PANEL ON TRANSPORTATION AND LOGISTICS MODELING

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ABSTRACT

Transportation and logistics are fertile areas for modeling. Simulation has traditionally been used in warehousing and inside the distribution center or processing hub in the trucking and package delivery sectors, for baggage systems and passenger queueing in the airline industry, and for detailed models of terminals and yards in the railroad industry. In addition, simulators are used for certain specialized applications, such as airspace applications and line-of-road railroad applications. Other non-simulation models based on optimization, networks and heuristics have dominated many other areas of transportation and logistics, especially large-scale supply chain issues such as logistics network design, vehicle routing, facility location, and scheduling.

The panel discusses a number of these and other issues: when to use simulation models versus optimization and heuristic models, the features (or lack thereof) in current generation simulation software relevant to transportation and logistics modeling, the possibility of combining simulation and optimization or mathematical models, and how to convince management of the benefits of simulation.

1 INTRODUCTION

The number of sessions at WSC in transportation and logistics has been increasing in recent years. The intent of this panel discussion is to bring to focus a number of issues related to simulation in the transportation and logistics industries.

The panelists will address a number of key questions, including the following:

1. Are simulation models the right kind of model for transportation and logistics problems? Which problems is it best for? Which ones not? Provide examples for which simulation modeling is the right approach or provides a better model, and examples where other types of models (analytical, optimization, network, heuristic) are better.

2. Without mentioning product names, do the available simulation packages provide adequate support for transportation/logistics applications? Should simulation packages have special features to facilitate

transportation and logistics applications (versus manufacturing and other applications)? Does the manufacturing orientation or motivation of some packages help or hinder (or is it irrelevant for) transportation applications?

3. Can simulation be combined with other models (optimization, heuristics, etc) to make better models for some applications? If not, why not? If so, give an example.

4. How do you convince non-technical management that simulation is worthwhile?

2 THE PANEL

The panelists represent a spectrum of industries in the transportation and logistics sector. As evidenced by their biographies, they have a diverse background from the trucking and package delivery industries, airlines, railroads, and software and consulting for the supply chain. Each panelist has prepared a brief position statement.

2.1 Mani Manivannan, CNF Transportation

Typically, a logistics and transportation (L & T) system is built on a network composed of one or more terminals or hubs connected by a set of traffic lanes. Accordingly, these networks form hub and spoke arrangements and/or direct linkages between origin and destination. These networks and the associated topologies have evolved over a long period of time. Therefore, it is very expensive and oftentimes consumes enormous time and effort to make radical changes to the network.

The L & T systems utilize many resources, classified broadly as:

- *Direct resources* used in the physical transportation of freight or goods from one geographic location to another, and
- *Indirect resources* involved in sorting, storing, handling, retrieving, and consolidating at the various transit locations known as flow through centers, terminals or hubs.

In a trucking system, trailers, tractors and drivers are the *direct* (moving) resources whereas, the dock doors at the terminals, refueling stations, fuelers, and maintenance crews are the *indirect* (stationary) resources. Likewise, in a warehousing and distribution system, the trucks, aircraft and cargo ships are the *direct* resources; however, the docks, doors, forklifts, carts, storage bins and racks inside the warehouse are the *indirect* resources. In an air transportation system, the *direct* resources are aircraft, pilots and air-containers and the *indirect* resources are the scissor lifts, tug and dollies, forklifts, and hub personnel.

It is important that these two types of resources operate together in the most efficient manner for a smooth and balanced operation of the entire L & T network. In addition, the management and deployment of these resources must ensure the least amount of delays at the terminals and hubs, maximum availability and utilization of resources and on-time pickup and delivery of the physical goods. A well-structured, scientifically proven approach is required to accomplish these goals.

For the past several decades, the design, analysis, and control of transport systems have been carried out mostly by the field engineers (civil, structural, and traffic engineers) and operations research (OR) scientists. A large number of these systems have evolved over time and become fairly huge and complex. The primary objective of a business enterprise involved in L & T is essentially to store and/or transport freight of varying size, form, and shape from its origin location to its destination at the lowest cost in order to deliver the right quantities at the right time to its customers who are geographically dispersed; however, the underlying L & T systems that are built to guarantee the on-time, damage-free, shortage-free delivery to customers, have become quite complex and oftentimes require expensive administrative, information, and decision support systems.

Conventional L & T planning involves the development of analytical models for trip generation, trip distribution, modal split and traffic assignment.. Numerous OR models were developed and applied during the past two decades in the design and configuration of L & T systems. In recent years, the descriptive modeling of L & T systems has been gaining momentum in transportation companies. In general, the computer simulation models are built to evaluate a set of operation policies prior to the implementation of large and complex L & T systems. Major challenges face analysts in applying simulation technologies to L & T domain. These are broadly listed below:

- L & T networks are quite complex and involve a large number of entities and resources
- Existing simulation software does not support all the modeling and analysis features required
- Unfamiliarity of simulation technology in the L & T industry
- Optimization/heuristic methods are widely applied.

However, there are several problem domains within L & T systems where the simulation approach is best-suited if applied properly. For instance, simulation is highly desired for the evaluation of alternative strategies to operate a terminal, a hub or a warehouse. Likewise, the impact of dynamic arrival and departure times of trucks and aircraft at a central hub on the processing time windows and expected service levels can be best understood using computer simulation.

In general, the L & T problems appropriate for simulation studies are divided into three major categories:

A) New Design
B) Evaluation of Alternative Designs
C) Refinement and Redesign of Existing Operations

Accordingly, we can build simulation models in L & T domains for the following purposes:

1. Models for Strategic Planning
2. Models for Tactical Planning
3. Models for Network/Traffic Control
   a) Off-line Control
   b) Real-time Satellite and Telecommunication Control
4. Models for Scheduling and Dispatching
   a) Off-line Scheduling
   b) Exception Handling
   c) Real-time Monitoring

The problem areas that fall under New Design (category A) are solved, in general, using optimization or heuristic approaches. Oftentimes, the optimized new L & T designs are verified and validated using computer simulation. The problems areas that fall under B) and C) can be solved using several well-known techniques; however many L & T businesses tend to utilize simulation modeling and analysis. Examples of problems that fall in each category are as follows:

(A) New Design
- Network Design
  - Hub and Spoke versus Direct Move
- Terminal/Hub Planning
  - Number and location of Terminals
  - Size (Dock dimensions, Number of doors)
- Fleet Planning
- Route Planning
- Least-Cost Transportation Modes

(B) Evaluation of Alternative Designs
- Transportation Mode Alternatives
  - On-the-road (trucks)
  - Rail (trains - single/double stacked)
  - Air (planes, helicopters)
  - Ocean (ships, barges)
- Intermodal Alternatives
- Service Performance Alternatives
  - Over-night/Premium service
  - Two-day service

(C) Evaluate and Redesign Existing Operations
- Operational Performance Analysis
  - On-the-road Movements
    -Linehaul, Regional, and Group Operations
    -Terminal Operations
    -Operating Rules
  - Rail Movements
    - Loading strategies at the Railyard
    - Train Time Tables/Scheduling
    - Capacity Requirements
  - Air Transportation
    - Origin Terminal Operations
    - End-of-line Operations
    - Central/Distributed Hub Operations

Today, many commercial software packages are being employed by the L & T industries depending upon the level of complexity and size of the problem investigated. These software tools range from standard Linear Programming packages such as *LINDO, CPLEX, OSL* to special purpose software shells such as *INSIGHT, SUPERSPIN*, and *CAPS Toolkit.* With respect to commercial simulation software, a large number of vendors provide packages that focus on modeling and analysis of simple material handling systems to complex flow-through centers and transportation networks.

As the degree of industrialization of an economy increases, there is a shift in preponderance from basic manufacturing industries to the service industries. The primary industries have a greater need for freight transportation and the existing L & T systems will continue to grow larger and more complex. In order to build transportation systems that are efficient, easy to operate and manage, and still cost-effective, the L & T companies will have to invest time, money and other resources in scientific and structured approaches for many years to come. This means that the applications of mathematical modeling and computer simulation will continue to grow in L & T companies.

2.2 Mark Brazier, CSX Transportation

The problems best suited to simulation, generally speaking, are large problems of a dynamic nature with stochastic behavior that don't require a real time solution. Problems that cannot be explicitly formulated in mathematical terms are also good candidates. [For instance, if a hump yard's departure process distribution is of interest, and the inter-arrival pattern to the queuing system is described by a general distribution, this creates a difficult mathematical situation (e.g., G/G/n problem).] Other problem characteristics that typically support simulation as the preferred approach include comparison of business operating rules, measurement of resource capacity, and the testing of alternative solution or operating approaches. Typical railroad applications for simulation at CSX Transportation (CSXT) in the past have included:

- Exploring alternative operating strategies – either at a terminal level (e.g., effect of a proposed yard connection or terminal handling standard change) or at a network level (e.g., impact of policy change with respect to train operation frequency, train size, locomotive assignment rules/strategy, train prioritization, etc.).

- Estimating resource utilization for long term planning purposes (e.g., crew or locomotive planning).
- Capacity planning studies for management of infrastructure investments associated with line-of-road (LOR) or terminals (e.g., siding length and frequency, track speed, track signaling, block size, yard track and switch additions, etc.).

On the other hand, we frequently deal with problems that don't lend themselves well to simulation. Examples of these kinds of problems at CSXT have included:

- Development of alternative network operating plans. Simulation requires an iterative approach and does not generate alternatives. Unfortunately, the story doesn't get much better with alternative methodologies. While applications currently exist that allow development of network blocking plans, they currently do not suggest the block to train assignment and subsequent train schedule component of the final solution - nor do they propose optimal solutions at the network level. CSXT is currently providing funding of university-level research for development of a network level application but to date has seen limited success due largely to the size and combinatorial nature of these problems.
- Stringline or meet/pass planning for development of train schedules. While approached in the past by simulation via the Canadian National Railroad (CN)-developed Route Capacity Model (RCM), a SIMSCRIPT-based LOR capacity analysis tool developed in the 1970s, data maintenance was onerous and the process tended to be too complicated and slow for the typical Service Planner's (i.e., scheduler) requirements. As a result, we are currently developing a heuristic-based scheduling application that is easier to maintain. More importantly, the user community is not overwhelmed with esoteric quirks associated with the application itself -- and the solution of course is very, very quick. While the current intent is to utilize this application in a planning capacity, we are also considering employment at our Operations Center for tactical, near real-time utilization.
- Dispatching of trains. We are currently evaluating near-optimal solvers that could be embedded within a next generation train dispatching system to assist in schedule adherence. These systems would assist the dispatcher in making decisions regarding meet/pass situations, train prioritization, siding assignments, etc. as the result of real-time events. Current generation dispatch management systems have been designed to primarily contend with train separation and safety of operation issues. Very little emphasis has been placed on schedule awareness and integration, from a systems level, with legacy planning systems. However, with increasing market demands for better service reliability, a much more robust decision support system must be made available to the train dispatchers of the future in order to manage the network service plan as optimally as is possible. Obviously, awareness of current resource status (e.g., crews, train consist, locomotives, etc.), system stochastics, and the network service plan is necessary in order to accomplish this task. On a larger scale, we may eventually see enterprise systems -- similar to MRP II -- that encompasses both the planning and execution components of rail operations to include direct (e.g., EDI) customer demand interfaces.

There are a few domain-specific simulators available for railroad operations. It appears that at this time only one viable LOR railroad simulator product exists. This product is a PC-based application that, in many respects, functions in a manner similar to the RCM product mentioned earlier. Of course, it is much more modern and as a result, includes many of the graphical user interface features normally associated with PC-based products. And while it provides a viable approach for representing many of the situations associated with railroad LOR operations, it is still deficient in many critical areas. First, its dispatch logic in both single and multi-track environments needs considerable enhancement. Second, it suffers from occasional deadlock. Third, it is not ODBC-compliant. Further, because this product has been developed outside of the mainstream simulation profession, it lacks many of the statistical features traditionally associated with commercial general purpose simulation applications. That said, it is still the application of choice by most railroads today because of its relative ease of use and, at least in my view, because of its ability to represent "special events" that allow it to more accurately reproduce real world operating situations. Because of the apparent lack of viable commercial alternatives, CSXT has joined in a joint funding agreement with other members of the application's user community in an attempt to address these deficiencies.

While commercial LOR rail simulators do exist, they have one other critical shortcoming not previously mentioned. Specifically, they treat rail yards or terminals as an infinite capacity nodes. Popularly termed a "black hole" within our community, this deficiency has had a significant impact on our LOR model validation process since it allows train origination's and arrivals to occur with minimal regard for terminal capacity, throughput, or requisite connections.

All this leads to an even more critical shortcoming -- no commercial terminal simulation applications exist for studies of yard operations and/or studies of terminal influence on LOR operations. As a result, the railroads have turned to general purpose applications and have (reluctantly) attempted to build their own yard models. While various articles have been published on these efforts [Atala et al., 1992; Sarosky and Wilcox, 1994; Weigel, 1994], there does not appear to be any development effort to date that has resulted in a viable generic terminal (hump or flat yard) modeling application as a surrogate solution for a commercial simulator. As a result, CSXT has recently initiated development of yard simulation models, via a commercial general purpose simulation application, to better understand these issues while also providing models for other research applications.

Our experience with the general purpose applications has clearly indicated that these packages lack critical features necessary to make them comparable in model building quality as compared to their more traditional role in manufacturing. While we have been able to successfully adapt the existing features of these tools to build railroad models -- it has not been easy. Specific areas that need to be addressed to make these tools more railroad-friendly would be the inclusion of features such as management of dynamic entity length (e.g., the addition of cars to an existing cut or group of cars in a train), the ability to compare entity length with geographic locations (e.g., switch clearance points, block entry/exit with respect to head and tail train components), the ability to represent specific railroad resources such as a switch and its orientation, straight track with attributes for length and speed that would allow train entities to interrogate track operating constraints, groups of track and switches called a "ladder" that would allow rapid definition of parallel track environments, locomotive entities that would follow user defined operating rules and capable of both acceleration and deceleration, etc. Of course, the ability to easily define interlocking rules for a group of tracks and switches would also be highly desired. Finally, these features would be embedded within a 4GL-like environment that would provide graphical model building.

While railroad-specific features would greatly simplify the building of models, it does not appear that the inclusion of features typically associated with manufacturing and/or other environments is an undue encumbrance. Rather, their availability for potential adaptation to particular modeling issues probably serves as an important tool to the simulationist. However, unlike manufacturing, as a general rule the railroad industry lacks the requisite training and experience with the current generation of general purpose simulation tools to fully appreciate their capability. As a result, a more simplified development environment such as those traditionally associated with a simulator product would probably be preferred.

For some applications, it can be advantageous to combine simulation and optimization models. For example, Clymer (1993) describes the use of an embedded expert system for evaluation of a single-track railroad system. Many of the general purpose application tools provide source code libraries that allow the user to embed so-called "black box" applications such as a C++ program or a commercial optimizer routine that is subsequently invoked via a subroutine call during model execution. At CSX, we are developing a cross docking application for a CSXT affiliated company, Customized Transportation, Inc. (CTI), that will hopefully embed a commercial optimizer in future iterations.

2.3 Eric Miller, SABRE Technology Solutions

SABRE Technology Solutions (STS) has been a pioneer in the introduction of simulation techniques to evaluate transportation facilities. STS grew out of the Operations Research department of American Airlines. STS' Transportation Planning Group has specialized in aviation planning, and also provides planning and consulting services to other areas of transportation including roadways, rail, and the maritime industry.

Most of today's airports were designed and built long before deregulation changed the face of the aviation industry. Prior to deregulation air carriers operated "point-to-point" service. Deregulation provided an incentive for the air carriers to modify the structure of how flights operate to "maximize" revenues. What grew from these changes is now known as a "hub and spoke" system.

Large airports such as Atlanta Hartsfield International, Chicago O'Hare International, Dallas/Fort Worth International, and Miami International Airports have become large centers for transiting passengers to their ultimate destination. These airports were not originally designed to handle the peak connecting traffic and spiked aircraft arrival patterns associated with a hub operation. As traffic grew at these airports that were originally designed to handle point-to-point traffic, the existing facilities needed to be updated to meet the new traffic patterns. Simulation became a natural design tool to evaluate the impact of growing traffic and to evaluate how airport design modifications could better accommodate passengers and airplanes. As air traffic has continued to grow, the need for airport redesign has become even more important.

Simulation has been an ideal tool to apply to airport planning problems since:

1. Airport processes are stochastic and rarely reach steady state conditions.
2. Passenger and baggage flow through an airport can be broken into well defined sub-processes.
3. Historical data to define process distributions is readily available.
4. Interactions are complex and cannot be easily solved using theoretical or other analytical methods.
5. Proposed changes in an airport's design are difficult or impossible to physically test.

STS uses the FAA's airspace and airport simulator, SIMMOD, to evaluate airspace and airfield capacity issues. For landside and terminal projects, customized discrete event models are developed. STS has evaluated airfield, airspace, and terminal designs at airports worldwide, including analyses of Berlin (Schönefeld and Tegel), Chicago (O'Hare), Dallas/Fort Worth, Honolulu, Houston (Intercontinental), London (Heathrow), Los Angeles, Madrid, Martinique, Melbourne, Miami, New York (John F. Kennedy), Paris (Charles de Galle and Orly), San Juan, Stockholm, Sydney, and Tokyo (Haneda).

2.4 Don Ratliff, Georgia Tech and CAPS Logistics

At CAPS, our expertise and our software is oriented toward the design of the supply chain and the creation of decision support systems for logistics network design, shipment planning, production scheduling, and vehicle routing. Simulation is not the right tool for designing such systems. Basically, there are too many network configurations and combinations of the fundamental parameters to evaluate. After the design, simulation may be the right tool for evaluating the design, especially when stochastic and other variability are major factors and the customer desires to evaluate a design in the presence of these factors. The CAPS Logistics Toolkit uses optimization and heuristic algorithms to design a logistics system or supply chain. These methodologies are deterministic and use averages or typical values for demands, travel times, and other fundamental parameters. Then on the back end, many of our customers desire to simulate the stochastic variability inherent in demand and other variables to see what happens under more realistic assumptions.

On the surface, at the user interface level, commercial simulation packages are not configured for these logistics applications; their orientation and constructs match more closely the manufacturing arena than they do the transportation and logistics sector. While the underlying simulation engine and built-in constructs may be adequate for modeling the supply chain and other logistics problems, currently it is more difficult than it should be. There is a need for simulation tools whose interface and fundamental constructs include the basic network, basic transportation units, demand, inventory, other resources and fundamental parameters in the supply chain.

We see a need for a closer interface between design packages and the simulation software that our customers use. The CAPS Toolkit, for example, has standard representations for the network, the transportation units (truck, air, ...), inventory and other fundamental parameters. While today it is possible to simulate a system after it is designed, it is not easy. Each simulation model is unique and must deal with tedious issues such as data conversion. In addition, if changes are made to the network or other fundamental parameters in the design package, it should be easy to re-simulate without having to undertake a massive data conversion or changes to the simulation model. Customers today have become conditioned to seamless interfaces and ease of use and expect the same in their modeling packages.

3 SUMMARY

Both simulation and optimization/heuristic models are needed to meet the challenges of the transportation and logistics/supply chain problems of today and the future. Simulation packages need to incorporate logistics and transportation constructs and terminology to facilitate model building in a more natural and easier manner. Finally, to leverage the strengths of both types of models, the design packages using optimization and heuristic methods could share a common representation of the network and other fundamental transportation, logistical and supply chain parameters so as to facilitate simulation for design evaluation and validation.

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JOHN S. CARSON is the Regional Consulting Manager for the Atlanta office of AutoSimulations. With ASI since 1994, he has over 20 years experience in simulation in a wide range of application areas, including manufacturing, distribution, warehousing and material handling, transportation and rapid transit systems, port operations and shipping, and medical/health care systems. His current interests center on the simulation of transportation systems, train systems, bulk and liquid processing, and software for simulation output analysis. He has been an independent simulation consultant, and has taught at Georgia Tech, the University of Florida, and the University of Wisconsin-Madison. He is the co-author of two textbooks, including the widely-used Discrete-Event System Simulation, Second Edition (1996). He holds a Ph.D. in Industrial Engineering and Operations Research from the University of Wisconsin-Madison, and is a member of IIE and INFORMS.

MANI S. MANIVANNAN received his Ph.D from the Pennsylvania State University in 1988. He specializes in simulation of logistics, transportation and manufacturing systems, artificial intelligence, and large database design. Currently, he is the Director of Quality and Strategic Planning for Emery Worldwide, A CNF Company. He is the Project Leader for building a series of simulation models to improve and redesign the Emery Worldwide Dayton Hub and a pioneer of CNF transportation simulation software, *SIMTRAN 2000.* Prior to coming to CNF, Dr. Manivannan worked as an Assistant Professor for five years in the School of Industrial and Systems Engineering at Georgia Tech. He established the Intelligent Manufacturing Lab at Georgia Tech with grants from NSF and Torrington Company. He is the recipient of the 1991 *Outstanding Young Manufacturing Engineer of the Year* Award from SME. He received the 1996 *Ray O'Brien Award of Excellence* from the CNF Board of directors. He serves as a panel member at National Science Foundation and a Program Chair for WSC'98 Conference. He is an active member of IEEE, SCS, ACM and SME.

ERIC MILLER is a Senior Director in STS' Transportation Planning Group. Mr. Miller received a Bachelors Degree in Mathematics ('86) and Masters Degree in Statistics ('88) from the Georgia Institute of Technology. Mr. Miller has more than nine years of experience in airport landside and terminal planning. He recently managed the evaluation of the impact of Positive Passenger Bag Matching for the Federal Aviation Administration (FAA) and is currently managing the development of a simulation model of the Panama Canal.

MARK BRAZIER is Director, Operations Research at CSX Transportation, a tier-1 railroad headquartered in Jacksonville, FL and operating throughout the eastern U.S. and Canada. He has developed a number of large scale simulation models in a variety of application areas including manufacturing, electronic, warehousing, distribution, material handling, and railroading. He received his B.S. degree in Computer Science and an M.S. degree in Industrial Engineering from Texas A&M University. He is a member of APICS, INFORMS, ASQC and IIE.

H. DONALD RATLIFF is Regents' and UPS Professor and Executive Director of The Logistics Institute at Georgia Tech. He is also Co-founder and Chairman of CAPS Logistics. CAPS Logistics is a leading edge supplier of logistics software with an installed base of more than 1000. Dr. Ratliff was recently elected to the National Academy of Engineers for his work in developing interactive network optimization methodology for use in the design and operation of logistics systems. His research has allowed the development of fourth generation logistics modeling languages which provide an order of magnitude decrease in the time required to develop software systems for integrated design and operation of logistics systems. Dr. Ratliff has served as the Editor-in-Chief of the Journal of Operations Research, Area Editor for Optimization, Departmental Editor for Applied Optimization in IIE Transactions and Associate Editor of Management Science. Dr. Ratliff was awarded the 1991 "Outstanding Research Award" of the Institute of Industrial Engineers for his work in logistics. He is also a Fellow of the Institute of Industrial Engineers.