Proceedings of the 2003 Winter Simulation Conference
S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, eds.

ITERATIVE OPTIMIZATION AND SIMULATION OF BARGE TRAFFIC ON AN INLAND WATERWAY

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ABSTRACT

This paper describes an iterative technique between optimization and simulation models used to determine solutions to optimization problems and ensure that the solutions are feasible for real world operations (in terms of a simulation model). The technique allows for the development of separate optimization and simulation models with varying levels of detail in each model. The results and parameters of the optimization model are used as input to the simulation model. The performance measures from the simulation output are compared to acceptable levels. These performance measures are then used to modify the optimization model if the simulation results are not acceptable. This iterative approach continues until an acceptable solution is reached. This iterative technique is applied to barge traffic on an inland waterway as an example. Linear programming is used as the optimization technique for the example while a simulation model is developed using Arena software.

1 INTRODUCTION

1.1 Relevance of Iterative Technique

Simulation and optimization techniques are commonly applied in tandem to study many types of real world problems. Both simulation and optimization are applied to the same problem mainly for two reasons. First, it allows an analyst to simulate a specific system and then determine the optimal value for some parameter within the problem through the application of an optimization technique. An example of this is the OptQuest optimizer within Arena. It allows a specific simulated system to be optimized to determine the optimal values for a set of specified parameters. Various other techniques can be used to optimize specific parameters within a simulation model. Extensive examples and methodologies of the optimization of simulation models are available. Fu (2000), Swisher et al. (2000), Glover (1999), and Azadivar (1999) all presented various techniques at previous Winter Simulation Conferences. Secondly, simulation is often applied to the results of an optimization problem in order to check the validity of the model and/or the results. The results of the optimization model are used as inputs to the simulation model

1.2 Separate Optimization and Simulation Models

This paper suggests developing separate optimization and simulation models, allowing for different levels of detail to be included in each model. An iterative procedure between the simulation and optimization model is suggested in order to guarantee a near-optimal solution is reached that is also feasible based on the simulation model constructs. Jaccard et al. (2003) and Brekke and Moxnes (2001) apply separate optimization and simulation models in order to compare the results. The results in both cases indicate that both types of modeling have a positive impact on decision making but for different reasons. The different techniques are compliments to each other, not substitutes. A related iterative technique was presented by Morito et al. (1999) in which optimization constraints were added to the model based on simulation results.

Applying an optimization technique alone to a real world situation leads to valuable information about the system. Obviously, the relevance of the results depends on the quality of the model. Optimization is useful for long term strategic planning. The optimization technique applied here for illustrative purposes is linear programming, but other techniques are equally applicable.

The linear program is not useful for day-to-day operational planning. For example, the LP may yield a result that 150 barges should be allocated from fleet 1 to elevator 2 over a planning horizon of one month. This information does not aid decision makers in making day-to-day decisions about barge routing.

The application of optimization to such a large problem can lead to difficulty in interpreting and validating results. The first issue is whether or not the solution determined by the optimization is a 'realistic' feasible solution. A realistic feasible solution refers to a solution that is not only feasible for the optimization model but also feasible for the real system. A realistic feasible solution is feasible for the optimization model, and the parameters of the optimization are acceptable in the simulation model. In certain situations it is not possible to include all the constraints and operating procedures for a real system in an optimization model. In these situations simulation can be a useful tool for incorporating all the required procedures and constraints of the real system.

The application of a simulation model will allow certain real world system requirements to be included in the analysis that are not considered in the optimization. Constraints and procedures may not be included in the optimization because it is not possible to include them in an optimization model or because they are not relevant to long-term strategic planning.

1.3 Application to Modeling a Barge System

This paper will apply the proposed iterative approach to simulation and optimization to a specific real world problem. The application is that of barge traffic in the lower Mississippi River region. Barges enter this area of the river from the Gulf of Mexico as well as from various river inlets. Figure 1 below shows a simplified example of a river system.

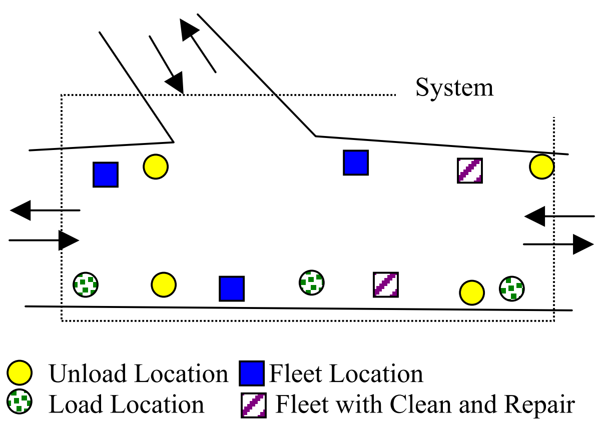

Figure 1: Simplified Example of a River System

The basic traffic flow begins with barges being brought into the system via tows. The entrances and exits to the system are illustrated by the arrows in Figure 1. A tow consists of a group a barges being moved by a towboat. Loaded barges have specific locations at which they are to unload their cargo. Tows are initially dropped at a fleet location (a location for organizing incoming and outgoing tows) to regroup and be sent to their assigned unload destination. Tows can be powered by different types of boats of varying sizes, towing capacities, and operating costs.

Barges are delivered to their unload location and then sent to various fleet locations for cleaning and repair activities as required. Following cleaning and repair, barges are redistributed for loading. Loaded barges are sent to fleet locations to be organized into tows to be taken out of the system in the appropriate direction.

The barge transport system is studied to determine barge routings through the system in order to minimize the cost of barge movement. The routings are based on unload location and exit direction of the barges. These routings are critical as barges can take various paths through the system to reach their destination. This means determining locations for barges to be redistributed and organized into tows as well as locations for cleaning and repair activities. This type of analysis can be beneficial in determining if boat capacity is adequate or if the addition of fleet space is justified.

2 ITERATIVE TECHNIQUE

2.1 Iterative Process Flow

The objective of this technique is to determine an optimal, 'realistic' solution to an optimization problem, a linear program in this example. A realistic solution refers to a feasible solution generated by the optimization that is also 'feasible' in the simulation model. This makes the results feasible based on both the optimization and simulation given the differing constructs and rules in both models.

The basis for the proposed iterative approach to optimization and simulation is shown below in Figure 2. Boxes shown with a dashed line represent steps that are performed by a computer while a skilled analyst carries out the other steps.

The following sections correspond to the numbered elements in Figure 2.

2.2 Solve Optimization Model

The first step in the iterative process involves solving the optimization model and determining a solution to that model. The optimization model can be solved using any an available solver, depending on the optimization technique applied. Thus, this is a computer performed task in the process. The results of this run may or may not yield a feasible solution to the optimization model. This step could involve either solving the initial optimization model developed or solving an optimization problem with parameters that have been modified through the iterative process.

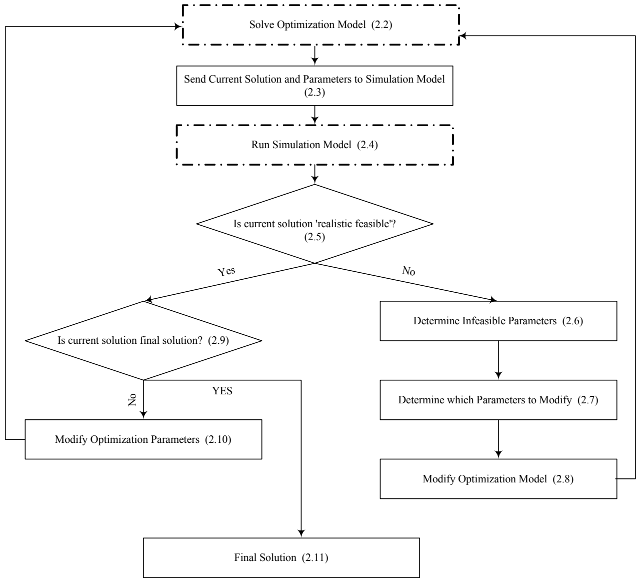

Figure 2: Flow between Simulation and Optimization Models

2.3 Send Optimization Parameters to Simulation

The next step is to send the results and parameters of the optimization model to the simulation model. The initial simulation model is based on the same parameters as the initial optimization model. This step is performed manually. The analyst determines which parameters to send to the optimization program and manually includes those determined parameters in the simulation model.

2.4 Run Simulation Model

The simulation model is then run. This is the only other computer-performed step in the iterative process. Any simulation software can be applied. The simulation model generates the predetermined performance parameters which are used to determine if the results of the simulation model are acceptable.

2.5 Is Current Solution 'Realistically Feasible'?

This decision making step is performed manually by the analyst. In this step the results of the simulation are analyzed to determine whether the results and parameters of the optimization model led to a 'realistic feasible' solution in the simulation model. A solution will be deemed 'realistically feasible' if a variety of performance measures generated by the simulation model are within acceptable levels predetermined by the decision maker. This set of statistics as well as their acceptable values will be determined prior to running the simulation model. The performance measures are specific to the system being studied.

2.6 Determine Infeasible Parameters

Once the current solution to the simulation is determined not to be 'realistic feasible,' the analyst will then determine which parameters from the optimization model led to a 'non-realistic feasible' solution. This is a step performed manually by the analyst. Determining which factors are infeasible will be based on the list of performance measures discussed in the previous step. Each performance measure will have specific optimization parameters associated with it. These are the parameters from the optimization model that affect the performance measure in the simulation model. Thus, the performance measures that are not at acceptable levels, as previously determined, will be used to determine which parameters are to be modified in the optimization model.

2.7 Determine which Parameters to Modify

Based on step (5), the infeasible parameters will have been determined by the analyst. This step involves determining which of those infeasible parameters to modify in the optimization model. This is a decision making step performed by the analyst. The determination of which parameters to modify when more than one is identified will be based on a ranking system. This ranking may be based on a sensitivity analysis of the parameters, percent variation from acceptable values of the performance measures, or other cost factors. One parameter will be changed per iteration so that the effects of changing each parameter are clear. This will aid in determining when to stop the iterative procedure because a 'feasible realistic' solution has been reached.

2.8 Modify Optimization Model

This step involves manually changing the infeasible parameter in the optimization model. The analyst manually makes the changes to the optimization model. The optimization model is then run again to determine a new solution and the iterative process returns to the beginning.

2.9 Is the Current Solution the Final Solution?

The determination of whether a termination criterion has been met is likewise a manual decision step performed by the analyst. It involves determining if the performance measures for a 'realistic feasible' solution are sufficient to be the final solution to the iterative process. It is thought that the first 'realistic feasible' solution reached will be the final solution.

2.10 Modifying Optimization Parameters

This step involves modifying parameters if a 'realistic feasible' solution is deemed unacceptable. This may occur if the analyst requires an improvement to a specific performance measure.

2.11 Final Solution

This block signifies that a final solution has been reached and the iterative process can be terminated. The final solution will yield a solution that is realistic and feasible for actual operations.

2.12 Information Flow

Figure 3 below shows the flow of information throughout the iterative process. Information flows between the optimization model, simulation model, and the decision maker.

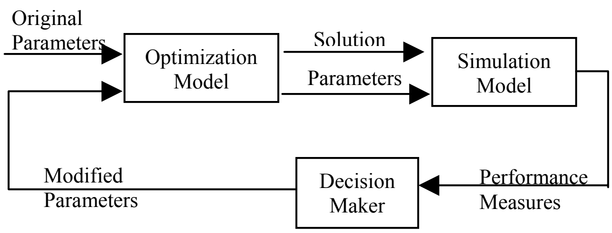

Figure 3: Information Flow of Iterative Process

As seen in Figure 3, the optimization model is run with the originally established parameters. These parameters and solutions from the optimization model are used as input to the simulation model. The output from the simulation model are the performance measures. These performance measures are used by the analyst to modify the parameters of the optimization model and then run the optimization model again. The decision maker is key in this process. This step involves linking the performance measures to parameters of the optimization model. Thus, when a performance measure is out of range the parameters tied to that specific performance measure can be modified.

A skilled analyst is required for decision making in the proposed procedure. It may be possible through future research to automate this step in the process, but the current state of development relies on a human-in-the-loop to assess the output from the LP model prior to establishing input for the simulation model, and vice-versa.

3 SAMPLE DATA SET

A sample data set was developed to test this iterative process. The data set contains a total of thirteen (13) locations. There are four (4) fleet locations, four (4) loading locations as well as three (3) unloading location as well as two locations specifically devoted to cleaning and repairs. This is in contrast to the actual river system which contains nearly one hundred locations. Three boat types were used for this data set and there are three directions by which barges can enter or leave the system.

4 OPTIMIZATION MODEL

For this application linear programming was used as the optimization approach. In general, any optimization procedure can be applied to the iterative process. In this case linear programming is suitable for the barge transport application.

The objective function of the LP is to minimize the costs associated with barge movement. These include travel costs relating to the type of boat used to tow the barges and travel distances.

The constraints are used to balance the movement of barges within the network, to ensure loading and unloading requirements, and to preserve capacities. These include location and boat capacities. The decision variables in the model are the volume of barges that travel a specific path through the system pushed by a specific boat type over a specified planning horizon. This is based on unload location and exiting direction of barges. Thus, the results of the LP assign optimal routings by boat type for barge movement, including cleaning and repair locations.

5 SIMULATION MODEL

Arena software was used to develop the simulation model for this test data set. The simulation model is based on the sample data set discussed. The purpose of the simulation model is to make sure that the barge routings determined by the linear program are feasible during river operations. The model can be expanded to include more aspects of the barge transport system.

The simulation uses the paths generated from the linear program to route barges through the system. The simulation model, though, is time dependent. While the LP assigns locations for barge movements, the simulation model accounts for time spent at each location.

This iterative procedure allows different levels of detail to be included in the optimization and simulation models. In this application there are two types of barges which are handled differently. The optimization model does not differentiate based on barge type because the number of covered barges is small (less than 5% of the total barges handled). The simulation model specifies the barge type, covered or flatbed. This ensures that specific barge type requirements do not cause performance measures to become out of range.

6 APPLICATION OF ITERATIVE TECHNIQUE

6.1 Performance Measure Selection

As detailed in Section 2, the iterative process involves selecting performance measures of the simulation model and linking these performance measures to parameters of the optimization model, in this case the LP. For the barge transport example several performance measures are applicable. These include but are not limited to the following: total cost of operation, over-utilization of fleet locations, queues at fleet locations, boat waiting time (idle time), tow waiting time, boat utilization per boat type, on time deliveries, time barges spend empty and/or unloaded, time barges spend loaded and waiting. Waiting times may include barge days spent waiting for a boat (in other words waiting to move to the next location) while the barge was either empty or loaded. Cost based performance measures may also be used.

For the sample data set the performance measures selected were the number of barges waiting at each at each fleet location, given a maximum capacity at each location. These measures are automatically generated by Arena. In larger applications more performance measures would be used and performance measures that are not automatically generated would be required. In a real world application the performance measures selected would be key to actual river operations.

6.2 Parameter Selection

The performance measures selected are tied directly to parameters of the optimization model, in the case the LP. It was determined that for the number waiting performance measure, for example, the number of available boats is a relevant parameter as is the capacity at each location. Thus, when the number of barges waiting exceeds the acceptable levels specified the number of available boats can be adjusted in the LP model or the location capacity can be increased. In a larger example the decision as to which parameters to modify could be based on a variety of factors, cost of the change being likely. The question becomes is it more feasible and cost effective to add more boat capacity or to add additional fleet space. For this example the decision was made to modify the number of boats.

Presently one parameter is modified for each performance measure. This selection of parameters to modify is the subject of ongoing research.

6.3 Iterative Results

The LP model was solved through CPLEX. The LP results yield a number of barges, over a specified planning horizon, that make a specific series of movements through the system. Thus, the LP results establish a path for barges given their unload location and exit direction. It also specifies the type of boat used to move the tow. The planning horizon for this example was thirty (30) days.

These established paths and boat type utilizations were used as input to the simulation model. Upon running the simulation model the selected performance measure, number of waiting barges, exceeded the maximum at some fleet locations at a given time. This leaves the decision as to whether to modify the number of available boats or the available space at violating location. As discussed in the previous Section 6.2, the number of available boats was increased by one in the optimization model. The new routings generated by the optimization model were input to the simulation model. Upon running the simulation with the increased number of boats and new routings, the performance measures were all within the required range.

This process gives the analyst key information for decision making. It shows the analyst the optimal solution to the LP and also why that solution is not feasible on the river. The LP averages boat use and capacities over the thirty (30) day planning horizon. Over the planning horizon selected the original number of boats is adequate, but in specific peak situations there are too many barges at a given location. This is the benefit to using both the optimization and simulation models. This procedure leaves the decision to the analyst as to whether a boat should be added or the number of waiting barges can be accepted.

7 EXTENSIONS AND CONCLUSIONS

There are several extensions to this work currently in progress. The simulation model is being expanded to include more details of actual river operations. Various data sets are also being developed to illustrate various aspects of the iterative process. There is also more research to be done in the area of how to best complete the iterative process including the selection of parameters and performance measures in larger scale models.

Developing a large scale model that more closely details river operations will allow the benefits of the process to be clearly identified. The real world applicability of the process depends upon the quality of the models developed. The iterative process, though, allows the user to implement optimization solutions that are guaranteed to be feasible for actual operations. It allows the user to study the actual river system in terms of both the optimization and simulation models.

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