SIMULATION MODELING OF TRAFFIC ACCESS FOR PORT PLANNING

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ABSTRACT

Landside access to cargo terminals is one of the most challenging issues facing today's port planners. Ports must improve intermodal surface transportation efficiency to accommodate cargo growth and coexist with increasing urbanization. Planning a port's access system involves analysis of roadway networks, cargo activity, and mixed-use traffic. Managing all this information and performing the analyses requires a significant effort. The simulation model TRUCKSIM provides a tool to efficiently evaluate the access system and to determine the impact of and benefits of changes in harbor usage and roadway design.

TRUCKSIM is a hybrid of travel demand and traffic operation models. This PC-based, discrete event simulation model allows comparative evaluations of policy, operations, and capital development decisions aimed at improving transportation efficiency. The model has been applied at the Port of Long Beach and in the state of Hawaii to evaluate the impact of mixed-use traffic, imposed truck-operating policies, and impact of and benefits from on-dock rail facilities, grade separation projects, and roadway design improvements.

INTRODUCTION

Port planners must deal with a variety of complex transportation issues involving shipping lines, rail companies, and the trucking industry. All these carriers are striving to achieve the highest efficiency in goods movement, and they rely on the port to plan the necessary transportation infrastructure and usage. A dynamic computer simulation model, TRUCKSIM, was developed to study landside access improvements and a range of traffic access issues. This PC-based model allows comparative evaluations of policy, operations, and capital development decisions. TRUCKSIM brings together several analytical methods and a large amount of data in a user-friendly system to enable a unified comparative evaluation of a large transportation network. The model can be used as a tool to address such diverse issues as master plans, environmental analyses, transportation cost analyses, and traffic planning.

The landside transportation requirements of a major port are highly complex, involving the movements of thousands of trucks and many trains each day. These movements are governed by patterns of ship arrival and departure. Each vessel generates a pulse of activity over the local road and rail network as cargo moves to and from the ship. Vessel and train schedules may vary by season and annual trends. The patterns of truck movements will vary with the days of the week and hours of the day. These variations and the traffic behavior on the roadway are ideal for analysis through simulation modeling.

The Port of Long Beach commissioned Frederic R. Harris, Inc., in cooperation with Automation Associates, Inc., to develop the discrete event simulation model, TRUCKSIM, to provide the analytical tool needed. TRUCKSIM was originally used to compare various 2020 scenarios at the Port of Long Beach with the port's existing conditions. Later, the model was used to perform a fuel consumption and emissions loading study for the Southern California Air Quality Management District. The model is generically structured to be input-data driven so that any transportation network can be modeled. Therefore, the model is available for use at other ports and is currently being applied by the state of Hawaii to evaluate Honolulu and Barbers Point Harbors. Both the Port of Long Beach and state of Hawaii Department of Transportation are operating the model with their own staff to evaluate various "what-if" scenarios. In Hawaii, the Harbors Division plans to use the model to evaluate access to harbors throughout the state.

MODEL USES

The 1991 Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) provides policy to improve access to the nation's ports and airports. Ports are a key transition point in the intermodal movement of goods. TRUCKSIM provides a tool to study the efficiency of landside transportation access through the analysis of ship/truck/train cargo transfer and resulting traffic. The model specifically addresses the traffic generated by goods movement. The model considers the amount of cargo to be moved by rail versus by truck, thereby allowing the evaluation of the benefits from and the impact of increased goods movement by rail.

Because of increasing cargo volumes, planning terminal access and resulting interactions with nearby port facilities requires as much time as designing the terminal itself. A new terminal at a port has its own transportation access problems that must be considered; however, the new terminal also will affect traffic access to existing and future terminals. Intermodal terminal design and access must meet the needs of the tenant, while considering the needs of tenants at existing and future terminals. The port planner must look at the port as an entire system, not just as a set of discrete terminals.

Almost by definition, new intermodal terminals must have railroad access. This may be along existing routes or may require the expansion of railroad facilities. New routes and trackage are needed to assemble full unit trains of up to 2750 m (9,000 ft) in length. A new terminal's design must consider truck access and queuing. All these factors can affect existing and future terminals.

A new terminal will alter truck traffic on port roadways. This traffic can slow down truck access to terminals, cause congestion, and increase operating costs for terminals. Trains moving to and from an intermodal terminal can block roadway grade crossings. These blockages can cause delays in truck access to terminals as the traffic waits for trains to clear. Even worse, the railroad tracks may pass in front of or inside existing terminals, blocking truck access or disrupting terminal operations as trains pass through the terminals.

The problem for the planner is to anticipate these types of problems and find ways to minimize them. The planner needs a tool that allows analysis of alternative solutions. TRUCKSIM was developed with the idea of helping the port planner analyze and compare alternatives. The TRUCKSIM model allows the user to look at and quantify the impact on surrounding port facilities resulting from a variety of transportation problems and decisions. The model allows the planner to analyze variations in cargo and traffic volumes to determine the adjustments that will accommodate future growth. Port planners can make specific investigations into operational and roadway modifications to alleviate bottlenecks and other transportation problems. The model allows investigation of how the roadway system responds to such changes as terminal operating hours, truck operating hours, roadway improvements, grade separation projects, intermodal rail operations, and truck route restrictions. The model also quantifies fuel consumption and air pollutant emissions associated with alternative solutions.

The model is designed to allow the user to easily change the factors that affect landside intermodal transportation efficiency. Among the "handles" that can be easily adjusted are the terminal cargo volumes; number of truck trips; timing of truck arrivals; number of trains serving terminals in the area; the trains' arrival times, lengths, and speeds; and hours of terminal operation. The planner can make changes to these handles and study the impact on different intersections, roadways, terminal access times, and even emissions of air pollutants. In addition, the planner can study the impact of benefits from changes to the roadway network.

By running a series of alternatives, the planner can study the sensitivity of the transportation system to certain changes and can solve some of the problems that may develop. The ability to study a variety of alternatives will allow the planner to gain insight into how the port transportation system works and to find ways to minimize the impact on existing operations when a new terminal is opened. The TRUCKSIM model, which is specifically designed to study truck behavior and terminal access, provides a tool for carrying out this analysis.

MODEL DESCRIPTION

Background

The Port of Long Beach sought an analysis tool capable of providing detailed, quantitative estimates of traffic system performance for a variety of projected scenarios. The tool to fulfill these needs was conceptualized as a simulation model with the ability to account for the following:

- Trucks on roadways accessing each of the port's major cargo terminals;
- Effects of mixed-use traffic on truck movements;
- User-friendly modification of parameters allowing alternative analyses;
- Statistical results on system performance that are meaningful to port planners; and
- Animation showing truck behavior and indicating congestion points.

A review of existing transportation simulation models found no single model adequately fulfilling these criteria. However, developing a model using existing dynamic simulation languages (commonly applied to manufacturing capacity problems) showed great promise. A project, therefore, was commissioned by the Port of Long Beach to develop and validate an integrated, discrete event simulation model, TRUCKSIM, to fulfill the port's modeling requirements.

General Description

TRUCKSIM is a hybrid simulation model incorporating capabilities from two types of models in standard use by the transportation/traffic industry: transportation systems (travel demand) models and traffic operations models. TRUCKSIM merges the concepts of these two model types through the use of discrete, event simulation modeling. Appropriate traffic flow and operations theories are implemented through the simulation model. The simulation model enables a relatively large network of roadways and all vehicular traffic to be analyzed within a given model system.

Dynamic simulation modeling is a powerful tool that permits any process or operation to be broken down into a system of events and activities. Entities can be modeled to negotiate through this system and to react to conditions or handle decision points based on probabilities or statistical functions. The user, therefore, can analyze the behavior of a very complex system and understand interrelations of processes and the performance of the system as a whole. Discrete event simulation allows the explicit portrayal of the operations of each truck "entity" as it negotiates through the model system.

TRUCKSIM simulates reality through statistical handling of parameters that vary with time, probablistic decision making where appropriate, and replication of logic in responding to conditions in the system. Some of the major model logic features are as follows:

- Generation of truck traffic originating at and destined for terminals around the harbor, based on cargo volumes and statistical distributions of arrivals and departures for each half-hour of the day;
- Determination of destination and route each truck will select, based on stoichastic functions;
- Calculation of truck speeds, based on roadway capacity analysis as well as intersection approach and departure functions; and
- Determination of approach/departure operations at signalized, controlled, and uncontrolled intersections.

The software platform used for the TRUCKSIM model is the SIMAN simulation language. The various traffic flow and operations theories relevant to modeling truck behavior are implemented through procedures in SIMAN and C program modules linked to the model. The range of model components are shown in Figure 1.

The model components simulate characteristics including queuing, delay, and flow formulations for the following:

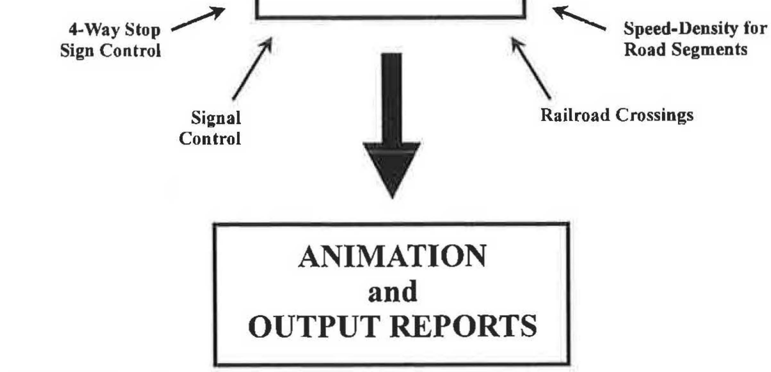

FIGURE 1 Range of model components.

- Intersections with yield, two-way stop, and four-way stop sign control;
- Signalized intersections;
- Ramp junctions with merge and diverge points;
- Weaving sections; and
- At-grade railroad crossings.

The model also includes the following:

- Speed-density functions for arterial and freeway segments;
- Functions for replicating the effects of auto traffic on truck movements;
- Functions for allowing primary and secondary route selection for each truck trip; and
- Formulas for vehicle emissions and fuel consumption as a function of fuel type, vehicle type, and operating conditions.

User Interface

The model was developed to be data driven and flexible so that conditions can be changed, alternatives tested, and other roadway systems evaluated, all by the port planning staff. A series of spreadsheets, read at run time, provide the format to manage the large data base required to perform traffic analyses. The series of spreadsheets can be maintained in a workbook environment so that spreadsheets can be opened simultaneously with one command. Changes can be made by flipping between any of the open spreadsheets, and files are automatically saved.

The files are managed in a scenario-based directory structure. The model parameters defined in the spreadsheets include the following:

- Roadway network configuration;
- Intersection configurations;
- Signal phasing and timing;
- Background traffic volume and distribution;
- Truck volume moving to and from various harbor terminals during each half-hour of the day; and
- Routes trucks take to and from terminals.

Input Data

Building a model scenario requires that the user first define the roadway network. The network is composed of links (roadway segments) and nodes (intersections and operational change points). The next step in building a model is to define cargo volumes, truck arrival and departure rates, and operating characteristics of the harbor terminals. The model includes gate operations and the effects of queues at the gates. Then, routes between the harbor terminals and their destinations are defined, and the propensities of trucks to use these various routes are identified. Finally, the description of roadway usage characteristics are defined, including actual highway speed and background traffic volume. A significant amount of data collection is required to define the harbor system. Roadway characteristics are defined based on records and field catalogs; gate operations and arrival rates are based on terminal records and field observations; truck destinations and routes are defined through interviews with terminals and trucking companies and through truck driver surveys; and background traffic volumes are obtained from available or collected traffic counts.

Roadway usage includes travel speeds, deceleration and acceleration at intersections, typical intersection delays, and impacts of curves and grades on travel speeds. These data are collected using the "Micro-Float system," a device attached to the speedometer of a car, incorporating an on-board microprocessor and laptop computer. The car repeatedly follows trucks along their routes to obtain a valid sampling for each route under a variety of traffic conditions.

Verification/Validation

Verification is defined as the process of checking and ensuring that a model is properly representing the physical phenomena it is meant to simulate. To accomplish this, the mathematical constructs and numerical methods of the model must be run with a known test case and result in an acceptable replica.

The TRUCKSIM verification process addressed the various model components to ensure proper replication during test case runs. These components include the following:

- Terminal arrival and departure volume and distribution;
- Routing of trucks;
- Operation of arrival/departure sequences at intersections;
- Operation of signal phase and timing; and
- Calculation of speed, considering acceleration, deceleration, and traffic congestion.

Validation is defined as the process of comparing actual project model results with known quantities. Validation of the results of the Port of Long Beach and

Honolulu Harbor models confirmed proper replication of truck movement through the existing harbor roadway networks. The validation points include the following:

- Terminal gate activity;
- Roadway traffic density (number of trucks);
- Travel time from origin to destination;
- Delays due to intersections and roadway congestion.

Model Output

The output from TRUCKSIM comprises a series of reports and an animation showing truck movements through the roadway network. Reports provide tabular results that are used to evaluate conditions and characterize the access system. These results then can be compared across scenarios for an alternatives analysis. The animation, which vividly portrays the behavior of trucks moving on the roadway network, is beneficial in visualizing volume of truck traffic, effect of roadway congestion and delays at intersections. One of the most apparent benefits from the animation is the identification of bottlenecks in the system, which become obvious by the formation of large queues of trucks.

TRUCKSIM simulates all traffic activity within the harbor area for a specific period. During a run, the model collects a variety of data and calculates the vinal statistical results. These results can be divided into four general categories: system wide performance, roadway segments, intersections, and terminal access. The results are provided in the following model outputs:

1. Systemwide Performance
   A. Fuel consumption in gallons, for all trucks and autos, idle and in motion
   B. Emissions in tons, for all trucks and autos, idle and in motion
   C. Fuel and emissions variations for alternative fuel types
   D. Count of truck trips through the system
2. Roadway Segments
   A. Level of service (reported as A through F based on 1985 Highway Capacity Manual)
   B. Vehicle counts processed through each link
3. Intersections
   A. Average delay encountered during each half-hour of the day
   B. Total vehicle delay time accumulated during the period
   C. Level of service (reported as A through F based on 1985 HCM)
4. Terminal Access
   A. Statistics (average, minimum, and maximum) on individual truck trip times to harbor terminals
   B. Total travel delay, by route, to harbor terminals

SAMPLE APPLICATIONS

Computer simulation can help answer a variety of questions for port planners, who often are asked to answer what-if questions. Should the port build an on-dock railyard? Will extra roadway lanes relieve congestion at an intersection? What will happen if cargo volumes change significantly? What will happen if a local jurisdiction decides to restrict the hours that trucks can operate on the local roadways? What will be the air-quality impact of port transportation system changes?

Port of Long Beach Applications

In 1990 officials at the Port of Long Beach decided they needed a new computer model to address several transportation issues. At that time the Disney Company was considering developing a major theme park, hotel, and recreational area within the port. Port officials wanted to know how terminal truck traffic and tourist traffic would interact in the port area. The officials recognized that analysis of the impact of major projects on transportation had been addressed previously using conventional transportation modeling tools. The TRUCKSIM model offered the chance to study truck-specific issues, not just general traffic questions. The model was used to study the impact of traffic on the surrounding roadways and to quantify the amount of additional delay terminals might experience with and without the Disney project.

But there were other policy questions that port officials wanted to address. The TRUCKSIM model, therefore, was designed to allow other types of operational and network changes to be studied. For example, during the late 1980s, the city of Los Angeles was considering imposing restrictions on the time of day that commercial trucks could operate on city streets. A policy of truck restrictions would have meant that trucks serving the port area would have been forced to change their hours of operation. If this policy had been implemented, the hours when trucks arrived or left the port would have changed because drivers would not have been permitted to deliver or pick up cargo in the metropolitan area during certain times. The model provided a picture of the potential impact of these restrictions on the port roadway network and at the port terminals.

Another type of question deals with the impact of increased on-dock rail facilities on port traffic behavior. The port has embarked on a program of providing rail facilities within port terminals. On-dock intermodal rail terminals can reduce the number of truck trips to port terminals, and truck volumes on local roadways, because the cargo travels on trains to and from the terminal. However, trains moving through the port can cause truck delays at roadway crossings. TRUCKSIM allows the planner to study reduced truck trips and increased delays simultaneously. The model also simulates how building grade separations can help avoid delays at rail crossings. By performing comparative analyses, the port has been able to estimate the time savings and emissions reductions that could occur by building grade separations. The model results confirmed the decision to pursue five grade separation projects in the port.

The model also provides significant detail for studying air pollution emissions. Air pollution is an important issue in Southern California; therefore, the port wanted a tool to investigate the effectiveness of various air pollution control measures. The model estimates the amount of emissions of five different pollutants from trucks and autos using various fuel types. The results have been used to detail the types of pollution reductions that might be achieved by various pollution control measures such as grade separations, truck restrictions, and the use of alternative fuels. The results of this modeling effort have been used to identify the air quality improvements of port projects in response to the Environmental Protection Agency's air quality plan for Southern California.

Another benefit from the modeling effort is a much better understanding of trucking and terminal operations within the port. This information was needed to accurately simulate truck operations. Before this effort, there was not nearly enough information available about goods movement activity and truck behavior. Developing the TRUCKSIM model allowed the Port of Long Beach to build a much better data base on truck operations within the port.

State of Hawaii Applications

The state of Hawaii wanted a tool to assist with many of the same issues that had faced the Port of Long Beach. For example, Honolulu Harbor is adjacent to Oahu's major downtown business district and shared the same access corridors. The state is evaluating a variety of proposed projects and roadway improvements and needs to ensure that efficient harbor access is maintained. The projects include modifications to harbor configuration and operation and commercial developments in surrounding areas. Through the application of TRUCKSIM, the state evaluated existing and 2020 conditions, incorporating proposed projects and roadway improvements, such as a viaduct that adds traffic lanes in an area with no available expansion area and many intersection and roadway improvements throughout the network. The 2020 conditions address increased truck traffic due to cargo volume growth and modifications to truck traffic patterns due to harbor reconfigurations. The state is also using TRUCKSIM to evaluate expansion plans for Barbers Point Harbor on Oahu and is planning to model other harbors throughout the state.

CONCLUSIONS

Landside access to harbor terminals is an important concern to port planners. Planning the landside access system requires analysis and understanding of the roadway system, the terminal activities, and the characteristics of mixed-use traffic flows. The simulation model TRUCKSIM provides a tool to efficiently analyze and evaluate the landside access system.

TRUCKSIM is data driven and flexible so that conditions can be changed and alternatives can be tested. The output from the TRUCKSIM model includes performance results on roadway segments, intersections, terminal access, and systemwide parameters. The model can be used to test various conditions, including cargo growth, harbor reconfiguration, and changes in harbor usage. The model also can be used to test solutions such as roadway widening, addition of turning lanes, intersection control upgrades, signal phasing and timing adjustments, grade separations, modal shifts, and traffic management strategies.

TRUCKSIM generates an animation of truck movements throughout the harbor access system. The animation is recorded during a simulation run and can be replayed as often as needed. The animation accurately depicts trucks operating on the roadway system and the effects of background traffic on truck operations.

TRUCKSIM will simplify the process of evaluating access issues while vividly and accurately portraying the characteristics of the transportation system. Users can apply this tool to evaluate alternative improvements to the roadway system or management strategies. Because TRUCKSIM is completely data driven, it can be applied to any roadway network so that the planner can analyze landside access systems to harbors, airports, inland rail terminals, and industrial parks. The technology developed for TRUCKSIM also has applications in other settings, such as intelligent vehicle highway systems and public transportation improvements.