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SIMULATION/OPTIMIZATION USING "REAL-WORLD" APPLICATIONS

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ABSTRACT

This tutorial will focus on several new real-world applications that have been developed using an integrated set of methods, including Tabu Search, Scatter Search, Mixed Integer Programming, and Neural Networks, combined with simulation. Applications include project portfolio optimization and customer relationship management.

1 INTRODUCTION

Many real world problems in optimization are too complex to be given tractable mathematical formulations. In a wide range of applications, classical formulations such as integer and mixed integer programming problems may take many days to run using the best available solvers. The resulting solutions can be drastically short of being optimal or even fail to satisfy feasibility requirements. Moreover, often, such formulations omit key aspects of real world settings.

Practical problems often contain nonlinearities, combinatorial relationships and uncertainties that cannot be modeled effectively by simply listing an objective and a collection of constraints in the "approved mathematical programming manner." Simulation becomes a highly valuable tool in these settings, but is not sufficient by itself to yield the quality of outcomes desired. An extra step is needed – a step that joins simulation and optimization. We propose to present a variety of the latest applications where combining simulation and optimization provides solutions that are achieved quickly and reliably. We will show how problems are identified, formulated, and analyzed, and demonstrate, using a software package, how solutions are achieved.

The applications chosen are relevant to participants since they are derived from ongoing work with client firms. They show participants what are "hot needs" in today's markets, and not only orient them to problem identification, formulation, and solution, but also illustrate the process requirements and economic benefits derived from using the simulation/optimization approach. The applications draw from current work in the following areas:

- project portfolio optimization
- customer relationship management

2 OPTMIZATION METHODS

Theoretically, the issue of identifying best values for a set of decision variables falls within the realm of optimization. Until quite recently, however, the methods available for finding optimal decisions have been unable to cope with the complexities and uncertainties posed by many real world problems of the form treated by simulation. The area of stochastic optimization has attempted to deal with some of these practical problems, but the modeling framework limits the range of problems that can be tackled with such technology.

The complexities and uncertainties in complex systems are the primary reason that simulation is often chosen as a basis for handling the decision problems associated with those systems. Consequently, decision makers must deal with the dilemma that many important types of real world optimization problems can only be treated by the use of simulation models, but once these problems are submitted to simulation there are no optimization methods that can adequately cope with them.

Recent developments are changing this picture. Advances in the field of metaheuristics—the domain of optimization that augments traditional mathematics with artificial intelligence and methods based on analogs to physical, biological or evolutionary processes—have led to the creation of optimization engines that successfully guide a series of complex evaluations with the goal of finding optimal values for the decision variables (Campos et. al. 1999;

Campos, Laguna and Marti 1999; Glover, Laguna and Marti 1999; Glover 1998; Laguna to be published). One of those engines is the search algorithm embedded in the OptQuest optimization system. OptQuest is designed to search for optimal solutions to the following class of optimization problems:

Max or Min	$F(x)$	
Subject to	$Ax \le b$	(Constraints)
	$g_l \le G(x) \le g_u$	(Requirements)
	$l \le x \le u$	(Bounds)

where x can be continuous or discrete with an arbitrary step size.

The objective $F(x)$ may be any mapping from a set of values x to a real value. The set of constraints must be linear and the coefficient matrix "A" and the right-hand-side values "b" must be known. The requirements are simple upper and/or lower bounds imposed on a function that can be linear or non-linear. The values of the bounds "g_l" and "g_u" must be known constants. All the variables must be bounded and some may be restricted to be discrete with an arbitrary step size.

A typical example might be to maximize the throughput through a factory by judiciously increasing machine capacities subject to budget restriction and a limit on the maximum work in process (WIP). In this case, x represents the specific capacity increases and $F(x)$ is the expected throughput. The budget restriction is modeled as $Ax \le b$ and the limit on WIP is achieved by a requirement modeled as $G(x) \le g_u$. Each evaluation, of F(x) and G(x) requires a discrete simulation of the factory. By combining simulation and optimization, a powerful design tool results.

In a general-purpose optimizer such as OptQuest, it is preferable to separate the solution procedure from the complex system to be optimized. A potential disadvantage of this "black box" approach is that the optimization procedure is generic and does not know anything about what goes on inside of the box and therefore does not use any problem-specific information (Figure 1). The clear advantage, on the other hand, is that the same optimizer can be used for many complex systems.

Figure 1: Complex system as a black box

OptQuest does allow the user to input problem structure through the use of constraints and has specialized mechanisms for analyzing specific types of problems. In particular, OptQuest contains an highly-efficient algorithm for determining solutions to problems that contain sequencing decisions. Additionally, OptQuest contains algorithms for problems of the type encountered in design where the decisions are of the form "pick one of the following choices."

OptQuest is a generic optimizer that overcomes the deficiency of black box systems of the type illustrated in Figure 1, and successfully embodies the principle of separating the method from the model (OptQuest Callable Library User's Manual 2000). In such a context, the optimization problem is defined outside the complex system. Therefore, the evaluator can change and evolve to incorporate additional elements of the complex system, while the optimization routines remain the same. Hence, there is a complete separation between the model that represents the system and the procedure that is used to solve optimization problems defined within this model.

The optimization procedure uses the outputs from the system evaluator, which measures the merit of the inputs that were fed into the model. On the basis of both current and past evaluations, the optimization procedure decides upon a new set of input values (see Figure 2).

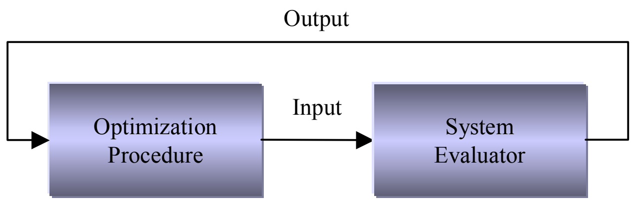

Figure 2: Coordination between optimization and system evaluation

The optimization procedure is designed to carry out a special "non-monotonic search," where the successively generated inputs produce varying evaluations, not all of them improving, but which over time provide a highly efficient trajectory to the best solutions. The process continues until an appropriate termination criterion is satisfied (usually based on the user's preference for the amount of time to be devoted to the search).

3 PROJECT PORTFOLIO OPTIMIZATION

In many industries, strategic planning requires executives to select a portfolio of projects for funding that will likely advance the corporate goals. In general, there are many more projects than funding can support so the selection process must intelligently choose a subset of projects that meet the companies profit goals while obeying budgetary restrictions. Additionally, executives wish to manage the overall risk of a portfolio of projects and ensure that cash flow and other such "accounting" type constraints are satisfied.

The Petroleum and Energy (P&E) industry uses project portfolio optimization to manage its investments in the exploration and production of oil and gas. Each project's proforma is modeled as a simulation capturing the uncertainties of production and sales.

The application illustrated here involves five potential projects with ten year models that incorporate multiple types of uncertainty in drilling, production, and market conditions. We examined three cases to demonstrate the flexibility of the software to enable a variety of decision alternatives.

3.1 Case 1

In case 1, the decision was to determine participation levels [0,1] in each of the five projects with the objective of maximizing expected net present value of the portfolio while keeping the standard deviation of the net present value of the investment below a specified threshold. In this case, all projects must begin in the first year.

Maximize *E*(NPV)
While keeping $\sigma < \$10,000$ M
All projects must start in year 1

In this case, the best investment decision resulted in an expected net present value of approximately $37,400 M with a standard deviation of $9,500 M. Figure 3 shows the corresponding NPV distribution.

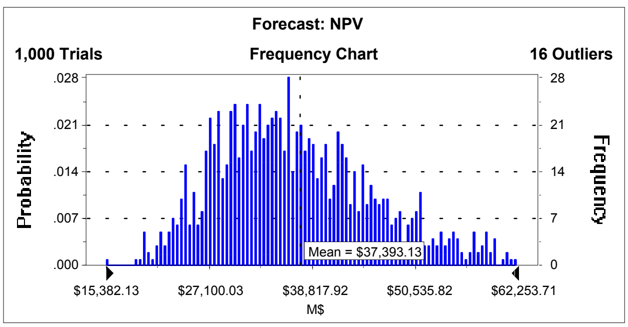

Figure 3: Case 1 NPV Distribution

3.2 Case 2

In case 2, the decision structure was modified to determine participation levels in each project where starting times for each project could vary over a three year horizon.

Maximize *E*(NPV)
While keeping $\sigma < \$10,000$ M
All projects may start in year 1, year 2, or year 3

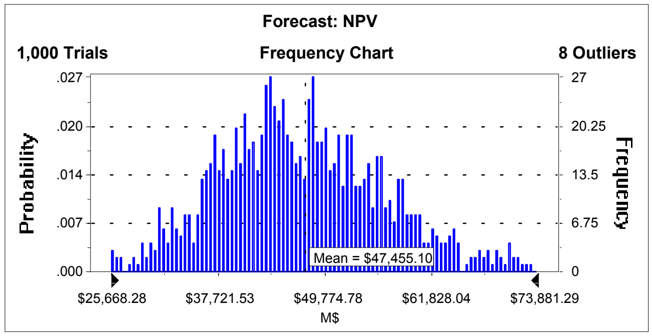

Figure 4: Case 2 NPV Distribution

In this case, where starting times could vary, the best investment decision resulted in an increase over the Case 1 expected net present value by approximately $10,000 M [$47,500 M with a standard deviation of $9,500 M]. This decision also achieved a 90% chance of returning an expected NPV of the investment greater than $36,000M (see Case 3).

3.3 Case 3

Finally, in case 3, the decision structure was further modified to determine participation levels in each project where starting times for each project could vary and we would maximize the probability of exceeding the expected net present value of $47,500 M which was achieved in Case 2.

Maximize Probability(*E*(NPV) > $47,455 M)
While keeping 10^{th} Percentile of NPV > $36,096 M
All projects may start in year 1, year 2, or year 3

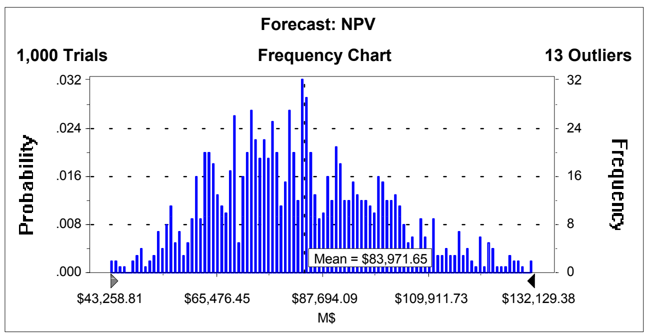

Figure 5: Case 3 NPV Distribution

In this case, where starting times could vary, and we wanted to maximize the chance of exceeding the net present value of $47,500 M, the best investment decision resulted in an expected net present value of approximately $84,000 M with a standard deviation of $18,500 M. The NPV had a 99% probability of exceeding $47,500 M. This case demonstrates that adopting measures of risk other than standard deviation can result in superior portfolios. Simulation optimization is the only technology that can offer these types of analyses.

4 CRM OPTIMIZATION

A critical component of Customer Relationship Management in the retail sector concerns the scheduling of employees who provide direct service to the customers. In the grocery supermarket industry, the scheduling of clerks and assistants determines customer service and labor costs Simulation is an excellent tool for modeling the complexities and stochastic nature of a supermarket. Such models consider customer arrivals, types of customers, numbers of items, and service rates. By modeling the store operations, the effect of different schedules can be accurately determined and simulation optimization can be used to determine the best service for the least cost.

In this application, we examined a typical day using point of sales [P.O.S.] data from Safeway for customer arrivals and processing times. We wanted to determine the best number of express lanes and regular lanes for every 15 minute time slot in order to maximize performance (Customer Service) defined as percentage of customers that are in lines of 4 or fewer people. The decision structure was also constrained by a budget restriction on available person-hours.

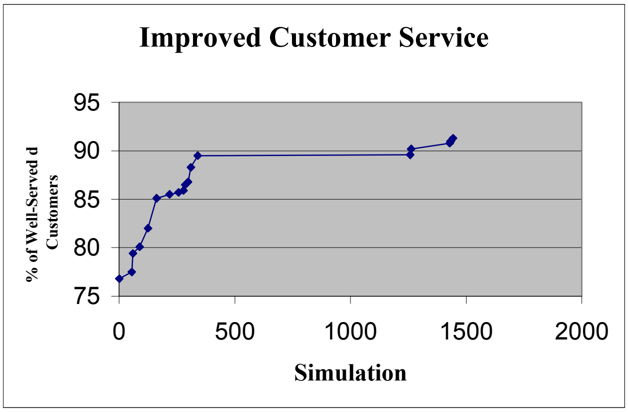

Figure 6: CRM Improvement Curve

Figure 6 illustrates the optimization results as the number of simulations increases. One can see how quickly the percentage climbs, achieves a plateau, and then jumps a small amount at the end of the run. The ending customer service is nearly 20% better than the starting solution and is achieved with no additional costs.

5 OPTTEK SYSTEMS, INC.

OptTek Systems, Inc. is an optimization software and services company located in Boulder, Colorado. We are the leading optimization software provider to the simulation software market and are confident that our products and services will add significant value to our customers.

OptTek software is recognized throughout the simulation and optimization market for its quality, speed, and customer service. Independent evaluations of our software demonstrate that our technology yields faster and higher quality solutions when compared to other optimization methods currently on the market. The software integrates state-of-the-art metaheuristic procedures, including Tabu Search, Neural Networks, and Scatter Search, into a single composite method. Some of the differences between OptTek's methods and other methods include:

- The ability to avoid being trapped in locally optimal solutions to problems that contain nonlinearities (which commonly are present in real world problems).
- The ability to handle nonlinear and discontinuous relationships that are not specifiable by the kinds of equations and formulas that are used in standard mathematical programming formulations.
- The ability to solve problems that involve uncertainties, such as those arising from uncertain supplies, demands, prices, costs, flow rates, queuing rates and so forth.
- The ability to solve decision support problems for extremely complex systems.

While other methods currently being applied in complex and highly uncertain environments have value, they either identify feasible solutions or locally optimal solutions. Both are typically improvements over the status quo but neither identifies the global optimum or "best" solution.

OptTek's methods, which are well known in both the simulation and optimization communities, are based on the contributions of Professor Fred Glover, one of the founders of OptTek and a winner of the von Neumann Theory Prize in operations research, who developed the adaptive memory method called Tabu search, and the evolutionary method called Scatter Search, singularly powerful search techniques in global optimization.

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Dr. Glover is the recipient of the distinguished von Neumann Theory Prize, as well as of numerous other awards and honorary fellowships, including those from the American Association for the Advancement of Science, the NATO Division of Scientific Affairs, the Institute of Management Science, the Operations Research Society, the Decision Sciences Institute, the U.S. Defense Communications Agency, the Energy Research Institute, the American Assembly of Collegiate Schools of Business, Alpha Iota Delta, and the Miller Institute for Basic Research in Science. He also serves on advisory boards for numerous journals and professional organizations. His email address is `glover@OptTek.com`.

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