by simulation, for different types of functions for the occurrence of different payoffs.

Other more theoretically inclined models have dealt with simulation for demand forecasts based on diffusion theory. These simulations have been more in line with Systems Dynamics, but in these cases of project forecasting with one value for each of say 40 years, Runge-Kutta based methods of continuous simulation are not needed, but DES gives enough precision (Ståhl 1995).

Several theory-focused projects have dealt with game theory. Some have dealt with oligopoly theory, in particular pricing. These projects have been based on observation of game experiments and have been in line with behavioral game theory; one has been on a Cournot game, where each player is without information about demand and costs, only being able to observe its own profit from different prices (Case 85 in Ståhl 2018); another on a Bertrand game where prices are adjusted according to changes in inventory (Ståhl 2018 – Case 90). A similar simulation refers to a small management game with stochastic demand with homogenous products (Ståhl 2010). Another game theory project involves the bidding on an oil exploration project, characterized by asymmetric information (Ståhl 2018 – Case 69).

Another theory-focused project has dealt with a consumer brand choice model, involving the probability of a switch between products, influenced by advertising.

The establishment of optimal equipment life is important in managerial economics, accounting (e.g. for determining the depreciation rate) and finance. A company does not want to spend too much money on new expensive equipment, but, on the other hand, it does not want to have obsolete equipment leading to high current costs. One method for determining optimal equipment life is the MAPI method, which determines equipment life taking technical development into consideration. Its critical assumption is that new equipment leads to lower production costs than old equipment. A machine that is new this year leads to *inFact* lower costs than a machine that was new last year. For a machine with the age *cl,* the extra cost, *xcost,* this year, due to not having the latest machine model, is *cl*inFact.*

One next calculates the present value, *prVal,* of this extra cost. For a machine that is kept *y* years, this value is next summed up for all years, going from 1 to *y.* To this total sum of present values we also add the initial investment payment *invest*. On the basis of this total cost of having the machine for *y* years, we next calculate the annual cost by multiplying this *sumPrV* with the annuity factor *anFact* needed to distribute the cost over *y* years. This calculation of the annual cost makes it possible to compare machines with different lengths of life.

In order to be able to investigate also the stochastic case when the inferiority factor is not fixed, we can assume that can vary following the normal distribution. We can next calculate the annual cost of having a machine differently many years. We started doing these calculations in Excel, but the spreadsheet became quite large and unwieldy. The aGPSS model is on the contrary quite small, as seen in Figure 5 on the next page.

```
        SIMULATE  1
        EXPERI    X$year,X$annui,10,1.0,10.0,10
! Original investment?
        INPUT     X$invest
! Average annual inferiority
        INPUT     X$infaAv
! Standard deviation of this
        INPUT     X$stdDev
! Annual interest rate
        INPUT     X$pRate
pvFact VALUEOF    (1/(1+x$irate))^cl
        GENERATE  ,,,1        !  Do at start
        LET       x$irate=x$pRate/100!  Interest fraction
        LET       x$sumPrV=x$invest!  Initial investment PRV start
        TERMINATE
        GENERATE  1,,,,1      !  Every year with priority
        LET       x$inFact=x$infaAv!  Ave. inferiority of old machine
        LET+      x$inFact,fn$snorm*x$stdDev!  Add variation
        LET       x$xcost=x$infact*cl!  Extra cost: CL years old mach
        LET       x$prval=x$xcost*v$pvFact!  Pr. value of year's cost
        LET+      x$sumPrV,x$prVal!  Add up present values
        TERMINATE
        GENERATE  x$year      !  Calculate for given year
        LET       x$smPVFa=(1-v$PVFact)/x$irate!  Sum of PV factors
        LET       x$anFact=1/x$smPVFa!  Annuity factor
        LET       x$annui=-x$anFact*x$sumPrV!  Annuity of total costs
        TERMINATE 1
        START     1
        END
```

Figure 5: aGPSS Model for Determining Optimal Equipment Life.

Another theory project is based on the well-known Secretary problem (Ferguson 1989). One can use DES to investigate the effect of different stochastic distributions to be used for the scoring function.

At present we work on a project to use DES for making it possible to make more realistic fertility and population forecasts. The idea is that one simulates a cohort of say 1000 women, following each individual woman. Stochastic functions determine the age when the first child is born, the time until the next child is born, etc., and hence the total number of children. Probability functions for death are also included. For the children thus born the process is repeated. One can then, when a woman has reached the age of say 50, calculate the number of children born and thus the average fertility for the total cohort. Within the DES model one can also have the birth of each child depend on certain conditions, e.g. that a woman waits to get married until some economic condition is fulfilled. With this program one can investigate the great variability of population forecasts over the next 50 – 100 years, in particular for the Sub-Saharan countries. This can in turn be of importance when investigating different forecasts for climate change.

3.9 Combined Problems

We shall end the list of projects by mentioning some larger projects that combine the project topics mentioned above. Most of them deal with integrated production, pricing, finance and cash flow forecast (Born and Ståhl 2013; Ståhl 2018 – Case 91). Another large model deals with the valuation of stocks of a high tech company based on forecasts of the diffusion process for new products, e.g. new computers (Case 99 in Ståhl 2018). Earlier this project was modelled in Excel, but the DES model is much easier to understand. Some larger projects have sent the output to an Excel file, in aGPSS using the Matrix block. Projects have also read data from Excel files. Finally, some projects in Norway have lately used an interface between aGPSS and R to get better output statistics and graphs.

4 CONCLUDING REMARKS

We hope that we by our list of projects have been able to show that DES offers a much broader area of economic applications than what is generally perceived, e.g. by looking at only the first part of DES textbooks. These books usually start with simple examples of queueing problems, e.g. with Barber Joe. Such an introduction with a one-server model is necessary for getting students started with simple and easily understood examples, but the applications that our students at the end of a one-month course have produced have covered a far broader field, of interest to many companies.

The list of projects above hopefully gives some idea of what characterizes a successful student project. The main criteria of success are that the project is completed in the prescribed time (usually four - six weeks) and that it receives a good grade. Some of the factors favoring such success are as follows: The project is such that the model can be built up step by step and even the first steps are interesting, also for people in the company for which the student builds the model. The process of constructing the model can then be stopped at a suitable time without a major loss. The project is such that data is readily available and the student does not have to guess "in the blue" about the parameters of possible distributions. There is at least one person in the company who is actively interested in the model and willing to give comments and help with getting data. The focus is on getting a simple and easy-to-understand model rather than a theoretically interesting and complex model.

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