A Scenario Simulation Methodology for Re-engineering Potential Assessment

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Abstract

The research objective of this paper is to experiment the applicability of scenario simulation methodology in a paper industry distribution problem. The methodology proved to be able to assess the re-engineering potential by producing quantifiable results for the performance measures. The methodology itself does not provide optimal re-engineering actions. Its function is to assess the improvement potential of re-engineering actions derived elsewhere.

Keywords

Simulation, modeling, logistics

1 SIMULATION AS A RESEARCH METHOD IN LOGISTICS

Today, the use of discrete event simulation as a research method is commonplace in logistics research. In fact, the importance of simulation can be described by the viewpoint that there are three pillars in scientific and technology research; analytic methods, experimental methods and numerical simulation (Strandhagen, 1994).

According to Bowersox (1986), the main advantage of discrete event simulation in logistics is that it incorporates the impact of time into performance evaluation. Hoover and Perry (1989) view simulation as a powerful problem solving method. According to Mott and Tumay (1992), simulation is a thorough and economic way

to express and evaluate ideas and alternatives before implementation. Simulation, however, will provide merely the best answer of the solutions tried and thus it is limited in its ability find the “best” answer (Menzer, 1989).

The popularity of simulation can partly be explained also by the following advantages of simulation in logistics research:

- In comparison to analytical models, it is flexible. You can include details, which are impossible with analytical models (Hoover and Perry, 1989). Even in simple systems analytical modelling of queuing disciplines and priority rules is extremely difficult (Johnsson, 1992)
- In comparison to the real system, the researcher has control over the other variables (Johnsson, 1992). In fact, simulation could be viewed as a test laboratory of logistics research.
- Non-existent systems can also be studied (Hoover and Perry, 1989).

2 SIMULATION PROJECT MODELS

A few authors have attempted to give guidelines for carrying out a simulation modeling project. Strandhagen (1994) has a summary of the simulation project models and he concludes that for many purposes it is convenient to distinguish only three major tasks:

- feeding information into a system
- running the model
- extracting information from the system

Figure 1 Simulation project models, left: Hoover and Perry, right: Law and Kelton.

Figure 1 shows two simulation project models by Hoover and Perry (1989) and Law and Kelton (1991). Both project models are almost in perfect agreement on how to perform simulation study, although Hoover and Perry view the project even more iteratively than Law and Kelton. Also Law and Kelton add finer detail in some of the phases than Hoover and Perry. Also Banks & Carlson (1984) give similar project guidelines. In the following, the major stages in simulation project models are discussed.

Problem definition

The problem definition is very important and as Hoover and Perry (1989) put it, one is not likely to find good solutions to ill-defined problems. Simulation textbooks and literature that cover simulation project, however, give only very vague guidelines concerning problem definition. For example, according to Law and Kelton (1991) a model should contain only **enough** detail to capture the **essence** of the system and Mitrani's (1982) advises it is necessary to abstract from the real system **all** those components that are considered **important** enough for inclusion in the model.

Model definition and data gathering and analyzing

According to Hoover and Perry (1989), an important part of model definition is to define system inputs, that can either be decision variables or given variables and outputs. Hoover and Perry (1989) advise to first make a conceptual model by either drawing a flowchart or by using a state change approach before implementing it. Defining the model is almost as vaguely covered as problem definition. According to Robinson (1994) there is a tendency to want to model everything without stopping to consider exactly what is **necessary**. He advises to include the minimum amount of detail to achieve the project's objectives. Law and Kelton (1991) advise that one should not have more detail in a model than is necessary to address the issues of interest.

Validation

A valid model corresponds to the real system. As Strandhagen (1994) points out, no model is ever completely valid corresponding perfectly to the real system. One approach, that is shown in Figure 2, to validating a simulation model is to see whether the simulation model can produce similar results as the real system has produced (Hoover and Perry, 1989). Law and Kelton (1991) call this the correlated inspection approach.

Figure 2 Correlated inspection approach to simulation model validation (Hoover and Perry, 1989)

According to Naylor et al. (1966) the ultimate test of a simulation model is the degree of accuracy with which it predicts the behavior of the actual system in the future.

Result analysis and experiments

A Simulation model as such does not give any indication of the possible changes in order to improve desired logistics system performance measures. There are a number of techniques for finding improved or optimized values for the decision variables that are based on probability and statistics theory.

The outcome of a particular stochastic simulation is a random variable. However, the usual independence of errors assumption of standard statistical methods is normally not met in a simulation study (Hoover and Perry, 1989). Both serial correlation of errors and heteroscedasticity can be present (Hoover and Perry, 1989). It can be proved (Pindyck and Rubinfeld, 1991) that the expected values still remain the same but confidence intervals are affected. Another problem is when input data is taken from the real figures the data itself is random variable and does not represent a true value in the statistical formula meaning (Vaughan, 1996). This means that the confidence interval of a performance measure represents the confidence interval inside that model and not the modeled system.

In a "what-if" experimental setting we need to decide between different scenarios and also estimate their difference. This can be achieved by establishing the confidence interval of the performance measure in question. The situation becomes much more complicated if the research objective is to find out how, given a set of decision variables, the performance measures could be improved or optimized. One possibility to deal with multiple input variables is to apply the statistical design of experiments approach. Other possibilities in analyzing the model include optimization methods (response surface methodology) and gradient method (Law and Kelton, 1991). Goldberg (1989) even suggests genetic algorithms for search of a local optimum. However, all these methods are ill developed in a non-independent errors environment (Hoover and Perry, 1989). The situation can be further complicated when there are more than one performance measure that cannot be combined into a single measure.

Implementation

Both Hoover and Perry (1989) and Law and Kelton (1991) ambitiously include implementation in their simulation project models. Unfortunately, the researcher in logistics has no control over the real system and cannot implement any changes. Gaining knowledge of systems functioning is less challenging than implementation, but still a good enough reason for building the simulation model.

3 THE SCENARIO SIMULATION METHODOLOGY

The research objective was to experiment with the applicability of scenario the simulation methodology in a paper industry distribution problem. The immediate objective was to evaluate the re-engineering potential. For this purpose, the scenario simulation methodology was applied. The steps of scenario simulation methodology are defined:

- 1) Analyze the existing system. If not possible, use interviews and documents.
- 2) Arrive at the improvement actions to test. System analysis, existing logistics theory and experience will help.
- 3) Define model scope and create conceptual model.
- 4) Create computer simulation model of the present system, called base case model.
- 5) Compare the results to the existing system.
- 6) Implement the changes to the present model to make it the scenario model.
- 7) Assess the improvement potential by comparing the present and scenario model results

The applicability of the scenario simulation methodology is experimented in a case in the following chapter. At the same time, the steps of the methodology are demonstrated during the case.

4 SIMULATION MODELING CASE

4.1 The existing system

The case included three Nordic paper mills that manufactured printing and writing papers and newsprint that were delivered in reels cut to customer specific widths at the mills. The main markets for all the mills were in Western Europe although mill 1 had large overseas sales. The mills share a common shipping arrangement to Western Europe that is shown in figure 3. The case mills have a customer dedicated call-off stock at the port terminal from which deliveries can be made by

customer call-off. This is shown with (B) in figure 3. This port terminal stock is replenished from the paper machines. Mills 1 and 3 manufactured standard grades and had no notable production cycle. Mill 2, however, had a three-week-production cycle. The production cycle in the mill 2 was not included in the simulation models.

Figure 3 The logistical chain of the case.

4.2 The improvement actions to test

The problem statement for the simulation study was formulated

- 1) to find out the inventory savings achievable by an alternative transport arrangement.
- 2) to study the feasibility of make-to-order deliveries instead of having customer dedicated call-off stock at the port terminals.

4.3 Model scope

The simulation study was carried out by making five independent one-year simulations with both the present model and scenario transport model arrangement. The comparisons between the models were made at equal availability levels.

Customer demand was modeled by 60 customers. Each of the customers had an expected demand of 24 tons per day. Twelve customers have a highly variable demand, 24 customers have medium demand variance and 24 customers have low demand variance. The foreign port terminal call-off inventory replenishment logic was reorder point control. Production control logic at each mill was FIFO. The mill was shut down when the order book was empty and reopened after there were enough orders for a few days' production. Reorder points and replenishment quantities for the call-off inventories were set so that a 95% availability level was achieved.

4.4 Simulation model of the present system

Figure 4 Base case logistical system.

Figure 4 shows the base case transportation system. Ship 1 serves terminal 1 and takes only paper from mill 1. Ship 1 can make a back and forth trip in five days. Ship 2 serves terminal 2 and makes a back and forth trip in five days. Ship 3 makes a seven-day round trip serving terminals 3-5. While the capacity of ship 3 is not enough to handle all the volume to terminals 3-5, ship 4 helps by making four additional round trips a year. This arrangement is also close to the present operating practice.

Table 1 Base case simulation results

	Inventory (tn)			Availability	Order book (tn)	Lead time (days)	
	Home terminal	In-transit	Foreign Terminal			1 and 2	Others
Average	4741	4042	24 624	94.5%	3590	8.8	11.4
2.5%	4375	3749	24 202	94.0%	3357	8.8	11.2
97.5%	5106	4334	25 046	95.1%	3824	8.9	11.7

The base case simulation results are shown in Table 1. The average-row gives the average of the five runs. Rows marked 2.5 % and 97.5 % give the 95 % confidence interval on the average under the assumption that the average is normally distributed.

Availability in the base case was a little under the target level of 95 %, but the target level was inside the 95 % confidence interval. Average lead time in the base case is 11.4 days to terminals 3-5 and 8.8 days to terminals 1 and 2.

The base case inventory in the first simulation run during its last half is shown in Figure 5. The total inventory in the base case model was 33 400 tn.

Figure 5 Base case inventory in the last half of one of the simulation runs.

4.5 Scenario model

The alternative transport arrangement used in the scenario model is shown in figure 6. The number of foreign port terminals is consolidated to three. All the remaining terminals are served three times a week. Each of the three ships visits all the terminals during each trip. A round trip takes seven days.

Figure 6 Scenario logistical system.

The existing ships do not have enough capacity because some capacity is lost due to longer travel time in new systems vs. short terminal 2 trips. This was noticed during the first trial of simulating the scenario model. The home terminal inventory increased wildly. When the results were studied further, it was found out that the ship utilization was 99.9 %. The transport capacity formed a bottleneck in the logistical chain.

Based on the results of the first simulation, the transport capacity needs were recalculated. To handle the production capacity of the mills, the smaller ship 1 is replaced by a new ship with 1400 tons more capacity. The total shipping capacity

then exceeds the total production capacity. The scenario simulation results are shown in Table 2.

Table 2 Scenario simulation results

	Inventory (tn)				Order book (tn)	Lead time (days)
	Home terminal	In-transit	Foreign Terminal	Availability		All terminals
Average	1569	4864	17 245	95.4%	3430	7.8
2.5%	1058	3659	16 707	95.0%	3220	7.7
97.5%	2080	6069	17 783	95.7%	3640	7.9

4.6 Assessment of the improvement potential

Average lead time for the scenario model was 7.8 days. The scenario model average lead time reduction to base case terminals 3-5 is 3.6 days or 32 %. A large part of the difference is due to the increased shipping frequency from once a week to three times a week. For terminal 2 the lead time reduction is less, down only one day from 8.8 days or 10 %. The shipping time to terminal 2 remains the same because it is the first terminal to be visited during the round trip. The lead time is affected also by a little larger base case order book, due to larger replenishment quantities which have a small effect on the average lead time.

Figure 7 Scenario inventory in the last half of one of the simulation runs.

The scenario inventory in the first simulation run during its last half is shown in figure 7. The alternative transport arrangement achieves a reduction of 9700 tn or almost 30 % reduction in the total inventory when compared to the base case.

The foreign port terminal inventory reduction in the scenario model is 7400 tn or 30 % as compared to the base case. Because the lead time is shorter, the

replenishment uncertainty and therefore safety stock needed is less. The cycle inventory is also decreased because the increased transport frequency in the scenario model allowed decreasing the replenishment quantity.

In the scenario model the home terminal inventory is greatly reduced as compared to the base case. A reduction of 3100 tons or 67 % was achieved. As can be seen from figures 5 and 7, the base case home terminal inventory is all the time larger than in the scenario model and has more cyclic variation. This is due to two reasons. First, the cycle inventory for all destinations is longer because ships leave less frequently to all destinations in the base case. Secondly, it sometimes happens that mills produce orders assigned to the same ship thus exceeding the capacity of the ship during a short period and forming a home terminal inventory. In the scenario model only a small cycle inventory accumulates between the three weekly sailings because all the ships visit all the terminals.

In-transit inventory is slightly increased in the scenario. The transit time to terminal 4 in the scenario model is about one day longer than in terminals 1 and 2. The increase in the in-transit inventory is 800 tons or 20 %.

5 CONCLUSIONS

The scenario simulation methodology was able to assess the improvement potential. It produced quantifiable results for the chosen performance measures. It also warned of possible problems like the inadequate shipping capacity.

Scenario simulation methodology calls for few models only: the base case model and the scenarios. The benefit of the scenario simulation technique compared to other results analysis techniques like the design of experiments or steepest ascent is that it reduces the time-consuming sets of simulation runs and elaborate results analysis. This is in line with the view that simulation is an economic way to evaluate alternatives before implementation (Mott and Tumay, 1992), although perhaps not as thorough as they claim. In their extensive article on production scheduling approaches, Rodammer and White (1988) reach the conclusion that once a problem has been defined and suitable candidates generated, the performance of candidate schedules could be verified using simulation models. This is the same approach used in the scenario simulation methodology.

One drawback of simulation is that model optimum is not found (Mentzer, 1989). This applies to the scenario simulation methodology also. However, not all re-engineering actions are found by optimizing present system parameters. The alternative shipping arrangement was not a part of the original, base case simulation model and cannot therefore be found by optimizing the base case model decision variables like reorder point and replenishment quantity. Simulation as such did not prove to be a powerful problem solving method, as Hoover and Perry (1989) believe. Instead, the improvement actions were discovered from the researcher's previous experience or from existing logistics theory.

The correlated inspection approach to validate the simulation models as suggested by Kelton and Law (1991) or Hoover and Perry (1989) to validate the base case models was not properly carried out. The exact replenishment policies and demand

structures were not known for a stock, so the actual system inventory level data was used to fine-tune replenishment policies. After this fine-tuning is done, comparing the model inventory level to the actual system inventory level is no longer a test of validity.

Another consideration is that the role of simulation modeling can be a decision support tool. The improvement actions are decided elsewhere. Then the function of the model is to assess the improvement potential of the suggested improvement actions. For this purpose, scenario simulation methodology is suitable.

REFERENCES

- Banks J. and Carson J (1984) *Discrete-event System Simulation*, Prentice-Hall, New Jersey.
- Bowersox, Donald J., Closs, David J., and Helferich, Omar K. (1986) *Logistical Management - A Systems Integration of Physical Distribution, Manufacturing Support and Materials Procurement*, 3rd edition, MacMillian Publishing, U.S.A.
- Goldberg, D. (1989) *Genetic Algorithms in Search, Optimization, and Machine Learning*, Addison-Wesley, Massachusetts.
- Hoover S. and Perry R. (1989) *Simulation - A problem-solving approach*, Addison-Wesley, USA.
- Johnsson M. (1992) *Discrete Event Simulation, An Evaluation Tool for Logistic Systems*, Lund Institute of Technology, Lund, Sweden.
- Law, A and Kelton, W. (1991) *Simulation Modeling & Analysis*, McGraw-Hill, U.S.A.
- Menzer, J. (1989) Symposium Feature: Approaches to Logistics Modeling, *Journal of Business Logistics*, vol. 10, no 1.
- Mott J. and Tumay K. (1992) Developing A Strategy For Justifying Simulation, *Industrial Engineering*, July 1992.
- Naylor, T., Balintfy, J., Burdick, D. and Kong, C. (1966) *Computer Simulation Techniques*, John Wiley, U.S.A.
- Pindyck R. and Rubinfeld D. (1991) *Econometric Models & Economic Forecasts*, McGraw-Hill, Singapore.
- Rodammer, F. and White, P. (1988) A recent survey on production scheduling, *IEEE transactions on systems, man and cybernetics*, Vol. 18, no.6.
- Strandhagen, J. (1994) *Operative simulation in production management*, Doctoral thesis, NTH Trondheim, Norway.
- Vaughan, T. (1995) The effect of sampling variability on statistical order point computation, *Production and inventory management journal*, 3rd quarter.

7 BIOGRAPHY

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