Proceedings of the 1994 Winter Simulation Conference
ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila

INTEGRATING SIMULATION AND OPTIMIZATION: AN APPLICATION IN FISH PROCESSING INDUSTRY

Sabah U. Randhawa

Department of Industrial and Manufacturing Engineering
Oregon State University
Corvallis, Oregon 97331, U.S.A.

ABSTRACT

Integration of optimization and simulation modeling can be used to aid industrial decision making. A decision aid for coordinating fishing (trawler operations on the sea) and fish processing at on-shore plants is described. The system combines a simulation model with a linear programming (LP) optimization model. The simulation model analyzes trawler operations, including catch generation, length of fishing trips, and trawler landings. The LP model uses simulation output to model and analyze plant operations.

1 INTRODUCTION

Industrial processes are complex systems. Besides involve process flow, they include such factors as scheduling priorities, machine failures, in-process inventory considerations, types of inputs and/or outputs, fluctuations in raw material supplies, variations in demand due to competition, and government regulations. The resulting mathematical analysis are extremely complex to conduct, and difficult to explain to production managers. A more versatile and practical analysis approach is simulation. Although simulation is not an optimization tool, it provides a method for exhaustively exploring many possible solutions when no simple analytical search for the optimum is available. However, in most cases the cost of developing and using simulation models will be greater than an analytical solution, if such can be found, because simulation models are usually more complex due to increased number of interactions and interdependencies represented in the model. An ideal combination, if possible, is mathematical analysis for system components that can be represented as analytical models, and simulation for stochastic and complex components and to integrate the sub-components. This paper describes an application in the fish processing industry that integrates simulation with an optimization model. The model is validated using a major fish manufacturer in Iceland.

Fish processing in Iceland's manufacturing plants depend on the fish brought ashore by fishing boats. The quantity and composition of catch at sea varies from day to day and from season to season. The quality of fish caught and processed determines to a large degree the value of the products that are marketed.

To handle the continuous decrease in fish supplies, the Icelandic government introduced quota regulations in 1984 on certain fish species. The quota is controlled by the total yearly catch, and each fishing vessel's share is based on its catch history over the previous couple of years. The randomness of the catch, increased competition, and quota regulations have forced the processing plants to schedule their resources effectively to control production. The result has been an increased emphasis on cooperation between the fishing operations on the sea and the fish processing at on-shore plants.

1.1 Literature Review

There is limited literature available on trawler (or fish fleet) operation. Sigvaldason et al. (1969) developed a model for a wet fish trawler operation. Digerness (1982) evaluated fishing vessel design and its effect on operation and efficiency. Arnarson (1984) studied the feasibility of operating a trawler versus operating a longliner. Gunn, Millar, and Newbolt (1991) studied tactical planning for a Canadian company with integrated fishing and fish processing. Andrason (1990) and Teitsson (1990) developed models for production management and processing aboard factory trawlers in Iceland. Arnarson and Jensson (1991) used these models as prototypes to develop a simulation model that analyzed the operation of a factory trawler.

Production planning at fish processing facilities is a typical product mix problem. Applications of mathematical models to the product mix problem are extensively reported in literature; many of these models can be applied to the fishing industry. Mathematical models that have been developed specific to the fishing industry include a multi-period LP model developed by Mikalsen and Vassdal (1979) and a product mix LP model by Jensson (1988). Jonatansson and Randhawa (1986) developed a simulation model for modeling a fish processing facility.

Only in recent years has there been an interest in integrating fishing and fish processing. Analyzing fishing and fish processing separately may lead to suboptimization of the total system. However, there is very little reported work on integrating these two areas. Gunn, Millar, and Newbolt (1991) studied integration of fishing and fish processing. Jensson (1990) proposed a mixed integer linear formulation to solve the coordinated scheduling problem of trawler landings and plant operations. However, these models do not focus on the trawler scheduling problem. Furthermore, important system characteristics including the stochastic nature of catch operations and the quality-time relationship that determines the value of fish products are not considered.

2 METHODOLOGY

A methodology is developed to improve the operation of fishing and fish processing by coordinating these two operations. The methodology integrates simulation with a linear programming (LP) model (Figure 1). The trawler operation is modeled using simulation. The simulation model determines trawlers' fishing schedule and generates the quantity of catch during the fishing trip. The LP model analyzes plant operations based on the simulation model output; it determines the allocation of raw material and labor, mix of products, and inventory of raw material. Also, the results of the LP model can be used to improve the decision making capabilities of the simulation model.

2.1 Simulation Model

The model simulates the operation of a fleet trawlers over a specified planning horizon. The objective is to provide the manager of a fish processing plant with an initial schedule for trawler landings, along with the

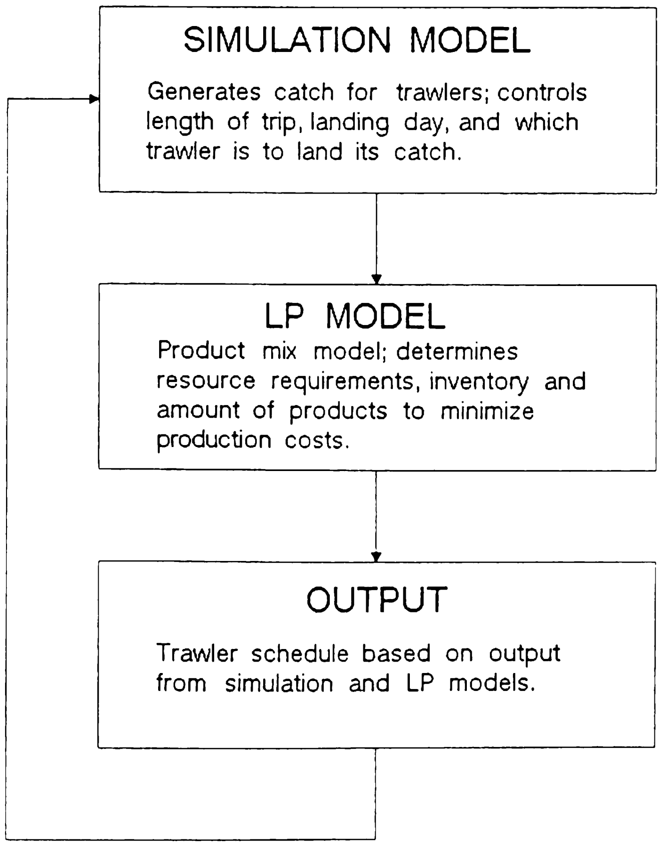


Figure 1: Modeling Methodology

amount of raw material that each trawler lands. The model simulates each trawler's catch for each day the trawler is fishing at sea; makes decisions on when each trawler comes in to land its catch; and keeps records on all the activities and data that relate to trawler operations, for example, the number of trips during the planning horizon, days at sea, catch on current trip, and year-to-date catch.

The primary components of the simulation model are:

1. Catch Generator. This component assigns the catch and the fish species mix to each trawler for each day of the scheduling period. The catch is generated using a log-normal distribution (Arnarson, 1984; Sigvaldason et al., 1969; and Teitsson, 1990). The average trawler time per day at sea and the season fluctuations in catch rate are modeled as a first-order autoregressive process (Arnarson, 1984; Teitsson, 1990; and Arnarson and Jensson, 1991). The mean value of catch rates changes on a monthly basis according to seasonal catch fluctuations (Randhawa and Bjarnason, 1994).
2. Trawler Operation. At the beginning of the planning period each trawler is sent out fishing. For each day of operation, the simulation model checks on the status of each trawler. If a trawler is fishing and is not eligible to land, or if it is eligible to land but is not required to, it continues to fish. If the trawler meets the criteria set by the decision rule (explained below), it lands its catch.

   A number of features of trawler operation are modeled in the simulation model. The three most important are the decision rule for selecting when a trawler lands its catch, the concept of "time value" to select the time when a trawler is sent on a new fishing trip, and the deterioration in the quality of raw material caught at sea. These three functions are briefly explained below; for details see Bjarnason (1992).

   (a) Decision Rule. The decision rule, representing "expert" decision criteria, includes trawler capacity and raw material considerations. A trawler has to spend a minimum of five days at sea before it can land its catch and can stay at sea no more than 15 days. The lower limit is the minimum number of days required to make a trawler's trip economically feasible; the upper limit is set by the aging of the raw material (see the discussion on quality below). If a trawler exceeds its holding capacity during a trip or reaches the quota assigned to it for the trip, the trawler is eligible to land its catch.

   All trawlers that are eligible to land are compared to select the trawler that is to land its catch that day. For example, if all of the trawlers have been at sea for less than eight days and there is a shortage of raw material at the processing plant, the trawler with the largest catch is assigned to land its catch. If the maximum number of days at sea is between eight and twelve and the plant inventory is low, the trawler with the lowest quality raw material onboard is required to land its catch. In case the processing plant does not need raw material, the system checks to see if there is a trawler that will reach the maximum allowable number of days at the sea during the weekend. Since processing plants minimize work over the weekend due to high overtime costs, such trawlers are assigned to land before the weekend.

   (b) Time Value. The concept of time value is used to model the fleet manager's decision to schedule a new fishing trip once a catch has been landed. The ratio of the quota for a trawler's scheduling period and the length of the scheduling period gives a measure of the average catch per time unit that the trawler has to catch to fully utilize the allocated quota. By comparing this ratio each time the trawler is in port to the ratio of the remaining quota and the time remaining in the scheduling period, the system decides on the trawler's long-term performance and subsequently makes the decision on when to send the trawler back to sea.

   (c) Quality of Raw Material. Because of the importance of raw material quality, this is one of the main criteria used in the decision rule for trawler operations. There is little information available that links the quality of raw material to its value as it ages while the trawler is fishing at sea. A relative quality function (Figure 2) was developed based on fish quality information in published literature (Hauss, 1988). When evaluating and comparing trawlers for landing, the function in Figure 2 is used to determine the relative quality of trip catch. The function assumes that the temperature at which raw material is stored aboard trawlers is constant; also, it ignores quality differences among fish species.

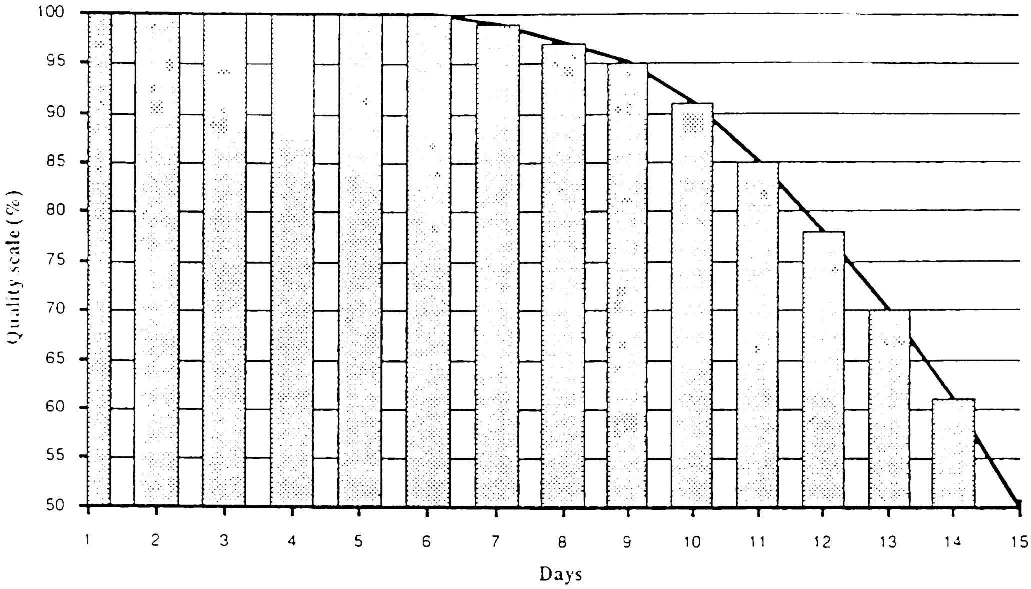


Figure 2: Relative Quality of Fresh Fish as a Function of Time

3. Plant Operation. When a trawler lands its catch, the raw material inventory at the processing plant is updated accordingly. Depletion of inventory is based on the production rate at the processing facility. To a large extent, the coordination between trawler operations and plant operations depends on the level of detail in the inventory control and production rates modeled in the simulation. Different scenarios representing different levels of accuracy and information requirements were evaluated; these are discussed in the evaluation section.

The simulation model generates a daily trawler activity report that contains information on the day's catch; a trip summary report for each trawler that contains information on the trip number, trip length, landing day, catch combination, and total catch; and an inventory status report, showing the daily inventory status of the raw material at the processing plant as estimated by the simulation model.

2.2 Linear Programming (LP) Model

The decision making activity considered in the LP model is at a macro level that focuses on the products manufactured and on the requirements of the critical resource, labor. The model can handle multiple time periods, multiple fish species, and multiple products per species. The objective function is to maximize net revenues over a specified planning horizon. Cost elements included in the objective function are: raw material, regular and overtime labor, hiring and firing of employees, inventory holding, and trawler operation. The constraints in the model include: availability of raw material, labor requirements for each product, availability of labor, workforce balance between periods, market demand for products, inventory balance between periods, freshness of raw material in inventory, and limits on storage for inventory. The output from the LP model includes the amount of each product type, the amount of raw material inventory held for each species, the labor hours used, and the resources used for each time period. For the mathematical formulation of the LP model, see Randhawa and Bjarnason (1994).

3 MODEL EVALUATION

The simulation model is programmed in Think C, version 5.0, for the Macintosh. The LP model was formulated and generated in MPL, a modeling programming language for LINDO. The decision support framework described above was validated using information from a major fishing company in Iceland. The primary focus was to help improve the decision strategies used by the operations management of the fishing company.

The primary data input to the simulation model is associated with the trawlers (capacity and quota for each trawler). The model evaluation is based on the company operating four fish trawlers. Only the two high volume fish species — cod and pollock — were considered; also, two primary products were produced from each species. Following the fishing practice of this company, the lower and upper bounds on the number of days a trawler spends at sea were specified for the decision rule in the simulation model. These bounds are 5 and 15 days, respectively, based on trawler economics and raw material quality. It was assumed that the company does not wish to keep more inventory on hand than can be processed in one week. This threshold value is used along with other information in the time value concept to send vessels back to sea for fishing.

The amount of catch from the simulation model is one input to the LP model. Other inputs include: raw material yield and quantity needed to produce a kilogram of product; raw material processed in one man-hour and the labor hours needed to produce one kilogram of product; resource availability over the planning horizon; and cost parameters.

As mentioned earlier, the performance of the system depends on the plant production characteristics imbedded in the simulation module. Three different scenarios were evaluated. In the first scenario, separate production rates were used for each fish species, but these rates were held constant throughout the year (Rule A). In the second scenario (Rule B), the production rates were varied to accommodate seasonal fluctuations for each of the fish species. In the third scenario (Rule C), the production rate was again varied, but the on-hand inventory in the processing plants and the potential inventory due to trawlers scheduled to land were also considered. Based on these inventory levels, the model determines the production rate that is appropriate for the available and expected amount of inventory.

The production system was analyzed for different periods during the year. Each period has different operating characteristics; for example, in spring the expected catch rate shows greater variation, whereas during the summer months the rate is high and relatively stable.

The results for the three scenarios for the spring and summer periods are summarized in Figures 3 and 4. Although the amount of raw material landed for the three rules is about the same, the weekly landing pattern is very different (Figures 3). In Rule A, trawlers land their catch on all days of the week. The pattern is similar for Rule B, but more catch is landed at the start of the week. For Rule C, most of the catch is landed on Mondays and Wednesdays.

The weekly landing pattern has important inventory implications. For A and B inventory is held over the weekends; for C weekend inventory is minimal. The result is high storage costs for A and B. Also, the value of products, particularly under A, is lower because in an attempt to minimize inventory over the weekend, the products with the higher production rate rather than the higher value are produced. The difference in revenues is greater in summer than in spring when raw material input is high when the production rates are high.

Figure 4 shows three different profit measures (ISK/kg-product, ISK/kg-raw material, and ISK/labor-hour, where ISK=Icelandic kronur); all three measures show the performance of rule A to be significantly lower than the other two rules. The results show that changing the production rate representation in the decision rule from fixed to variable has a greater effect on the revenues generated than adding additional inventory information to the decision rule.

4 CONCLUSIONS

The paper presented an approach for coordinating fishing and fish processing. Including fish quality measures and processing plant considerations in the trawlers' operational decisions (as represented in the simulation model) enhances the performance of the system. Building decision rules based on experience is equivalent to embedding an expert system module in the simulation model. The quality function can be improved in future research by incorporating the effects of temperature and differences among species. Integration of optimization and heuristic modeling to aid decision making can be used effectively in other application areas.

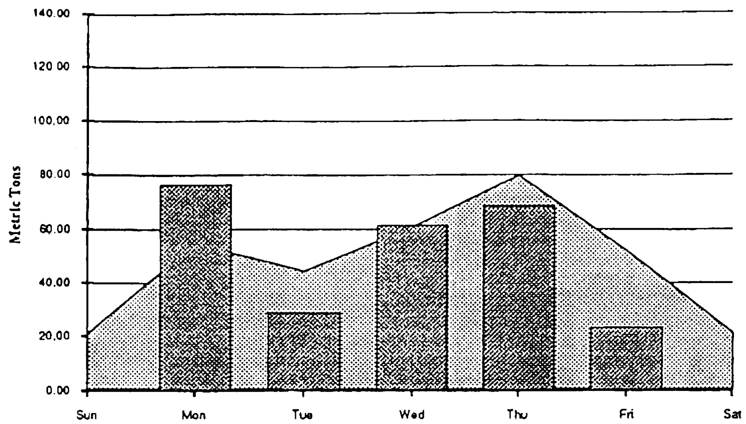
REFERENCES

Andrason, T.I. 1990. Production management onboard factory trawlers. Final Thesis, Engineering Faculty, University of Iceland.

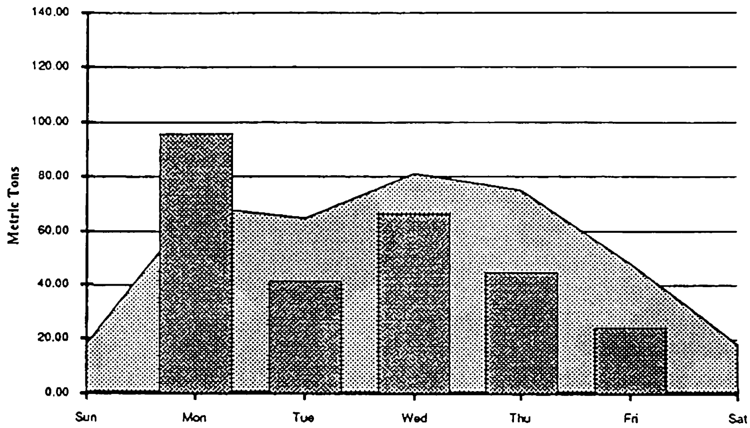
Arnarson, I. 1984. Economical analysis of fishing vessels: A comparison between stern trawlers and longliners. M.Sc. Thesis, Norwegian College of Fisheries Science, Tromso, Norway.

Arnarson, I. and P. Jensson. 1991. Simulation model of factory trawler operation. Unpublished working paper, Agriculture and Resource Economics, Oregon State University, Corvallis, Oregon, USA.

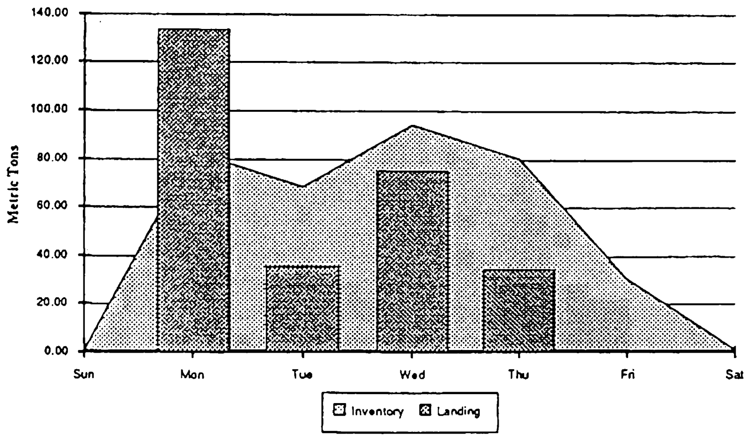
Bjarnason, E.T. 1992. A decision support system for integrating fishing and fish processing. M.S. Thesis, Department of Industrial and Manufacturing Engineering, Oregon State University, Corvallis, Oregon, USA.



(a) Rule A



(b) Rule B



(c) Rule C

Figure 3: Average Weekly Landings and Inventory During the Summer Season

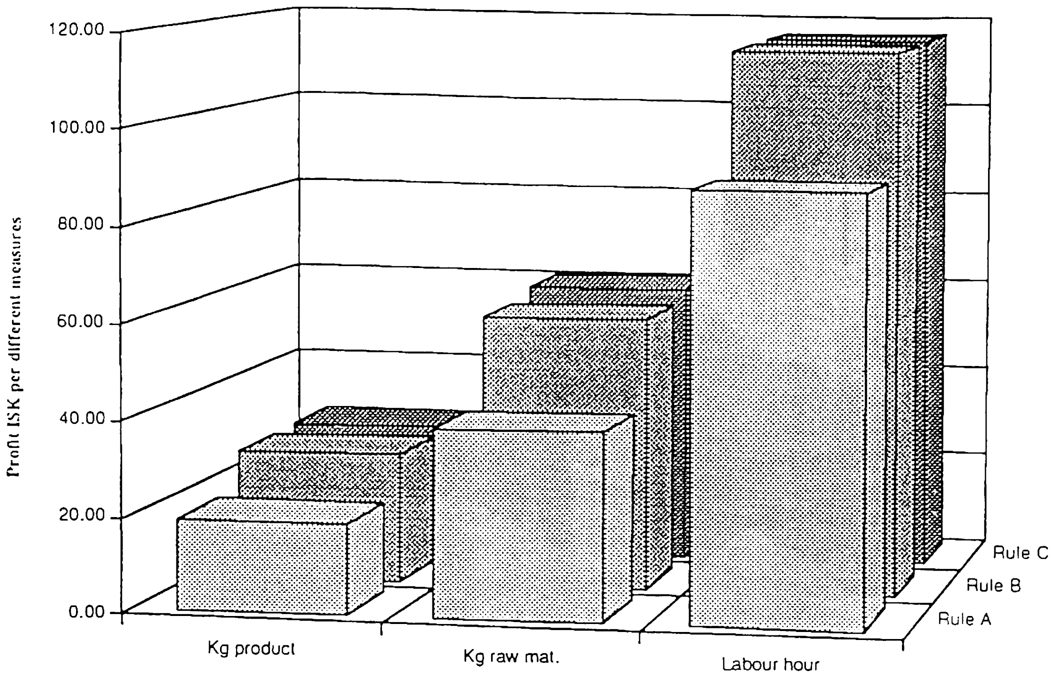


Figure 4: Comparison of Different Profit Measures During the Summer Season

Digerness, T. 1982. An analytical approach to evaluating fishing vessel design and operation. Dr. Ing. Thesis, Norwegian Institute of Technology, Trondheim, Norway.

Gunn, E.A., H.H. Millar, and S.M. Newbolt. 1991. Planning harvesting and marketing activities for integrated fishing firms under an enterprise allocation scheme. *European Journal of Operational Research* 55:243-259.

Hauss, H.H. 1988. *Fresh fish - quality and quality changes*. Rome: Food and Agriculture Organization of the United Nations, Danish International Development Agency.

Jensson, P. 1988. Daily production planning in fish processing firms. *European Journal of Operational Research* 36, 410-415.

Jensson, P. 1990. Coordination of fishing and fish processing. Unpublished paper, Engineering Faculty, University of Iceland.

Jonatansson, E. and S.U. Randhawa. 1986. A network simulation model of a fish processing facility. *Simulation* 47(1):5-12.

Mikalsen, B. and T. Vassdal. 1981. A short term production planning model in fish processing. In *Applied operations research in fishing*, K.B. Haley, ed. New York, NY: Plenum Press.

Randhawa, S.U. and E.T. Bjarnason. 1994. A decision aid for coordinating fishing and fish processing. To appear in *European Journal of Operational Research.*

Sigvaldason, H. et al. 1969. A simulation model of a trawler as a raw material supplier for freezing plants in Iceland. Technical report, University of Iceland.

Teitsson, A. 1990. Processing onboard on factory trawlers. Technical report, Icelandic Fisheries Laboratories.

AUTHOR BIOGRAPHY

SABAH RANDHAWA is an Associate Professor and Acting Department Head of Industrial and Manufacturing Engineering at Oregon State University. He holds a BS in Chemical Engineering and a MS and PhD in Industrial Engineering. His research interests are in simulation modeling and decision support systems.