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A FLEXIBLE PORT TRAFFIC PLANNING MODEL

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ABSTRACT

This paper reports on a comprehensive simulation model developed to assist in future growth planning for the Port of Long Beach, California. The model simulates truck, auto, and rail traffic in a single model, using techniques developed to control complexity and run time, allowing the model to be implemented on a "386" class PC. Traditional traffic modeling practices (based on queuing models from traffic flow and capacity research reports) were integrated with discrete modeling techniques, resulting in a "hybrid" model that tracks individual vehicles, yet produces system wide performance measures consistent with generally accepted traffic flow modeling and reporting practices.

1 INTRODUCTION

The original concept for the model developed out of the observation that "managing port growth in times of increasing urbanization and heightened environmental awareness is perhaps the greatest challenge facing ports today". There are few cases more illustrative of this than the Port of Long Beach in California. An early advocate of containerization, Long Beach had become one of the world's premier ports by the 1980's, forming with the adjacent Port of Los Angeles the largest and most diversified cargo handling complex in North America. Together, these ports anticipate a doubling of cargo volumes in the next two decades.

In early 1990, the Port Authority in Long Beach faced unique problems of multiple challenges: managing the continuing cargo growth while at the same time planning for city mandated truck restrictions during rush hours, and additional traffic from a new Disney theme park complex proposed for the current location of the Queen Mary (situated adjacent one of the major port access routes). The limited access to the Port (bounded by water on three sides) and existing roadway network were already near saturation at peak times. The Port's planning staff sought an analysis tool capable of providing detailed, quantitative estimates of traffic system performance for a variety of projected scenarios and alternative solutions to problems anticipated by the year 2010. Consideration of the issues the Port faced lead to a search for a simulation modeling system with the ability to explicitly model or account for:

1: Trucks on roadways accessing each of the Port's major container terminal clients.
2: Effects of roadway characteristics on truck movements including signal and sign controlled intersections, laneage, intersection geometries.
3: Effects of differing ship arrival and departure schedules, and ship carrying capacities.
4: Effects of implementing on-dock rail facilities as a means to reduce truck traffic.
5: Effects of imposing truck movement restrictions during peak commuting periods.
6: Effects of congestion on container truck movements including that related to the proposed Disney

theme park.
7: Animation of model results using dynamic displays, showing truck behavior and movement as influenced by roadway and congestion effects.
8: Provision for statistics of system performance measures that are meaningful to Port engineers.
9: Provision for a user interface allowing for easy modification of frequently changed input data to expedite alternatives testing directly by Port planning staff.

A review of existing transportation simulation models (see section 2) found no single model meeting a majority of these requirements. However, applications with similar requirements were demonstrated that had been developed using existing "industrial" simulation languages - programming languages commonly applied to manufacturing capacity problems (Carpenter and Ward, 1990). Based on the results of a pilot model, a project was commissioned to develop and validate an integrated discrete event simulation model (named TruckSim) to meet these requirements. The model is reviewed in this paper.

2 MODEL REQUIREMENTS

The Port of Long Beach planning staff was particularly concerned that the resulting model support the container truck-specific performance issues, that the animation would allow port management staff to observe model operation, and that they would be able to independently use the model for on-going planning issues.

2.1 Background

The project's model design team considered a number of approaches for addressing the Port's modeling problem and requirements. These considerations included application of existing software used by the transportation and traffic engineering community, modification of existing software to address the specific project requirements, and application of simulation software used in other fields.

The existing "traditional" transportation software tools in general use can be classified into two general classes: travel demand software, and traffic operations models. A brief review of each class is presented here, with considerations for the project requirements. For a more thorough discussion, see (Byrne, et al. 1982) and (Santiago and Chen 1990)

Travel demand software is used in gross-level analyses related to such measures as: determining lane deficiencies and requirements for roadway segments and corridors; levels of service (or congestion) of roadway segments; per-vehicle and total travel time and operating speeds on a roadway segment or corridor; or for the entire modeled area: vehicle emissions and fuel consumption aggregated over all vehicle trips. A number of travel demand software packages are available for mainframes, workstations, and especially microcomputers. Examples include TRANPLAN, MicroTRIPS, MINUTP, EMME/2, QRS, and TMODEL. The scope of travel demand models range from small areas of one square mile to entire metropolitan areas and even to entire states. These are static models - used to evaluate travel supply (i.e., roadway capacity) against anticipated travel demand. Travel demand models to not provide the types of detailed statistics relating to individual vehicle entities, required for the POLB project to measure intersection delays and level of service, and queue lengths. Further, dynamic animation is not possible since these are static models - they describe the behavior of the system at a single point in time.

Traffic operations models, on the other hand, are very detailed since they are used to evaluate specific design features of roadway systems, including proper signal timing at signal-controlled intersections, specific lane assignments and number at intersections, and effects of large trucks, transit vehicles, and pedestrians on intersection level of service. Traffic operations models are of both the static and dynamic type. They can account for random events such as double parking and vehicle mixes throughout the modeled time period since they describe the behavior of the system over a period of time.

The most applicable examples to the POLB project are network simulation models such as TRANSYT-7F and TRAF-NETSIM, which are also the most widely used traffic operations models. Both are discrete event simulation programs which work in one-second time updates. These traffic operations models provide for very detailed evaluation statistics including queue lengths by intersection approach, intersection delays and level of service, vehicle emissions and fuel consumption.

Among the traffic operations-type software, the TRAF-NETSIM model was considered to be the most applicable to the POLB project. However, the model was found to be unsuitable for the POLB modeling for a variety reasons, the discussion of which is too lengthy for inclusion in this paper.

Thus, the design team elected the third option - to develop a new model based on a dynamic, discrete event simulation language, with extensions added as required. This allowed the explicit portrayal of each truck "entity", instead of aggregating traffic in somewhat less detailed statistical fashion.

2.2 Design Objectives

The guiding design objective was to achieve a balance between the necessary detail needed to allow specific performance issues to be evaluated and a more high level or less detailed representation where possible to limit model complexity, data and run time requirements. The goal was to provide a tool with enough detail and accuracy to allow comparative performance analysis of different scenarios, but not necessarily the high level of complexity that would allow evaluating all system performance measures in an absolute sense. Specific design objectives established for the model included:

- o Represent truck activity related to major truck traffic generators within the Port with sufficient detail and accuracy to provide for meaningful assessments of impacts on truck traffic associated with alternative scenarios to be investigated, including peak period truck movement restrictions.
- o Simulate traffic conditions for a 24 hour, peak activity day in the Port.
- o Provide for analysis of truck movements affected by periodic influences throughout the day (peaking characteristics of cargo loading/unloading operations, rush hour congestion, train movements, etc.)
- o Provide for the assessment of impacts related to auto traffic growth, including alternative major new traffic generators such as the proposed Disney theme park complex.
- o Provide for the assessment of impacts related to assumptions of future cargo growth, transportation modes (rail vs. truck), terminal operating characteristics (gate hours, processing times, etc.), and train schedules.
- o Provide for the assessment of impacts related to development of the POLB Road and Railway Transportation Master Plan, and other reasonable roadway improvement alternatives.
- o Provide output statistics meaningful for comparing the relative benefits and disadvantages of the above considerations.
- o Provide a user interface which facilitates the changing of data associated with the principal analysis concerns of the Port.
- o Implement dynamic animation with sufficient detail to allow traffic congestion and queues to be observed.
- o Implement the model on a 386 class computer.

3 DESIGN METHODOLOGY

3.1 Overview

The TruckSim model is regarded as a hybrid model because it mixes "travel demand" type modeling techniques (using averaged traffic flow rates and densities) with "traffic operations" modeling practice, in which vehicle entities are explicitly represented in a dynamic model.

TruckSim merges the concepts of these two model types through the use of simulation software more typically used in industrial engineering applications. Refer to Figure 1 for a presentation of the basic elements of the TruckSim modeling system. The software platform for the model is the SIMAN simulation language. Individual events, such as the arrival of a truck at a stop controlled intersection, trigger processes replicating the movement and behavior of individual truck "entities".

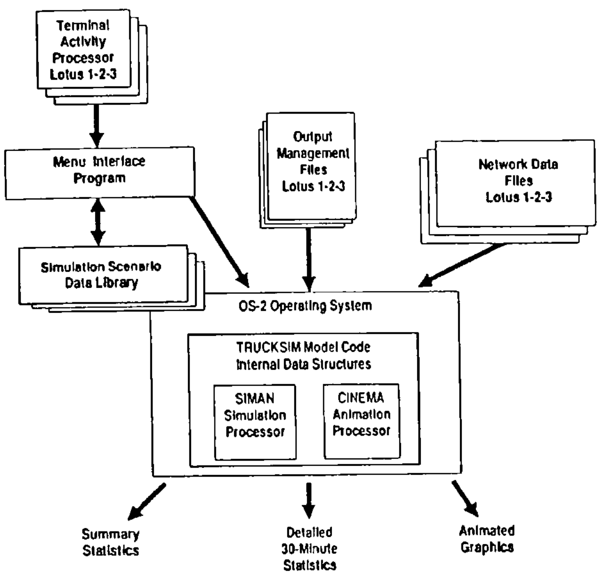

Figure 1: TRUCKSIM Modeling System

The various traffic flow and operations theories relevant to modeling POLB truck behavior are implemented through procedures in Siman and C program procedures linked to the model. These include:

- o Queuing, delay and flow formulations for sign controlled intersections including yield, two-way stop, and four-way stop sign control.
- o Queuing, delay and flow formulations for signalized intersections.
- o Queuing, delay and flow formulations for ramp junctions including merge and diverge points.
- o Queuing, delay and flow formulations for weaving sections.
- o Speed-density functions for arterial and freeway segments under uncongested and congested conditions.
- o Queuing, delay, and flow formulations for queues at at-grade railroad crossings.
- o Formulas for vehicle emissions and fuel consumption as functions of vehicle type and operating conditions.
- o Functions for replicating the effects of "background" auto traffic on truck movements.
- o Functions for allowing primary and secondary route selection for each truck trip, based on origin-destination pair (i.e., specific to each destination terminal).

3.2 Modeling Approach

A complete description of the design and implementation of the model is beyond the scope of this paper. However, there are four primary modeling assumptions underlying the design of the TruckSim model system, which should be noted:

1: A well defined method to systematically sub-divide the roadway network into segments for representation and processing by a computer model.
2: The separation of simulated vehicle traffic into two categories to reduce the size and execution time of the model - roughly equivalent to those of interest to track explicitly (trucks), and those that can be treated in a less detailed fashion (automobiles);
3: Development of operational theory to translate established and accepted traffic density vs. flow rate equations into usable forms for use in assigning link traveling speeds for trucks.
4: Detailed and realistic modeling of truck traffic behavior at intersections is necessary to achieve the accuracy desired from the model.

3.2.1 Network Encoding

The physical characteristics of the POLB study area are encoded into a network of links and nodes for utilization by the model. This provides the information necessary for the processing of each truck entity through its assigned route.

The representation of the study area into a network was possible after a survey of the existing site. Each link is unidirectional and assumed consistent in terms of its lane configuration, posted speed, and traffic behavior. Additional links are defined whenever one of these fundamental characteristics change or when a potential obstruction is encountered. Obstructions can be classified as controlled intersections, at-grade railroad crossings, or marine terminal entrance gates.

A link is always bounded by two nodes which may be any combination of the following types:

- Network entrances
- Network exits
- Intersections
- At-grade railroad crossings
- Diverges
- Merges
- Traffic flow control

Network entrance nodes are origin points for truck routes and are boundaries to the network and POLB study area. These nodes allow for trucks to enter the network via designated major highways or from the water side of a marine terminal facility. For major highways that extend beyond the borders of the study area, it is assumed that trucks may attempt to access the network as soon as they are scheduled to arrive.

Network exit nodes are similar to entrance nodes in that they are also boundaries to the network. Additionally, they serve as destination locations for the truck routes. Inbound trucks are destined for marine terminals and outbound trucks for major outbound routes. It is assumed that when a truck reaches an exit node to a major route, it will be able to leave the network immediately.

Intersection nodes are the most complex type of node in the network due to the substantial amount of logic incorporated in the model to precisely process a truck through an intersection based on its turning movement, approach, and the control configuration implemented. To attain the desired performance accuracy for the potentially wide variety of physical geometries, the control type, and the allowable turning movements within in each lane for each approach is specified as a part of the network definition data.

As a truck approaches an intersection the appropriate lane must be assigned based on its required turning movement and the defined approach lane configuration. If more than one lane is available to accomplish the turn, the truck will select the lane with the fewest number of trucks. This decision results in the placing of the truck entity into one of three queues for the approach: 1) left movement, 2) general movement, and 3) right movement.

The procedure as to how the truck gets serviced through the selected queue depends upon the control employed at the intersection. There are three general classes of control supported by the model: 1) signalized control, 2) all approaches are stop controlled, 3) not all approaches are stop controlled.

Signalized control is implemented using actual signal patterns and timings that are typically utilized in traffic engineering. Each intersection that is governed by a signal may have a unique signal pattern associated with it. A signal pattern consists of a cycle of "phases"; each phase dictates which lanes within each approach may allow traffic movement. Each phase has a time duration during which these movements are possible.

The signal patterns along with the static intersection lane configurations allow for virtually every type of traffic situation to be modeled as required. This includes protected lefts, permissive lefts, right on red after stop, etc.

Trucks processed through intersections that have all approaches controlled by stop signs are moved through the intersection on a first come, first serve basis. The only exception are trucks that can execute a right on red after stop.

3.2.2 Differentiation of Vehicles

Trucks are introduced into the network as discrete entities, each with unique attributes. Each truck is assumed to execute a trip which consists of a set of routing instructions that explicitly describes a journey from an origin to a destination. At the time of entry, the following information is associated with a truck:

- Cargo type
- Truck size
- Route number and destination
- Time trip started
- Various elapsed time and statistics collection registers

There are four general classes of terminal operators that are included in the model. They are: 1) container, 2) petroleum coke, 3) non-container, and 4) container-freight stations. The cargo type indicates the type of terminal a truck is visiting. The behavior of a truck at a terminal in terms of gate processing delays, queuing at the gate complex is dependent upon the type of cargo being moved.

Depending upon the terminal type, there are a variety of size classes that are typically handled. For example, container terminals accommodate fully loaded container trucks, bare tractors, and bare chassis while petroleum coke terminals exclusively utilize double bulk loaders. The size of the truck is considered in terms of speed calculations, emissions/fuel consumption and how it may traverse through congested links.

The route number dictates the exact sequence of links and nodes that the truck must execute through the network. This information is critical to determine the turning movements required through intersections and to determine when an obstruction such as a railroad crossing is encountered.

There is a substantial component of automobile traffic that is a part of the total traffic situation in the POLB study area. Because of the volume and the goal of maintaining the model on a 386 class PC, the model does not explicitly generate discrete automobile trips. This constituent is considered to be "background" traffic and is considered within the overall vehicle density levels on each link in the network.

Each link in the network is defined to have a finite capacity in terms of passenger car equivalents (PCEs). The capacity of each link is a function of the number of lanes and length. Truck entities have an assigned PCE value based on their size attribute when they enter the network. The model allows truck entities to traverse through individual links only if they can gain access to the link required. A truck is temporarily restricted to entry to a link if the current vehicle density has reached a level close to the calculated capacity.

The vehicle density level is maintained by the model for each link and contains the current level of both automobile traffic and truck traffic. Trucks increase and decrease the density as they enter and leave the link.

The background traffic levels are based upon a traffic engineering study which tabulates the levels anticipated and observed throughout the network. This study includes the background traffic levels for roadway segments during various time periods throughout a typical operating day. The timing aspect of the background traffic is critical due to rush hour behavior and the patronage profile that is projected for the Disney theme park.

To include automobile traffic in the model, an independent process is built into the model to encompass this component. The influence of background traffic in terms of PCE levels is updated for each link in half-hour intervals. As a result of this process, the available capacity of each link is reduced for truck entities. This impedes trucks from entering links that are heavily congested with automobile traffic and has an impact upon allowable truck speed.

The background traffic levels are also utilized by the model in the intersection processing logic. This is of particular consequence when considering the yield aspect for permissive left turns and two-way stop intersections.

3.2.3 Link Speed Assignments

As trucks gain access to different links through their routing sequence, the model re-evaluates the current traveling speed for the entity. This is accomplished using a speed calculation that has been established in traffic engineering practice (see Figure 2).

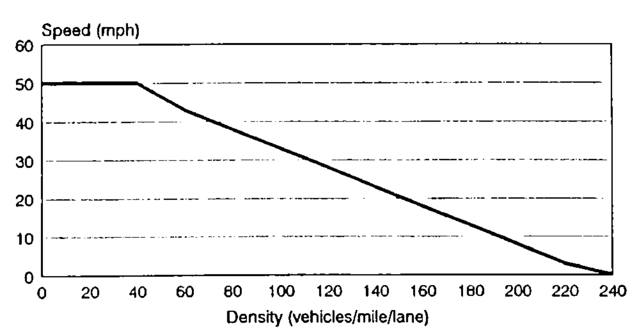

Figure 2: Speed/Density Curve Relation

A linear relationship is utilized by the model that uses the posted speed for the link and a general "jam density" as constants. The variable component of the equation is due to the current total traffic density in PCEs of the link. This equation is only used for truck speed calculations if the current traffic density is greater than the critical density. The critical density is a constant that is specific for each link and provides a theoretical threshold which is used to evaluate whether a speed reduction from the posted or free-flow speed should be assessed.

Each time a truck entity enters a new link, the model calculates whether the current total traffic density is greater than the critical density. If it is, the speed equation is used to determine the new operating speed for the truck. It is assumed that the truck will travel at this speed throughout the distance of the link and will be maintained until an obstruction is encountered or a new link is accessed. This method is used for every facility type of found in the network.

If a truck is stopped at an obstruction or is prevented from moving into an upstream link due to high levels of congestion, an acceleration delay is assessed. The magnitude of this delay is a scalar multiplier of the truck size of the entity. Any deceleration delays that may occur due to anticipated stops or slowdowns are assumed to be included in the overall traveling speed through a link.

4 DATA STRUCTURES

The model allows for a port planner to experiment with a proposed network definition among a variety of port and terminal operating scenarios. The data structures and files used by the model consider this objective and have been intentionally designed to be easily modified by the port staff as infrastructure changes are proposed and terminal business conditions change.

A significant advantage of having the input data for the model contained within easy-to-edit external files is that the port planner is removed from the process of changing model logic and recompiling files for many infrastructure and operation variations. The input files required by the model are of two broad categories: 1) network definition and 2) port and terminal demand forecasts.

4.1 Network Definition Data Files

The network definition files are maintained in either a spreadsheet format or in standard text files. These files are:

- Link characteristic definitions
- Intersection configurations
- Signal patterns
- Origin to destination route sequences
- Auto density rates

The link definition file requires the following data elements for each link: 1) length, 2) number of lanes, and 3) posted or free-flow speed. This spreadsheet file also calculates and maintains the capacity and critical density for each link. Figure 3 shows an example of part of this file.

Link ID	Length	Speed	Number of Lanes	Spd Adj Factor	Capacity	Critical Density	From Node	To Node
1	715	55	3	95	92	12	1	300
2	470	55	3	95	60	8	300	431
3	265	55	4	95	57	6	431	305
4	600	30	1	135	25	3	300	432
5	225	20	1	100	24	1	432	443
6	450	25	1	100	19	2	303	431
7	790	20	1	100	34	4	301	434
8	375	35	4	130	64	8	434	303
9	620	50	4	105	107	14	301	430
10	280	55	4	105	48	6	430	100
11	1125	25	1	140	48	6	302	430
12	160	35	3	115	20	2	302	434
13	565	35	3	115	73	9	2	302
14	150	35	3	115	19	2	304	454
15	525	35	3	115	68	8	454	101
16	750	20	1	150	32	4	304	453
17	790	50	4	115	170	17	453	301
18	340	55	4	95	58	7	305	306
19					22	0		
20	375	35	4	110	64	8	572	304
21	150	35	3	115	19	2	303	433
22	490	35	3	115	63	8	433	200
23						0		
24	360	35	3	110	46	6	341	570
25	150	35	3	110	19	2	570	572
26	225	30	1	85	9	1	211	200
27						0		
28	320	30	2	85	27	3	200	211
29	280	10	2	100	24	3	51	211
30	280	10	2	100	24	3	211	151
31	560	30	1	85	24	3	219	211
32	560	30	1	85	24	3	211	219
33	660	35	3	100	57	11	309	272

Figure 3: Link Definition File

The intersection configuration file contains information describing the physical geometry for each intersection node. The spreadsheet format provides a data-driven approach allowing for intersections to be re-designed with respect to many features including control type, number and type of lanes per approach, without any model logic revisions.

The signal pattern file designates the light(s) actuated per phase within a cycle and the associated time durations. The quantity of phases per cycle is a variable allowing for a wide range of patterns to be implemented. Each phase is described by the approach(es) and the lane(s) that may allow traffic movement. The lighting pattern may be specified in combinations of: 1) protected left, 2) permissive left, 3) green, and 4) right only.

The route sequences are each specified by the series of links and nodes that must be executed for trucks to travel between an origin and destination pair. Additional routes or revisions to existing routes are possible by modifying the file with a text editor.

The auto density rates are specified in a spreadsheet file which describes the static levels in PCEs for each link within half-hour intervals throughout an entire operating day.

4.2 Port and Terminal Demand Data

Once a network definition has been finalized, demands are imposed on it using a terminal operating scenario. This data is entered into a customized menu interface program which has been designed to support specific port-planning issues such as the impact of varying levels of truck restrictions during peak commuting periods.

The menu provides a user-friendly interactive environment to organize, guide, and assist in changing values to create different operating plans. The interface also allows for sets of scenarios to be constructed, labeled, and archived for future use.

5 OUTPUT PRODUCTS

The output products of TruckSim provide four general classes of performance statistics:

- Overall port traffic performance
- Roadway segments
- Intersection nodes
- Terminal operators

The number of possible locations in the network for data collection is quite large; there are hundreds of links, nodes, and queue locations. To manage the size of output files, the user may select a set of links, intersections, and terminals to be tagged for each simulation run through a spreadsheet file which is read by the model at the beginning of each simulation run.

The overall port performance report describes the fuel consumption for both autos and trucks during idle and in-motion, the emissions by pollutant for both autos and trucks, and the total count of trucks processed through the network. In computing both emissions and fuel consumption, the model logic considers the truck size/weight category, time at speed for various speed categories, idle time, and start/stop acceleration. Table 1 shows summary fuel consumption data from model outputs comparing the alternative scenarios against the baseline scenario. For example, from the table we observe that Scenario 5 (peak period truck restrictions, with Disney) shows an overall increase in fuel consumption of 41% over Scenario 1 (1990 year baseline).

Table 1: Fuel Consumption

	Fuel Consumption (Thousands of Gallons/Day)				Difference Compared To Scenario 1		
	Autos	Trucks	Total		Autos	Trucks	Total
Scenario 1	36.6	9.7	46.3	Diff	--	--	--
				%Diff	--	--	--
Scenario 2	55.0	9.8	64.8	Diff	18.4	0.1	18.5
				%Diff	50%	1%	40%
Scenario 3	36.8	9.7	46.5	Diff	0.2	0.0	0.2
				%Diff	1%	0%	0%
Scenario 4	N.A.	N.A.	N.A.	Diff	N.A.	N.A.	N.A.
				%Diff	N.A.	N.A.	N.A.
Scenario 5	55.5	9.8	65.3	Diff	18.9	0.1	19.0
				%Diff	52%	1%	41%

The roadway network performance statistics provide the "Level of Service" rating for selected links for each 30 minute interval. The method in which the rating is determined is based on the relationships defined in the Highway Capacity Manual. Also, the link traffic counts for the total number of trucks processed per 30 minute interval are reported.

The intersection statistics supply the level of service and average delay for individual trucks processed through specified intersections for each 30 minute period. For the same set of intersections, the total truck delay time summed across all trucks processed, is reported for each 30 minute span. Table 2 shows how the simulated peak period intersection level of service varies over the five scenarios for a few selected network locations.

The terminal statistics report the total individual trip times averaged across all trucks inbound and outbound to and from designated terminals. For the same set of destinations the total amount of travel delay time is reported. The travel delay time is the time greater than the "free-flow" time for each truck trip. The free-flow time assumes there are not any traffic delays due to congestion or obstructions.

Table 2: Peak Period Intersection Level of Service

INTERSECTION	PERIOD	SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
EL EMBARCADERO @ WINDHAM	AM	B	B	B	B	B
	PM	B	B	A	B	B
PICO @ EIGHTH STREET	AM	C	C	C	C	B
	PM	C	B	B	C	B
PICO @ SEVENTH STREET	AM	B	C	C	C	B
	PM	B	B	B	B	B
PICO @ SEASIDE BLVD.	AM	C	C	C	C	C
	PM	C	C	C	C	C
PICO @ WATER STREET	AM	B	B	B	B	B
	PM	B	B	B	B	B
EDISON @ NINTH STREET	AM	A	A	A	A	A
	PM	A	A	A	A	A
WINDHAM @ VAN CAMP	AM	B	B	B	B	C
	PM	C	C	C	C	C
PANORAMA @ HSD	AM	C	B	B	C	A
	PM	B	B	A	B	B
PANORAMA @ QUEENS HWY NORTH	AM	B	B	B	C	A
	PM	B	B	B	B	B
HSD @ MAERSK GATE	AM	A	A	A	A	A
	PM	A	A	A	A	A
HARBOR PLAZA @ HSD SB OFF-RAMP	AM	B	B	B	B	B
	PM	B	B	B	B	B
ANAHEIM @ HARBOR AVE	AM	B	B	B	B	A
	PM	C	C	B	C	B

6 ANIMATION

To assist with the validation process, and to comprehend the impact of infrastructure improvements considering the high volume and variety of truck traffic through the study area, an animation is provided. The animation uses the high-resolution version (HGA) version of the real-time CINEMA package in conjunction with the simulation model constructed in SIMAN.

7 MODEL VALIDATION

Extensive debugging using the animation was performed to validate the logical correctness of the model code. The process included preparation of test input data sets providing for isolation of specific elements of the model for observation. The verification consisted of observation of the model animation as well as comparison of numeric output against actual data collected from field observations during the project.

To gain confidence in using the model to gauge relative differences among simulated scenarios and improvements, a validation process using field data collected from the existing network was completed. This process is referred to as calibration. The purpose of the calibration was to define the parameters which are used in TruckSim to represent, mathematically, the behavior of traffic by the model. Through this effort, the model's mathematical relationships which describe vehicle movement are refined. The model was calibrated against 1990 conditions at the Port, as measured on a specific day of the week at various locations.

Due to the magnitude of this project, there were many possible measures that could be compared. In addition, there was significant difficulty and expense in collecting the field data. Considering these issues, the following measures were selected:

- Size of container terminal gate queues
- Link truck counts
- Link operating speeds
- Truck travel times

These standards were applied because they validate different assumptions and aspects of the model.

Table 3 shows the calibration results for travel time comparisons for a few selected routes. Table 4 shows the calibration results for terminal queue lengths for five of the primary destination terminals. The comparison of simulated versus actual travel times were closely replicated especially in the heaviest traveled corridors.

Table 3: Travel Time Comparisons

ROUTE	DIRECTION	Ave. Travel Times (minutes) Observed	TRUCKSIM	Difference
Harbor Scenic Dr I-710 to Maersk	SB	369	380	2.9%
Harbor Scenic Dr Maersk to I-710	NB	343	379	9.5%
Windham/Harbor Scenic Dr Sea-Land to I-710	NB	266	284	6.3%
Ocean/Pico/Pier A W Ocean to LBCT	EB/SB	498	631	21.1%
Pier A/Pico/Ocean LBCT to W Ocean	NB/WB	696	621	-12.1%

Table 4: Terminal Queue Length Results

Period	CUT			LBCTM			LBCTB			SLS			SLN		
Ending	Max	Cur	Obs	Max	Cur	Obs	Max	Cur	Obs	Max	Cur	Obs	Max	Cur	Obs
6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	15	11	15	20	20	21	0	0	0	0	0	0	0	0	0
8.0	28	27	27	91	77	92	4	2	5	20	17	21	21	14	21
8.5	32	16	18	91	47	47	3	0	0	24	24	29	28	27	29
9.0	17	0	8	47	0	0	0	0	0	27	22	34	34	33	34
9.5	6	4	11	0	0	0	0	0	0	23	17	12	35	12	12
10.0	7	0	3	0	0	0	0	0	0	17	7	3	12	6	3
10.5	0	0	0	0	0	0	0	0	0	7	0	1	6	2	1
11.0	0	0	0	0	0	0	0	0	0	1	0	0	6	3	0
11.5	7	4	6	0	0	0	0	0	0	1	1	7	14	11	7
12.0	13	11	14	0	0	0	0	0	0	5	4	4	12	10	4
12.5	19	17	20	0	0	7	1	1	1	10	10	2	10	6	2
13.0	20	14	17	11	0	19	8	6	7	15	14	9	14	9	9
13.5	16	13	11	0	0	0	8	0	0	14	9	0	11	0	0
14.0	16	10	6	0	0	0	0	0	0	10	4	5	11	10	5
14.5	12	8	6	0	0	0	0	0	0	5	0	7	14	12	7
15.0	10	0	0	0	0	0	0	0	0	1	0	5	12	9	5
15.5	0	0	0	0	0	0	0	0	0	1	0	3	12	9	3
16.0	0	0	0	0	0	0	0	0	0	1	0	1	11	7	1
16.5	0	0	0	0	0	0	0	0	0	0	0	0	9	6	0
17.0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	0
17.5	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
18.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22.5	0	0	0	0	0	0	0	0	0	7	7	14	13	13	14
23.0	0	0	0	0	0	0	0	0	0	13	13	27	27	27	27
23.5	0	0	0	0	0	0	0	0	0	13	0	0	27	0	0

Max = Maximum simulated queue length during period
Cur = Queue length at period ending time
Obs = Observed queue length at period ending time

8 OBSERVATIONS

By properly configuring the roadway network, truck trip demands, and background auto density, the model provides relative measures to estimate cost, air-quality, and delay impacts of different operating scenarios with a precision not possible with previous existing models.

When making infrastructure changes to the network, it was generally observed that the effect of improvements may be advantageous to some terminal operators while they may impede the productivity of others. For example, when significant congestion and associated travel delays were observed at a particular intersection, it was found that simply modifying the design of that intersection (without regard to the overall network design) resulting in "moving" the problem elsewhere in the network - to the location of the next "weak link". Several iterations of these runs were required to achieve a set of design modifications that balanced the traffic activity. This result suggests that port planners have a significant application of the model for examining the aggregate effect of modifications.

After the global effect of network changes are resolved, the detailed animation and output reports provide quantitative measurements of the magnitude in which intersections, roadway segments, and terminal gate queues are individually affected. The port planner has the opportunity to adjust the applicable parameters for a critical area through the network definition files.

There is considerable detail implemented in the model and input data especially within the realms of intersection behavior and link definition. During the model development phase, the appropriate level of accuracy to be represented in the model was debated in response to the project goals. The amount of detail implemented created a model that is surprisingly sensitive to variations in traffic generation rates and network changes. For example, this became evident when the projected traffic volumes for the year 2010 were imposed onto the existing area network. One of the signalized intersections adjacent to terminals with significant increases in cargo movement was unable to process the increased volume of trucks at an adequate rate, creating congestion levels with widespread impact. To correct this situation, the intersection was reconfigured in the spreadsheet files by adding left-hand turn lanes and adjusting the signal phase pattern for protected left turns. From this simple modification, the revised network was able to respond to the increased demand, showing dramatic improvement over the previous design.

9 CONCLUSIONS

The objective to construct a hybrid model with enough detail to encompass the operations over a wide-ranging area was achieved. The model replicates reasonably accurate traffic behavior at both an aggregate and localized detail level. This was accomplished using the 386 class computing platform with an acceptable run execution time of approximately 50% of real time.

The external data-driven approach has been found to be flexible enough to allow significant variations of network design to be assembled reasonably quickly, and also for alternative overall port operating plans including truck restrictions during peak commuting periods, on-dock rail proposals, and others to be implemented.

Maintaining the majority of the data outside of the model has produced an environment that removes the port planning staff from the simulation process and allows for emphasis to be placed on infrastructure and operation proposals.

Despite the fact that the overall model integrates numerous activities across an extensive network area, the model is sufficiently sensitive to detect unstable traffic conditions imposed by inadequately configured intersections and increased cargo arrival rates at expanded terminals. These conditions can be monitored by a comprehensive set of animation screens as well as output reports specifically tailored to the areas under investigation.

Finally, the model has been designed to be extendible to investigate issues that may be demanded in the future such as additional air quality issues and terminal operating cost impacts due to port improvements. Further enhancements currently under investigation include automatic generation of input data sets from an enhanced AutoCad drawing using an "intelligent" interface program; automatic route selection and dynamic re-routing of truck entities during run time based on congestion encountered; enhanced animation using more detail for zoom and pan presentations.

REFERENCES

Blunden, W. R. 1971. *The Land-Use/Transport System.* Pergamon. New York.

Byrne, A.S. et al (1982), "Handbook of Computer Models for Traffic Operations Analysis". Report No. FHWA-TS-82-213, Federal Highway Administration.

Carpenter, B.C., and T. Ward. 1990. The Use of Computer Simulation For Marine Terminal Planning. In *Proceedings of the 1990 Winter Simulation Conference*, ed. O. Balci, R. P. Sadowski, and R. E. Nance, 802-804. Institute of Electrical and Electronics Engineers, New Orleans, Louisiana.

Gerlough, D.L. and M.J. Huber. 1975. Traffic Flow Theory. Special Report 165. Transportation Research Board. Washington, D.C.

Highway Capacity Manual. 1985. TRB Special Report 209. Transportation Research Board. Washington, DC.

Santiago, J.S. and J. Chen. 1990. Traffic Modeling Software for IVHS Applications. In *Proceedings of the 1990 Winter Simulation Conference*, ed. O. Balci, R. P. Sadowski, and R. E. Nance, 759-762. Institute of Electrical and Electronics Engineers, New Orleans, Louisiana.

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