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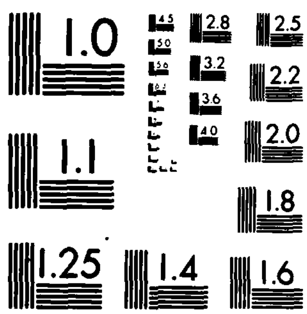

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THE PENNSYLVANIA STATE UNIVERSITY

GREAT LAKES-ST.LAWRENCE SEAWAY SIMULATION STUDIES

Volume 3

SUMMARY REPORT

Joseph L. Carroll
Department of Business Logistics

Srikanth Rao
Department of Management

Hoyt G. Wilson
Department of Business Logistics

Final Report

Contract No. DACW23-72-C-0066

December 1973

PENNSYLVANIA TRANSPORTATION
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In developing a computer model for the simulation of the Great Lakes and St. Lawrence Seaway navigation system, this report is a summary of NETSIM II (a network simulator); PROSIM (a simulation processor for NETSIM II) including a very brief mention of support programs. The model is applied to the Lake Erie-Lake Ontario Navigation Study as well.

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U.S. Army Corps of Engineers

North Central Division

Pennsylvania Transportation and Traffic Safety Center

The Pennsylvania State University

University Park, Pennsylvania 16802

December 1973

ABSTRACT

A computer simulation model developed to study the operating characteristics of the Great Lakes and St. Lawrence Seaway navigation system is described. The model is comprised of a simulation program (NETSIM II), a report generation program (PROSIM), both written in SIMSCRIPT, and four FORTRAN support programs used to structure selected input data in the required format for simulation.

The model is addressed to the task of analyzing the performance of a waterway system under various structural and nonstructural improvements in terms of delays, congestion and utilization. Major features of the model include the ability to simulate bi-directional traffic flows through lakes, channels, locks and ports and the ability to balance the supply and demand of transportable commodities and transport equipment units in the system.

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FOREWORD

The work described in this summary report was performed by The Pennsylvania Transportation and Traffic Safety Center (PTTSC) at the Pennsylvania State University for the U. S. Army Corps of Engineers, North Central Division, under contract number DACW-23-72-C-0066. The contract period is from July 1, 1972 to August 31, 1973.

This report is the third in a series of four volumes documenting the development and application of a computer model for the simulation of the Great Lakes and St. Lawrence Seaway navigation system. Other titles in this series are as follows:

Volume 1	NETSIM: A General Network Simulator
Volume 2	Lake Erie-Lake Ontario Navigation: A Simulation Study of Alternative Subsystems
Volume 4	NETSIM II and PROSIM: A Waterway Simulation Package

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The authors would like to take this opportunity to thank each member of the project team listed in the Foreword for their efforts in bringing this study to a successful conclusion. Thanks are also due to Mrs. Ru-Fen Chow of PTTSC for her editorial assistance.

The opinions, findings, and conclusions expressed in this publication are those of the authors, and not necessarily those of the Corps of Engineers nor The Pennsylvania State University.

I. INTRODUCTION

A. Great Lakes-St. Lawrence Waterway System

In June of 1972, the Army Corps of Engineers, North Central Division entered into a contract with the Pennsylvania Transportation and Traffic Safety Center (PTTSC) for the development of a simulation model that would facilitate a systematic analysis of the capacity of the Great Lakes-St. Lawrence Waterway System (GL-SLS). The development of this simulation model has been carried out in three phases:

1. development of a Lake Erie-Lake Ontario (LE-LO) Navigation Simulation model;
2. application of the LE-LO model to simulation studies of the Welland Canal and proposed alternatives to the Welland;
3. revision of the LE-LO model to include the capabilities needed for comprehensive GL-SLS system simulations.

This report is intended as a general summary of the entire project. However, since phases 1 and 2 were in large part steps on the road to phase 3, the report will focus mainly on phase 3, the comprehensive simulation model. The work in phases 1, 2 and 3 is described at length in [1], [2] and [3], respectively.

The Great Lakes-St. Lawrence Waterway System consists of the St. Lawrence River, the five Great Lakes (Lakes Superior, Michigan, Huron, Erie and Ontario), Lake St. Clair and several connecting channels, including the Welland Canal. A map of the system is shown in Figure 1. Commodities moved via the system include coal, iron ore, sand, gravel, cement, grain, petroleum and general cargo. Since the system is linked to the Atlantic Ocean by the St. Lawrence River, it serves not only for intra-system commodity movements, but for trade with salt water ports outside the

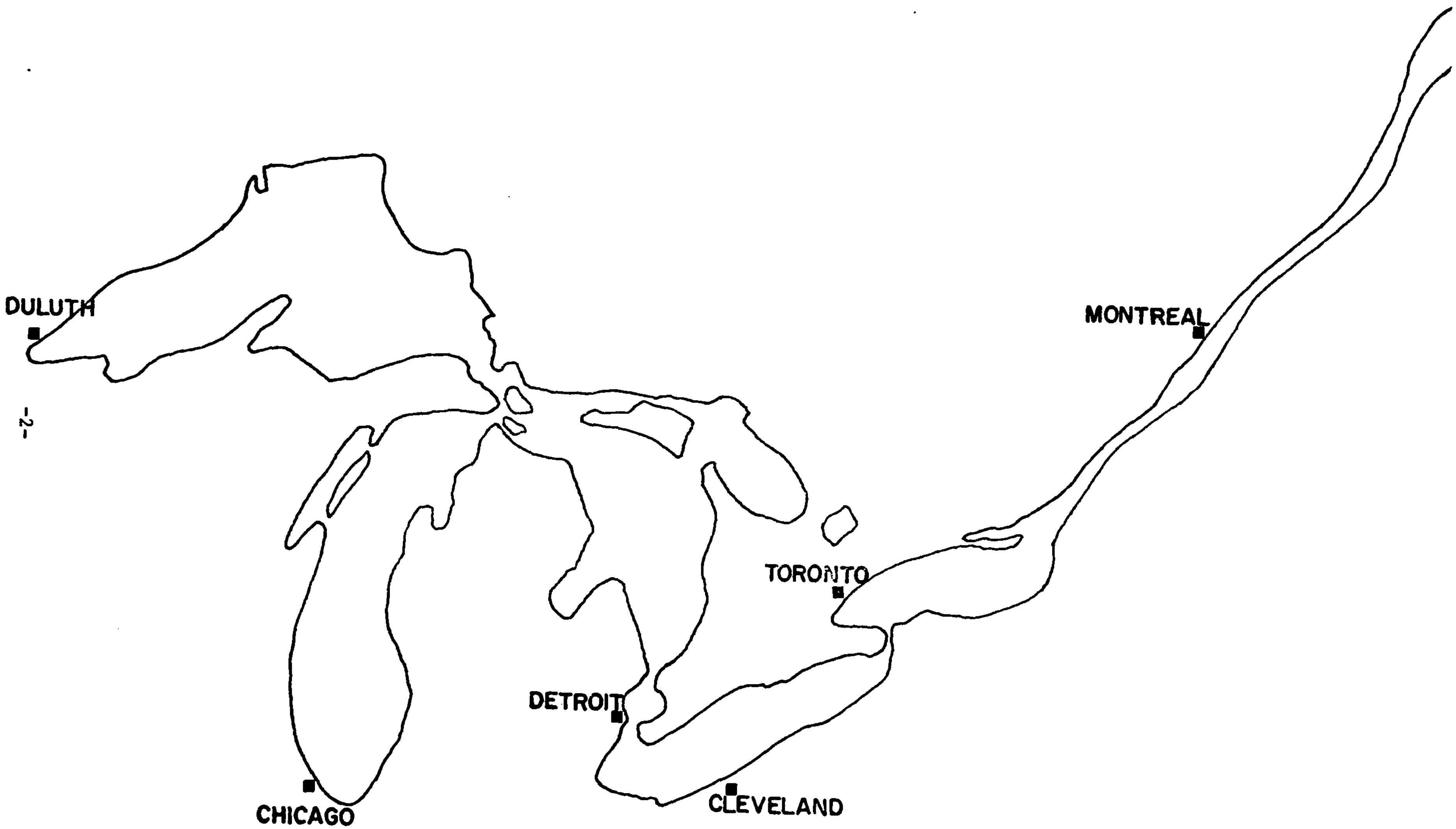

Figure 1. Great Lakes-St. Lawrence Seaway System

system as well.

The lakes are relatively uncongested and allow free movement of vessels on them. Width and depth of some of the reaches, however, along with traffic regulations, provide significant constraints to vessel speeds. Further, the locks in the St. Lawrence River, the Welland Canal and at Sault Ste. Marie are potentially serious impediments to traffic flows.

B. Simulation Approach in Analysis of Navigation Improvement - Historical Development

Historically, development of the current GL-SLS simulation model dates back to the use of computerized simulation models on the inland waterways. The circumstances leading to their development and the results of that research are reported in a six-volume technical report entitled Waterway Systems Simulation [4]. The groundwork for the current model was laid in Volume V of this series, entitled Simulation of Multiple Channel Deep Draft Navigation Systems [5]. The model presented in Volume V will be referred to as the MCDD model (Multiple Channel Deep Draft).

One of the objectives of the MCDD model development was to formulate a methodology for assigning vessels between parallel routes. That research has led to the "experience data bank" (EDB) concept used in the GL-SLS simulation model described herein (NETSIM II). In the EDB approach, a special run of the simulation model is made in which parallel route choices are made at random. Each time a vessel traverses such a parallel route segment, its transit time is recorded along with data describing the status of the facilities involved at the time the route choice was made. Such data might include queue sizes and numbers of vessels in transit in each segment. When the run is completed, a statistical analysis is carried out externally in order to find the relationships between the system status parameters and expected transit time for each segment.

Hence, expected transit time formulas are inferred from the "experience data bank" produced by the EDB run. These formulas are then used in the decision mechanism for subsequent simulation runs. Each time a parallel route choice must be made, the "Alternative Selector" selects that route which offers the smaller expected transit time.

Another integral part of the GL-SLS simulation model which is heavily influenced by the previous research cited above is the lock processing. Locks are typically the greatest potential bottlenecks in waterway systems; as a result, a great deal of effort has been put into development of routines that will simulate their operations realistically.

C. NETSIM II - PROSIM Model

The model used in the LE-LO simulations was originally named NETSIM/SHIP and is now referred to as NETSIM I. It was developed specifically for a study of the LE-LO and Welland Canals, and so did not have the capacity for a comprehensive GL-SLS simulation. The current GL-SLS simulation model has been named NETSIM II in order to distinguish it from its predecessor.

The primary capability which has been added in order to give NETSIM II the capacity for systems simulation is a vessel scheduling mechanism. Whereas, NETSIM I required a schedule of vessel movements as input data, NETSIM II develops these schedules dynamically based upon the requirements for commodity transport. This dynamic scheduling capability allows study of such matters as vessel fleet requirements, efficiency of various scheduling rules and implications of hypothetical changes in the mix of commodity flows.

NETSIM II has retained flexibility in two respects. First, it is written in a powerful language--SIMSCRIPT--with its logic modularized to a great degree. This means that modifications to one aspect of the model (e.g., calculation of transit times across lakes) can often be made by altering only one or two subroutines and leaving the rest of the program untouched. Second, the model can simulate networks of virtually any reasonable size and configuration. This means that the program can accommodate the entire GL-SLS or any part of it. Also, the number of ports, locks, etc., to be included may be changed at will. The only constraint on system size is the amount of computer core memory and run time available. Requirements for auxiliary input/output devices are modest.

The primary output of NETSIM II is an event log, which consists of a separate detail record for every event of interest during the course of the simulation. Here, by "event" is meant such status changes as "vessel enters berth", "vessel exits lock chamber", "vessel enters queue for berth" or "vessel departs reach". These data in their raw form are rather incomprehensible, so a separate SIMSCRIPT program, PROSIM, has been provided to process the event log data and produce meaningful reports for the user.

In addition to NETSIM II and PROSIM, the simulation package includes a number of auxiliary programs for input data preparation. These facilitate such tasks as preparation of vessel fleet data and arrivals of commodities (overland) into ports. Although they are quite independent of the NETSIM-PROSIM model, the auxiliary programs have been written in such a way as to coordinate directly with the use of the model.

D. Concluding Remarks

The following three sections of this report give descriptions of the three components of the GL-SLS simulation package--the NETSIM II program, the PROSIM program and the auxiliary support programs. Section V deals with model applications. It describes both the LE-LO study using NETSIM I and potential applications of NETSIM II to the GL-SLS and elsewhere. Section VI presents conclusions. The reader is reminded that this is intended as a summary report. A considerably more detailed account of the simulation package is given in the complementary report, Volume 4, entitled, NETSIM II and PROSIM: A Waterway Simulation Package [3].

II. NETSIM II : A NETWORK SIMULATOR

As mentioned in Chapter I, the Great Lakes-St. Lawrence Waterway Simulation package developed in this research consists of two programs. The first program, NETSIM II, is the actual simulator which processes vessel through ports, lakes, locks and channels comprising the navigation system under study. The second program, PROSIM, is the report generator which processes the event log output from NETSIM II. The present chapter is devoted to a summary description of NETSIM II.

A. Model Design Considerations

In developing this extended simulation package, considerable emphasis was placed on constructing a generalized planning tool. Although the model has been developed with an eye towards entire Great Lakes-St. Lawrence Waterway Simulation capability, the model could be used for analysis of smaller subsystems. Generalized capability has also meant the additional concentration on commodity movements between multiple origins and destinations as opposed to simply the simulation of vessel movements (as in NETSIM I), however, its extended potential can be attained only with additional data preparation by the user.

The model was designed and programmed to be flexible enough to be adapted to any waterway subsystem. The model can accommodate as large a system for study as is permitted by hardware capabilities. That is, limits on system size are not embodied in the program. The amount of core required depends upon the number of lakes, reaches, locks, ports, commodities and vessels in the system. As an example, a system with 22 ports, 12 commodities, 1,000 vessels, 5 lakes, 10 locks, 50 nodes and 15 reaches would require about 240,000 bytes of core. Requirements for input-output devices are modest, even for large systems.

Flexibility also exists in the use of the computer programming language used to encode the model. Both NETSIM II and PROSIM are programmed in SIMSCRIPT II.5. Although SIMSCRIPT requires considerable programming skill, and is not as widely available as FORTRAN, it is capable of representing more complex data structures and can execute more complex decision rules. These attributes are extremely important for modeling a system so large and complex as the Great Lakes-St. Lawrence Waterway.[1] In addition, SIMSCRIPT's English-like readability facilitates program documentation. Thus, the flexibility of SIMSCRIPT can be summarized by saying that in complex models, SIMSCRIPT is able to produce a more compact model that requires less storage space, and that generally will be executed more rapidly.

Flexibility is further enhanced by the fact that both NETSIM II and PROSIM exist as sets of subroutines modularized in a fashion that permits the insertion, removal or modification of any program segment to provide a desired simulation. For example, the program can be used to study channel deepening by reworking the port and control routines separately from all the other modules. It would not be necessary to redevelop the entire program.

B. NETSIM II Input

The input to NETSIM II is made up of the following basic data groups (illustrated in Figure 2):

(1) commodity arrival list at ports;

(2) vessel fleet data;

[1]Many of the support routines do not require these characteristics of SIMSCRIPT and hence have been programmed in FORTRAN.

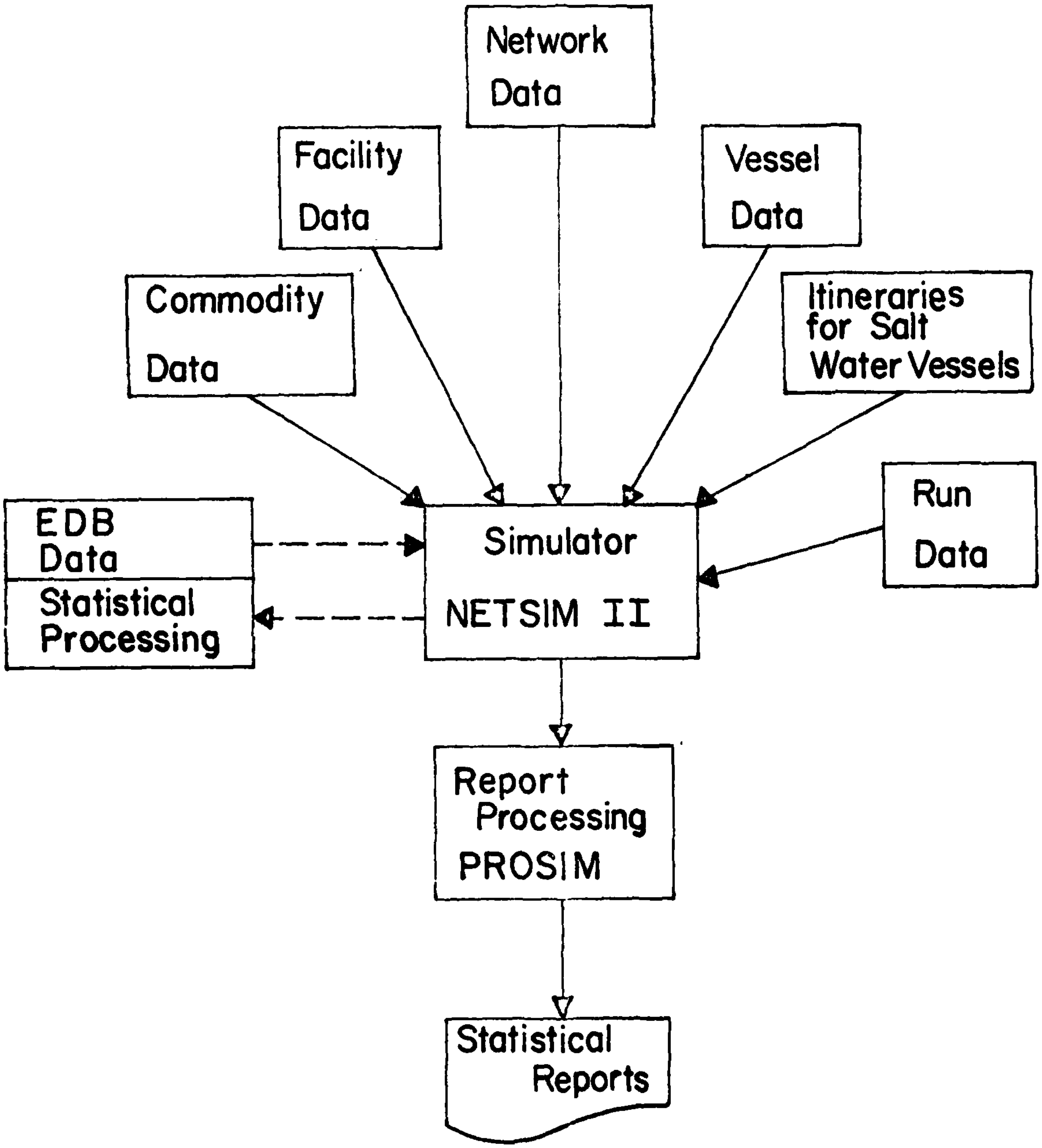

Figure 2. System Structure

(3) description of the navigation facilities;

(4) description of the navigation network;

(5) run parameters.

The commodity arrival list at ports constitutes an external event list in the simulation program and consists of data records specifying the port of origin and the commodity type, quantity, destination and time of arrival. A support program is available to aid the user in generating this commodity list.[2]

The vessel fleet data are also used to generate external vessel introductions into ports at the start of the simulation. These external events place vessels at their home ports to simulate season opening and must therefore specify the port, vessel identification and other vessel attributes. A support program is available to generate these vessel introductions from user supplied fleet data.[3]

The facility description consists of a series of data records for each facility in the system. These facilities are lakes, reaches, locks and ports. Facilities are described in terms of both physical attributes (i.e., its identification, where it is located, etc.) as well as their service times to process a vessel. Ports, by virtue of their special status as nodes where vessels may terminate their journeys, load, unload and assume new journeys, require some additional information such as the specification of the extent of backhaul traffic for each commodity.

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[2] See Chapter IV, Section B.

[3] See Chapter IV, Section A.

The network description consists of three matrices which completely specify the network configuration. The first table is used in the simulation program as a route map for vessels. The second table normally identifies the type of facility that is encountered by a vessel, although in the case of route options, that is, where more than one route alternative is available, the third table is used in the determination of a vessel's path. The contents and the functions of these tables of data are more elaborately described in the next section.

Finally, the run parameters are standard to any simulation run and include such specifications as the season length, input-output devices, and certain other options.

C. NETSIM II Operation

The network of interest is represented in NETSIM II as a system of links and nodes. Reaches, lakes and locks constitute the links, while ports and link interfaces are the nodes. A simulation, then, involves representing the movements of vessels among and through these fixed facilities of the network.

NETSIM II begins by referencing the initialization routine to read all input data and make certain basic data validity checks. If no data errors are discovered, the actual simulation is begun.

The basic element which moves through the system is a vessel. The vessel fleet consists of a fixed set of local bulk carriers plus a varying number of saltwater vessels. The adjective "local" refers to the fact that these bulk carriers never leave the Seaway for overseas ports. It should be noted also that they carry no general cargo. During simulation their movements are determined dynamically by the destinations of cargoes available at ports. Saltwater vessels, on the other hand, enter the Seaway (from the Atlantic Ocean) with predetermined itineraries. Each itinerary lists the allowed ports-of-call for the vessel. A support program is available to generate these itineraries from user supplied distributions of vessel and tonnage movements in the system.[4] The saltwater vessels are created and destroyed as they enter and leave the system via the St. Lawrence River. Associated with each vessel, both bulk and saltwater, is a list of attributes which carry the following information:

1. Vessel type - whether saltwater, dry bulk or liquid bulk
2. Physical data
   (a) Capacity
   (b) Draft
   (c) Horsepower
   (d) Length
   (e) Unloading rate (for self-unloaders)
3. Dynamic system variables such as current location, destination and current cargo.

The heart of the simulation program is the movement control routine which controls a vessel's movement through the network. The selection of each successive node in the path from origin to destination is made by reference to a table of next nodes which is the route map mentioned earlier. This is the basic system description matrix which stores, for each current node and final destination, the next intermediate node on the path. The facility id table is then referenced by the movement control routine to

[4]See Chapter IV, Section C.

identify the type of facility encountered by the vessel, whether it be a lock, lake, port or channel, and subsequently control is transferred to the appropriate link routine for actual vessel processing. Processing of the vessel continues within the link routine until the vessel completes movement to the next most immediate node specified by the physical system description. Transfer of control is then passed back to the movement control routine which once again initiates the loop process of referencing system description tables and invoking other routines as prescribed by the vessel's travel itinerary on the waterway system.

A vessel's itinerary may contain alternative route options. In NETSIM II, a vessel confronted with a choice between two parallel routes to the same destination selects the route with the lower expected transit time. In order to establish the criteria for estimating such expected transit times, a prior EDB simulation run is made in which the parallel route selections are made randomly and resulting transit times are recorded along with parameters which describe the state of the route segment of interest. Then, based on these simulation "experience" results, statistical analysis provides the relationships between usage parameters (for example, queue length at a lock) for each parallel segment and the corresponding transit times.

In the normal simulation run, then, when a vessel is confronted with two or more route options, the entry in the table of next nodes is a pointer to a parallel facilities table which lists the alternatives available. The relationships derived from the EDB run are now used to determine the route with the lower expected transit time.

A series of individual routines governs the timing of the vessel's movement through lakes, reaches and locks. The lake and reach routines are rather simple. Transit times for these facilities are based upon an average speed with an adjustment for vessel horsepower. In addition, a no-passing rule may be imposed upon any reach. Vessel processing in the lock routines, by comparison, is quite complex. This logic is the evolutionary product of several years of simulation studies, both of shallow draft inland waterways and of the Great Lakes-St. Lawrence Waterway System (see [4]).

For simulation purposes, the locking operation is broken into five segments as shown in Figure 3. The timing for each segment is governed by an empirical probability distribution. These five segments may further be adjusted at user's specification to represent special conditions. The long entry, for example, can be adjusted to reflect both chamber entry from a stationary position at queue and a moving entry into chamber. This detailed micro-modeling of the locking operation is warranted by the fact that locks present the greatest potential for system bottlenecks. Simulation results can be quite sensitive to small changes in the locking operation.

The port routines control the amount of time a vessel spends in port as well as selecting the cargo that the vessel is to take on, if any. Since the destination of a local bulk carrier is determined by the destination of its cargo, the dynamic scheduling of these vessels is in effect carried out in the port routines. The inventory of available cargoes at a port is a two-dimensional matrix of tonnages by commodity type and destination. A vessel's cargo is taken from the matrix cell with the largest available tonnage, considering, of course, only those cargoes which the vessel is capable of carrying. A certain minimum amount of cargo must be available

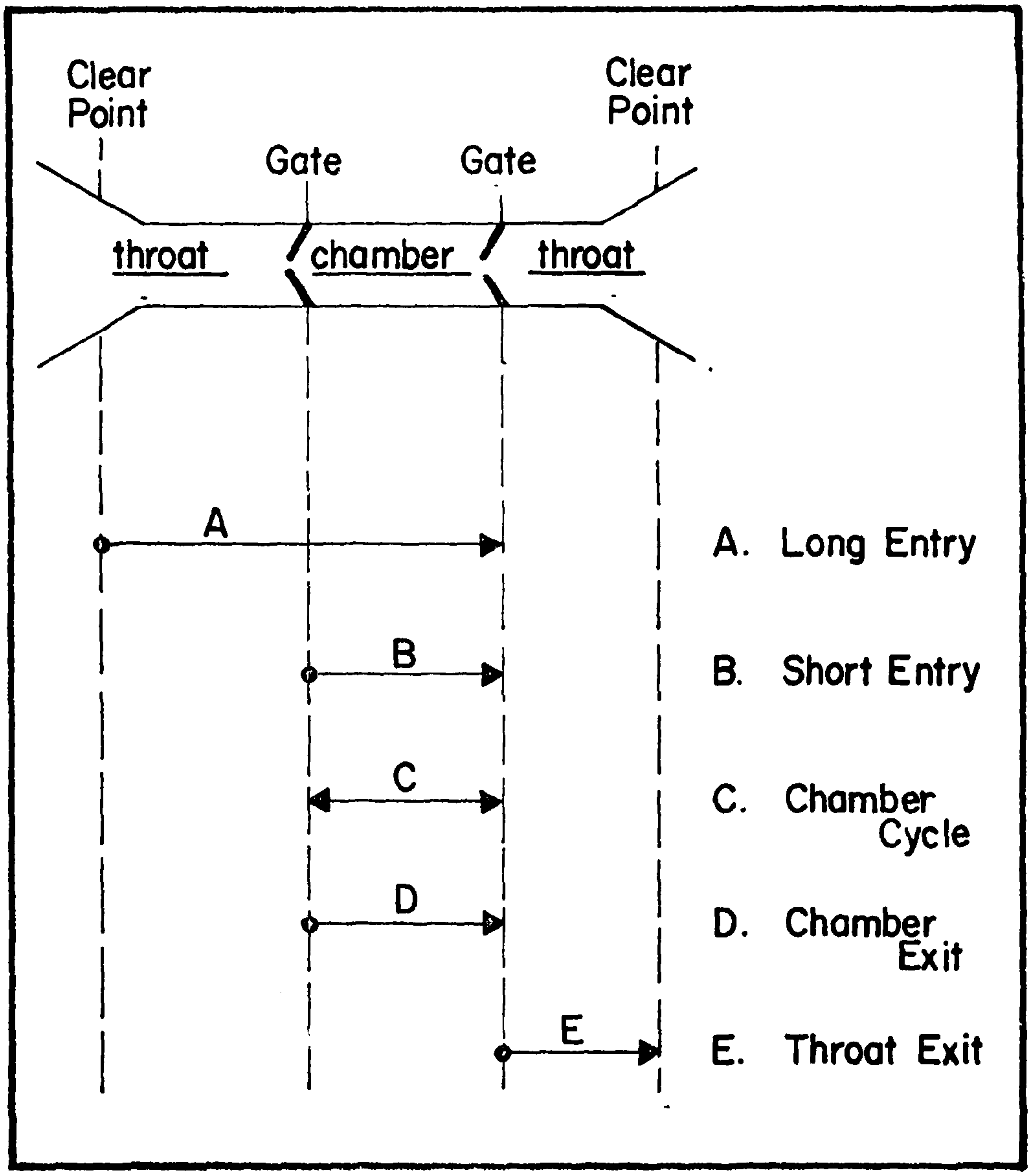

Figure 3. Locking Time Segments

to qualify for loading onto a vessel. If no minimum load is available at the port, inquiry can be made at one or more nearby ports to determine whether a suitable cargo is available there. If so, that cargo is earmarked for the particular vessel and the vessel is dispatched to the nearby port for loading.

Bulk carriers in the Great Lakes-St. Lawrence Waterway System do, in fact, make a large percentage of empty backhauls. In order to reflect this situation, the model allows for specification of the percentage of empty return trips by port-of-origin and commodity. During a simulation run, then, each loaded transit may or may not be followed by an empty return trip according to the appropriate given probability.

A port is represented as having a number of berths classified into four types: general cargo, bulk liquid, grain and other dry bulk. Time in port is the sum of four elements: (1) a small minimum time to enter and exit the port; (2) actual loading and unloading time, which is determined by the tonnage being transferred and the transfer rate for the berth (or for the vessel if it is a self-unloader); (3) time spent in queues waiting for a berth or for cargo and (4) a random factor to account for other delays.[5] In addition to the lake, reach, lock and port routines, there are a number of support routines to carry out repetitive tasks such as searching tables and sampling from probability distributions. The diagram in Figure 4 shows the interactions of the routines that comprise NETSIM II.

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[5]For example, the time to change berths, weather delays, etc.

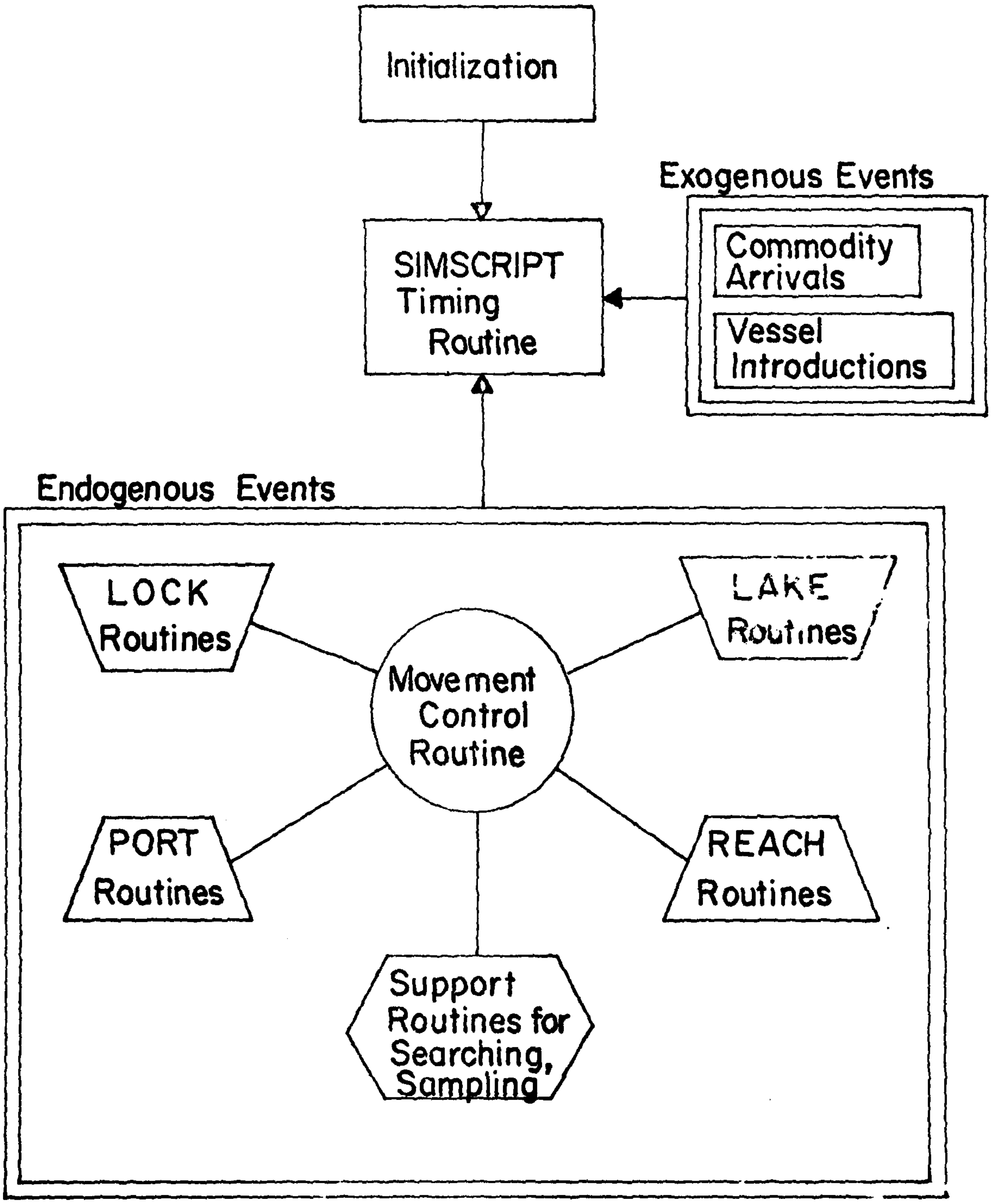

Figure 4. *NETSIM II* Program Flow

If the simulation is to proceed properly, the passage of simulated time must be controlled. This control is carried out automatically in SIMSCRIPT. The SIMSCRIPT provided timing routine controls the simulation clock by event-scheduling. Scheduled activities are ordered chronologically by the scheduled time of their occurrence, and the simulation clock is updated to the next event. As shown in Figure 4, the event list may contain exogenous events generated during simulation by the lock, port, lake and reach routines and also exogenous events consisting of commodity arrivals at ports and vessel introductions into the system.

D. NETSIM II Output

NETSIM II provides as output an event log which is a description of all events that occurred during the simulation. Each event description lists the time of occurrence, vessel identification, vessel attributes, the relevant facility identification, facility attributes and an event code which specifies the nature of the event. This event log along with parameters specifying output options form the input to PROSIM, the statistical report generator.

E. Model Testing and Calibration

The bulk of the testing of the NETSIM II program was carried out on a hypothetical navigation system network. The hypothetical network is very similar to the GL-SLS, but with a greatly reduced number of ports, locks, reaches, vessels and commodities. Running the model on this smaller system allowed testing of the workability of various calibration and adjustment factors.

These calibration factors allow the operation of the program to be adjusted to coincide more closely with that of the real-world system being simulated. Some of the calibration factors available in NETSIM II are listed below.

1. Vessel loading and unloading rates.
2. Vessel speeds in reaches.
3. Vessel speeds on lakes.
4. Adjustment of vessel speeds according to horsepower.
5. A random component of time in port. This is added to actual loading time in order to reflect unusual delays such as weather, equipment failure or labor problems.
6. Times required for various elements of the locking operation.
7. Average vessel cargo tonnage as a fraction of the vessel's stated capacity.
8. Specification, for each port, those other ports that will be considered "nearby." When a vessel cannot find a suitable cargo in its current port, it will search for cargo in "nearby" ports.
9. Percentages of empty backhaul movements for bulk vessels.
10. Maximum cargo queue limits. When the number of vessels in a port waiting for cargo exceeds this limit, other vessels will be sent back to their ports of origin empty rather than being allowed to remain and wait for cargo.
11. Maximum commodity inventory limits. If the amount of a commodity awaiting transit has built up past this limit in a port, vessels departing loaded will be marked for

empty backhaul. This is to ensure that they will be returned to this port--where they are sorely needed--rather than being assigned to some other movement.

The general workability of the simulation program structure, which includes the above factors, has been confirmed through simulation of the hypothetical navigation system. Also, a run has been made on a system very nearly representing the GL-SLS in order to demonstrate the feasibility of simulating a system of that magnitude. Time and data were not available, however, to carry out a realistic calibration of NETSIM II for the GL-SLS.

III. PROSIM : A SIMULATION PROCESSOR FOR NETSIM II

A. PROSIM Objectives

The primary purpose of PROSIM is to remove the statistical output generation burden from NETSIM II. Main factors dictating the separation of statistical processing from the actual simulation were:

1. the critical need to reduce space requirements for the simulation program;
2. ease of debugging and error detection;
3. the ability to tailor the output format to fit the needs of the user without conducting several reruns of the time-consuming simulation phase; and
4. the creation of a permanent, detailed record of the simulation for calibration and operational analysis apart from the aggregate statistical reports.

These desirable features were not obtained without some sacrifice in the time requirements. Clearly, some duplicative effort exists between the two programs with regard to input-output processing and program structure. Nevertheless, the flexibility afforded by the separation of statistical processing from the simulation phase is deemed to be of sufficient merit to warrant this approach.

B. PROSIM Description

Figure 5 presents a generalized program flow for PROSIM. The input data requirements for PROSIM are extremely modest compared to NETSIM II; apart from the event log which is usually passed from the simulation phase

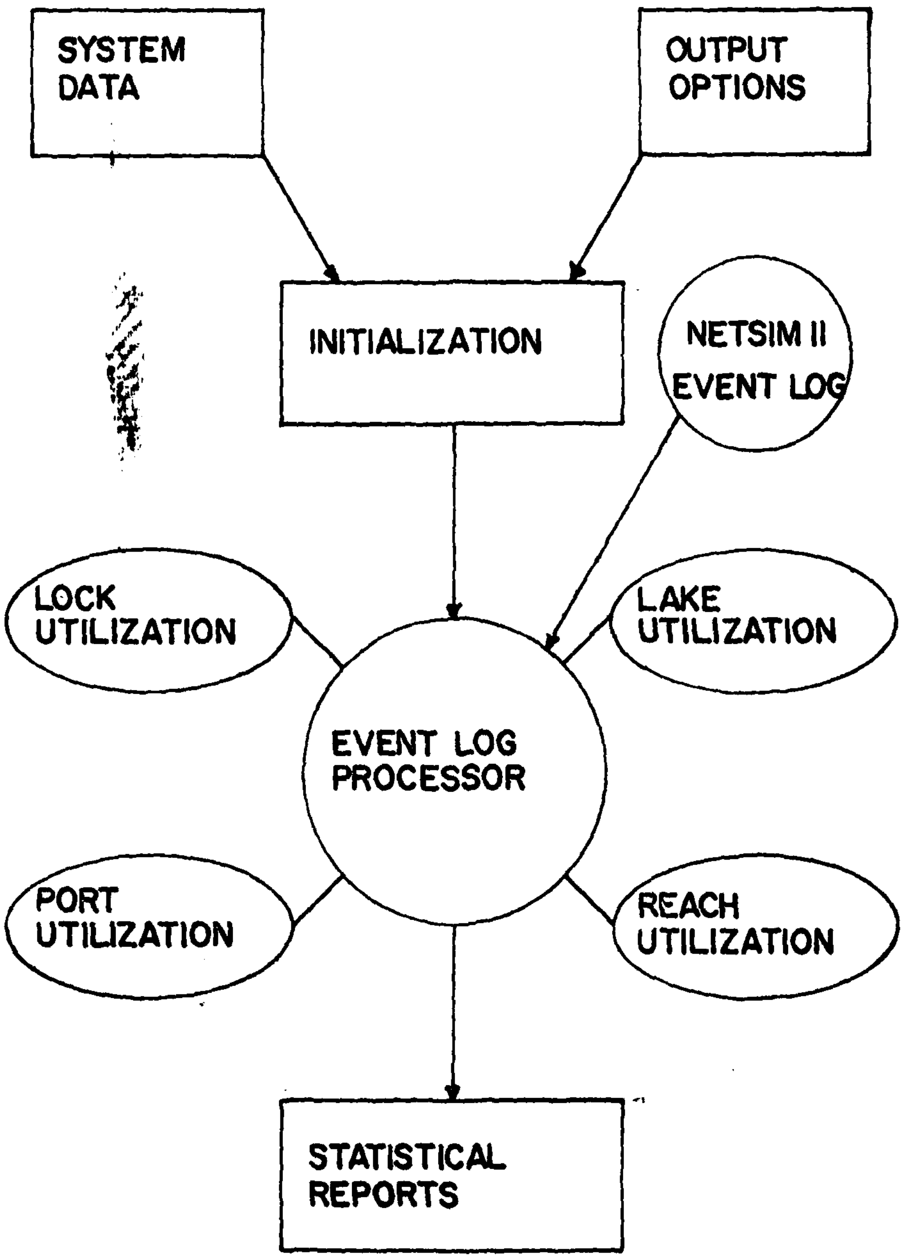

Figure 5. PROSIM Program Flow

through some auxiliary unit such as magnetic tape, they consist merely of some system parameters to set up the entity structure and a number of output options specifying the type, form and time frame for statistical reports.

Program flow is controlled by the event log processor routine whose main function is to read and interpret the event log and invoke the appropriate support routine to extract the necessary information for generating user specified output tables. The support routines have been written with the objective of grouping informational items in a logical and meaningful manner so as to effect ease of interpretation and to facilitate monitoring control over certain variables which reflect the model's approximation of the real world. The modular structure of the program should be of considerable assistance in tailoring segments of the program to user needs.

PROSIM provides statistical output in three forms. These three forms are: (1) generation of all output tables at the end of the run; (2) generation of all or selected output tables at user specified intervals during the run; and (3) punching selected statistics for further tests of statistical inference at user specified intervals. PROSIM also prefaces these output forms with a description of the waterway system being analyzed and other items which may aid the user in interpreting the values presented in output tables.

PROSIM provides performance summaries for each category of system facilities. The output consists of fifteen different tables detailing performance results for locks, ports, lakes and reaches. Data in these tables may either be accumulated output or calculated output. Accumulated output is simply that which is tabulated as each occurrence takes place within the simulation. For example, total delay is simply the accumulated value for delays experienced by all vessels. Calculated output is that which results through some combination of accumulated data within the model itself. For instance, lock utilization is a statistic which is found by taking total lock processing time (an accumulated value) as a percent of total available time for processing (an input value - usually the simulation length).

In the intermediate output form, PROSIM can produce selected output displays if desired, rather than all fifteen output tables. This selection capability allows generation of less interval output, hence speeding up the program by reducing expensive computer operating time. An instance where all output might not be desired is the situation in which emphasis was placed on only a specific set of variables (e.g., locking operations only) as opposed to the complete simulation results. It should be noted that the final output form always produces a complete set of output tables, regardless of which tables (if any) have been suppressed in the intermediate output form. In any case, the user can, through intermediate output, increase the sample size for his analysis without conducting several separate entire simulations.

The use of intermediate output, however, involves an implicit assumption about the independence of the data. That is, proper application of many statistical methods requires that the data used in the analysis be independent. Observations on a random variable generated at successive points in time in a simulation experiment, however, are generally autocorrelated; treating them as independent underestimates the variance of the corresponding sample mean. This problem can be avoided by taking observations at widely spaced intervals, at the expense of a considerable loss of statistical power, or by data transformation which unfortunately is inappropriate in many situations. An alternative approach involves the use of spectral analysis to measure the degree of autocorrelation and take it into account in subsequent tests of inference. This approach has been documented elsewhere [6]; no description is given here. The use of this approach requires periodic observations on random variables of interest (for example, delays). Therefore, the third output form in PROSIM provides punched data on selected variables to be used as input into subsequent tests of spectral analysis and statistical inference.

In summary, the primary output in PROSIM is the set of performance summary tables for each category of waterway facilities represented in the simulation model. The output data tables for locks and ports are the most important of these since they contain the most information. Figures 6 and 7 display the format for these tables.

		Soo	St Lmbrt	Catherin	L Beauhr	U Beauhr	Snell	Eisenhow	Iroquois
For All Vessels									
Total overseas cargo	up	200,000	2,300,000	.	.	.	.	.	.
	down	280,000	2,450,000	.	.	.	.	.	.
Total dry bulk cargo	up	2,200,000	3,200,000	.	.	.	.	.	.
	down	20,000,000	2,800,000	.	.	.	.	.	.
Total liquid bulk cargo	up	240,000	700,000	.	.	.	.	.	.
	down	50,000	800,000	.	.	.	.	.	.
Utilization Rate (%)		57	22	.	.	.	.	.	.
Current queue length	up	1	1	.	.	.	.	.	.
	down	4	1	.	.	.	.	.	.
Maximum queue length	up	4	3	.	.	.	.	.	.
	down	9	3	.	.	.	.	.	.
For Vessels of Length 1-399 ft.									
Delayed trips	up	215	94	.	.	.	.	.	.
	down	193	101	.	.	.	.	.	.
Average delay	up	14	6	.	.	.	.	.	.
	down	11	7	.	.	.	.	.	.
Total delay	up	5,880	564	.	.	.	.	.	.
	down	4,521	707	.	.	.	.	.	.
Std. error for delay	up	8.1	6.7	.	.	.	.	.	.
	down	7.4	6.9	.	.	.	.	.	.
Total trips	up	420	275	.	.	.	.	.	.
	down	411	281	.	.	.	.	.	.
Average transit time	up	72.9	39.2	.	.	.	.	.	.
	down	69.4	38.7	.	.	.	.	.	.
Total transit time	up	30,620	10,780	.	.	.	.	.	.
	down	28,525	10,880	.	.	.	.	.	.
Std. error for transit	up	20.7	15.4	.	.	.	.	.	.
	down	19.7	15.6	.	.	.	.	.	.
For Vessels of Length 400-730 ft.									
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Indicated figures are for illustrative purposes only. Time in minutes. Cargo quantities in tons.

Figure 6. Performance Details for Locks

	Duluth	Chicago	Detroit	Clevelnd	Buffalo	Toronto	Montreal	Quebec
Total Tonnage Into Port								
Overseas	50,000	650,000	.	.	.	.	.	.
Liquid bulk	60,000	100,000	.	.	.	.	.	.
Dry bulk (excl. grain)	550,000	2,400,000	.	.	.	.	.	.
Grain	7,000	15,000	.	.	.	.	.	.
Total Tons Out Of Port								
Overseas	55,000	800,000	.	.	.	.	.	.
Liquid bulk	15,000	50,000	.	.	.	.	.	.
Dry bulk (excl. grain)	5,200,000	2,100,000	.	.	.	.	.	.
Grain	1,500,000	750,000	.	.	.	.	.	.
Total Ships Into Port								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Total Ships Out Of Port								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Average Turnaround Time In In Port								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Average Delay For Berth Use								
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Indicated figures are for illustrative purposes only. Cargo quantities in tons.

Figure 7. Performance Details for Ports

IV. SUMMARY OF SUPPORT PROGRAMS

A. Vessel Generation

Vessels are introduced into the simulated system via CREAT.VESSEL external event notices. Each notice specifies the time that the event is to occur (the simulation time at which the vessel is to be "created"), the port at which the vessel is to be created and a number of vessel attributes. Each event notice is contained on an 80 character record, so that a straightforward method of creating the vessel fleet would be to keypunch a CREAT.VESSEL card for each vessel in the fleet. If detailed data are available for the fleet in question, this is certainly not an unreasonable approach.

The Vessel Generation Program has been provided to generate a fleet with a desired mix of vessels without necessitating the keypunching of each individual CREAT.VESSEL card. It also provides an easy means for varying the number of vessels in the fleet and for experimenting with varying the mix of vessel attributes. The program is written in FORTRAN.

For each of the three vessel classifications (dry bulk, liquid bulk and saltwater) the user must supply a pool of representative vessels. The vessels for the fleet will then be selected from these three pools according to user-assigned probabilities. The user also provides the probabilities for choosing the port at which a vessel of a given class will be created. A sequence of input cards dictates (deterministically) how many vessels of each class will be created at what times.

The CREAT.VESSEL cards produced by the Vessel Generation Program might easily be supplemented with some keypunched cards. This could be done in order to introduce a few special vessels into the system at particular ports.

B. Commodity Arrivals

Overland commodity arrivals into ports in the simulated system are triggered by COM.ARRIVAL external event notices in NETSIM II. The Commodity Arrival Generation Program provides a convenient means of producing the COM.ARRIVAL event notices as long as the pattern of commodity arrivals is invariant over time. The program is written in FORTRAN.

The user must supply the mix of commodities that will arrive in the ports periodically. This "mix" involves four pieces of information for each module of cargo:

(1) the commodity type

(2) the port into which it is arriving

(3) its destination

(4) the quantity (tonnage).

Once the mix of arrivals is defined, it is reproduced in COM.ARRIVAL event notices. An event notice is produced for each time the user specifies that commodity arrivals should occur. For example, if the arrival mix data specify an average daily arrival pattern, then one might want arrivals to occur, say, at midnight of each day (simulation times 0, 1440, 2880, . . .). If a smoother arrival schedule is desired, then more frequent arrivals in smaller quantities would be called for. Any schedule can be specified so long as the mix which is to arrive at any one time does not vary. If this mix is to vary during the period of a single simulation run, either a modified arrival generation program or multiple runs of this program would be required.

C. Itinerary Generation

Saltwater vessels enter the system via the St. Lawrence River with predetermined itineraries. The Itinerary Generation Program is an auxiliary

FORTRAN program which produces these required itineraries for use in NETSIM II. An itinerary consists of a sequence of ports of call and, for each port, a specification of the fraction of the vessel's inbound tonnage to be unloaded and the fraction of the vessel's capacity to be loaded. The latter, of course, is the maximum amount to be loaded; in any individual case, if the full specified amount of cargo is not available at the port, only the amount available will be loaded.

Itineraries are built randomly based upon user-supplied empirical distributions which describe actual saltwater vessel movements in the Great Lakes-St. Lawrence Waterway System. The generated itineraries must reflect the observed vessel movement patterns as well as providing capacity for observed commodity movements.

The itineraries are written as output records which are in turn used as input to NETSIM II. Each time a saltwater vessel is introduced into the system, NETSIM II reads in the next itinerary and assigns it to that vessel. Itineraries are assigned independently, without regard for a vessel's capacity, speed or national origin.

D. EDB Processing

The EDB processing program is a FORTRAN program that is used to process the "experience data bank" (EDB) generated during an EDB simulation of parallel route facilities in a system. In NETSIM II, a vessel confronted with a choice between two or more parallel routes to the same destination selects the route with the lower expected transit time. In order to establish the criteria for estimating such expected transit times, an EDB simulation run is made in which the parallel route selections are made randomly and resulting transit times are recorded along with certain usage parameters (such as lock queue size) which describe the state of the route segment of interest. The EDB processing program processes these records and arranges the usage parameters for each parallel segment with their associated vessel transit times so that they can be input directly to statistical analysis (commonly a canned regression program).

V. MODEL APPLICATIONS

This section summarizes the application of NETSIM I to the LE-LO Navigation System and discusses the potentials of the NETSIM II-PROSIM model for simulation studies of the GL-SLS and other waterways. NETSIM I, alternatively referred to as the LE-LO simulation model in this report, was used in the simulation studies of the Welland Canal and proposed alternatives to the Welland. To date, the NETSIM II-PROSIM model has not been applied to any existing waterway although a number of runs on hypothetical configurations have been performed. The primary objective of this chapter is, then, to draw focus upon the type and character of information derived from the use of each simulation model, rather than upon detailed documentation of each simulation run.

A. Lake Erie-Lake Ontario Navigation Study

1. Scope and Objectives of the Study

The purpose of this study was to utilize the NETSIM I model in simulation studies of the Welland Canal and proposed alternatives to the Welland. Its scope encompassed the following subtasks:

1. to establish the expected limits of service of the existing Welland Canal,
2. to establish the expected incremental increase in service potential of the existing Welland Canal under assumptions of improved locking procedures and an improved traffic control system,

3. to determine the expected performance of a combined Welland-Niagara system with configuration alternatives of four, five and six locks in series in the Niagara Canal in combination with the existing Welland Canal,
4. to examine the expected performance of a replacement for the Welland Canal consisting of a series of four super locks plus a guard lock towards the mouth of Lake Erie.

These configurations were subjected to current and anticipated levels of traffic, fleet composition, ship size, and operating procedures. The primary measure of system performance was system transit time. This variable reflects both the service levels provided by system facilities and any delays that occur due to congestion. In addition, measures of lock utilization, lock processing time, and time spent in queues were taken so that the system response could be stated in terms of delays due to congestion and lock utilization. However, no analysis of the effects of delays and system congestion upon demand was undertaken. Hence, the emphasis of the study was placed upon determining what configurations of navigation facilities are required to meet the prospective transportation demand and to enable the network to function effectively as a system.

2. LE-LO Navigation System

Passage between Lake Erie and Lake Ontario is accomplished through the Welland Canal which stretches between Port Weller--a man-made harbor serving as the Lake Ontario entrance to the canal--and Port Colborne on Lake Erie, a distance of twenty-seven miles. Its eight locks, three of them twinned, have a total lift of three hundred twenty-six feet to the level of Lake Erie.

Its minimum channel width in the open reaches is two hundred feet while its locks can accommodate a vessel of maximum dimensions 730' x 75'6". As the canal traverses a densely populated area, numerous bridges must be lifted for a ship to transit; however, in 1973, ships began to utilize the Welland Bypass, a new section which bypasses the city of Welland and is free of all bridges. The location and extent of this system are shown in Figure 8.

Vessel transit through the Welland Canal is supervised by a semi-automated traffic monitoring and control system installed by the St. Lawrence Seaway Authority in 1965. This traffic control system permits the exact location of each vessel to be monitored by sensors placed at strategic locations in the canal. This information is supplemented by closed circuit television cameras with which the controller can see the status of lock components and ship gear. Information is transmitted to the vessel by status lights as well as radio and loud speaker so that it may transit with a minimum of delay [7, 8].

3. System Design Alternatives

Six alternative system configurations were simulated in this study. Three of the alternatives consisted of a single channel, the Welland Canal, while the rest consisted of two parallel channels in a combined Welland-Niagara system. The single channel configurations were: (1) the existing Welland Canal; (2) the non-structurally improved Welland Canal; and (3) a structurally improved Welland Canal consisting of a series of five locks[1] of greater lift and 1200' x 110' dimensions. The two-channel

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[1]Includes a guard lock.

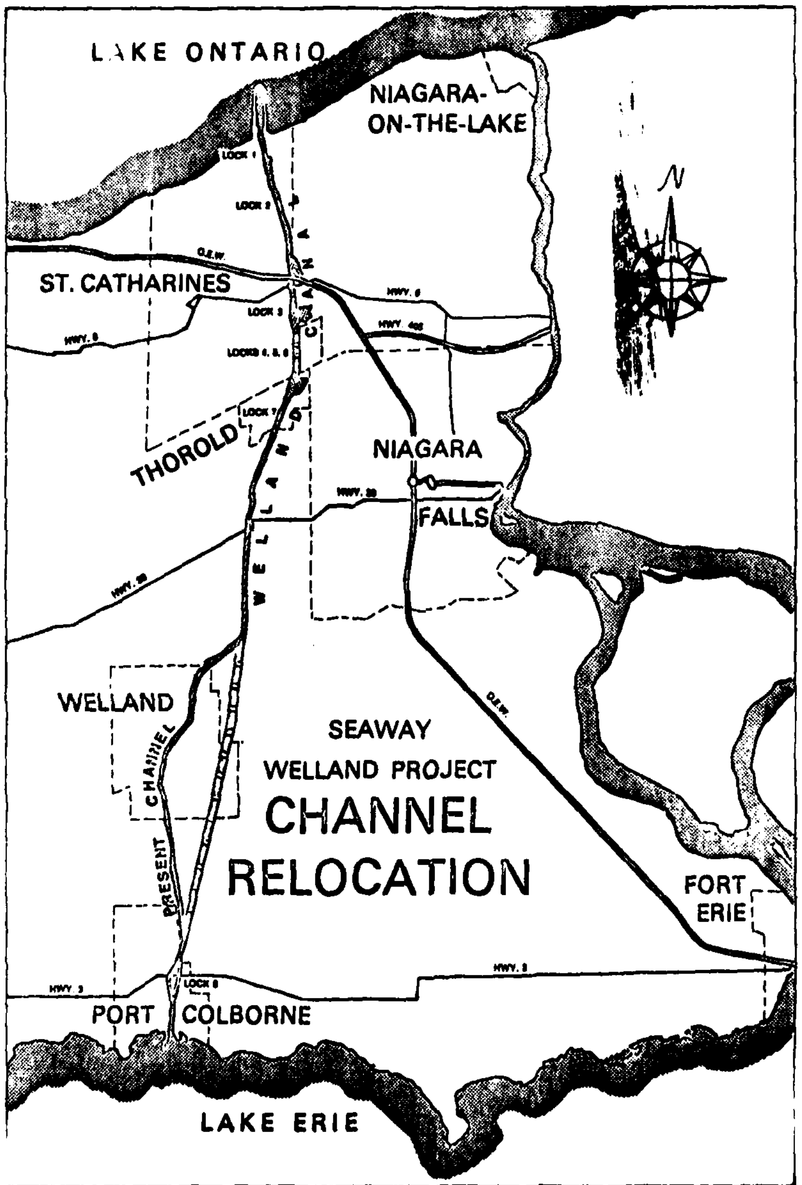

Figure 8. Location of the Welland Canal

systems were configurations of four, five, and six locks in series in the proposed Niagara Canal in combination with the existing Welland.

For the purposes of this study, the Welland Canal was modeled as a set of six entities where operations within each entity were inferred rather than specifically modeled. Recent traffic data [9] for the canal were used to establish relationships between vessel transit time and the state of the canal (number of ships in the canal, etc.). Transit times through the canal were then derived in the simulation as a polynomial function of the state of the canal.

4. Simulation Runs

The basic methodology for the Welland-Niagara simulation experiments entailed the division of traffic between parallel facilities. This factor dictated the use of the model's EDB channel choice mechanism; thus, EDB simulation runs were performed on each Welland-Niagara configuration to derive ETT functions.

The simulation run for the existing Welland Canal under a 1971 traffic load served as the base run in establishing calibration values for the model's parameters. Subsequent simulations subjected each network to increasing transport demand from 1980 through to 2030, if necessary, in five-year increments up to year 2000 and in ten-year increments thereafter. Each simulation was examined for signs of saturation to determine if the next higher level of demand experiment was necessary.

Transport demand was represented in the input data by two factors, projected levels of traffic and traffic composition. Two estimates for each of the projected levels were given in order to allow for the uncertainty of future demand. Traffic composition was allowed to vary over the study period and it reflected an estimated trend towards larger vessel size. Tables 1 and 2 show the actual data used for these two factors.

TABLE 1. AVERAGE DAILY VESSEL TRANSITS (ships/day)

	Traffic Level "A"	Traffic Level "B"
1970	25.50	25.50
1980	26.50	27.40
1985	27.00	28.55
1990	27.50	29.70
1995	28.00	31.15
2000	28.50	32.60
2010	29.50	35.70
2020	30.90	39.80
2030	32.20	44.30

Note: Data for 1970 are actual, for the others are projected.

TABLE 2. FLEET COMPOSITION-PERCENTAGE DISTRIBUTION BY CLASS

	Class I (1'-399')	Class II (400'-730')	Class III (731'-1150')
1970	30.00	70.00	0.00
1980	23.30	74.70	2.00
1985	19.85	74.60	5.55
1990	16.40	74.50	9.10
1995	14.00	73.45	12.55
2000	11.60	72.40	16.00
2010	9.60	68.60	21.80
2020	6.60	65.00	28.40
2030	5.30	60.00	34.70

Note: Data for 1970 are actual, for the others are projected.

5. Results and Conclusions

Some specific simulation results are enumerated below.

1. All twin-canal simulations used a single set of locking data. Under these conditions, no statistical differences could be established among any of the three configurations. Changes in locking data among the various networks could revise this result.

2. Practical capacity[3] of the existing Welland Canal was achieved between 1990 and 2010 under the projected traffic levels.

3. Nonstructural improvements to the Welland Canal leading to a reduction in the lock cycle, increased the capacity of the system by five to ten years under projected traffic levels.

4. For the structurally improved Welland Canal (replacement of the existing seven 860' x 80' locks by four 1200' x 110' locks), a set of canal transit time curves for varying lock service rates was developed. The capacity of this system was found to be extremely sensitive to lock service times.

The most clear-cut result of this simulation study is that the twin-canal configurations are able to provide better service over a longer period of time than the single Welland configurations. This is pictorially demonstrated in Figures 9 and 10 showing the average canal transit time under each projected traffic level. The Welland-Niagara configurations distinctly reflect excess capacity through the end of the current millennium and in fact any of the four-, five-, or six-lock Niagara Canals in combination with the Welland would perform equally well under projected traffic up to year 2030.

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[3] Practical capacity was defined in this study as that point at which the system reaches [illegible] percent of its theoretical maximum capacity.

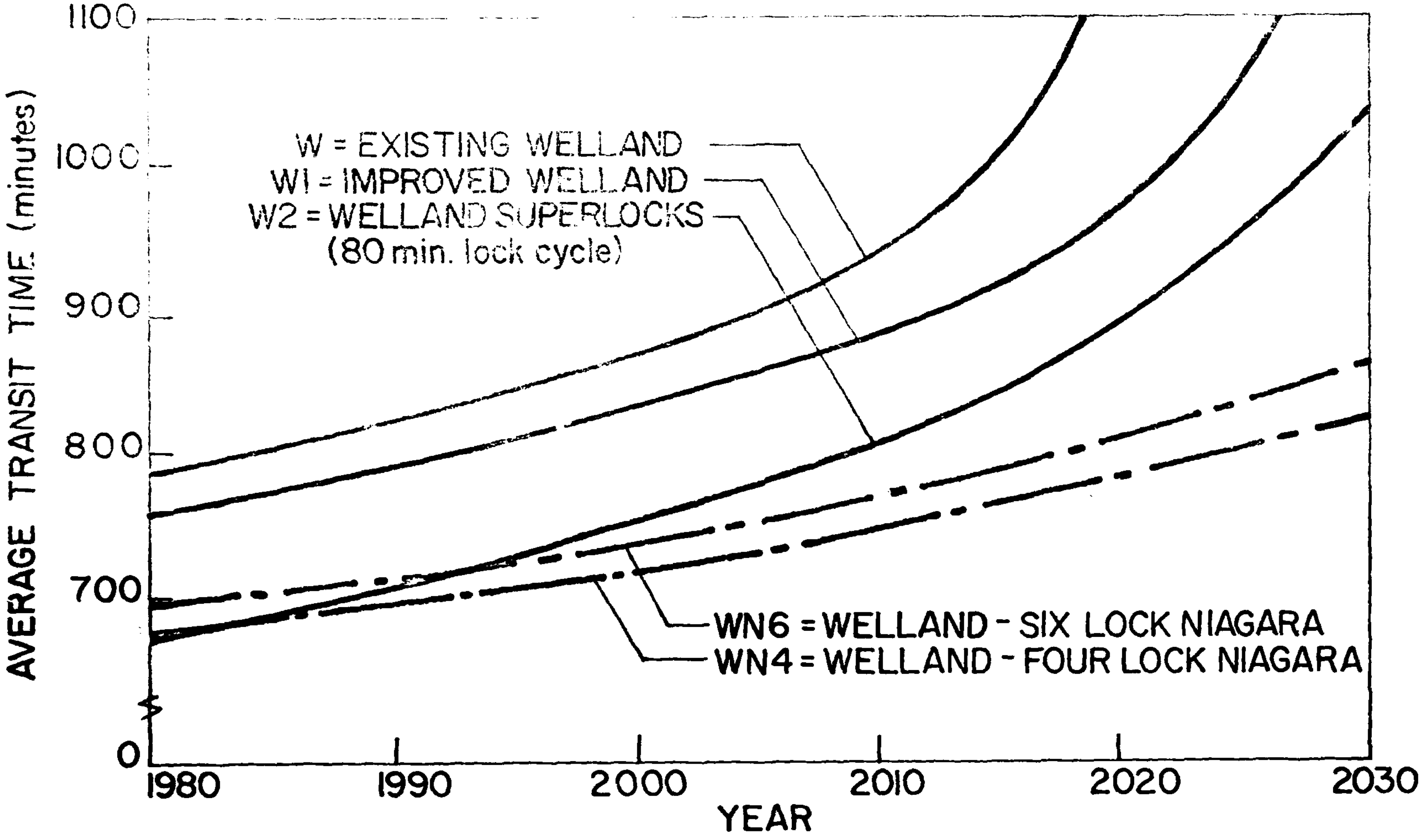

Figure 9. Transit Summary Under Traffic Level "A"

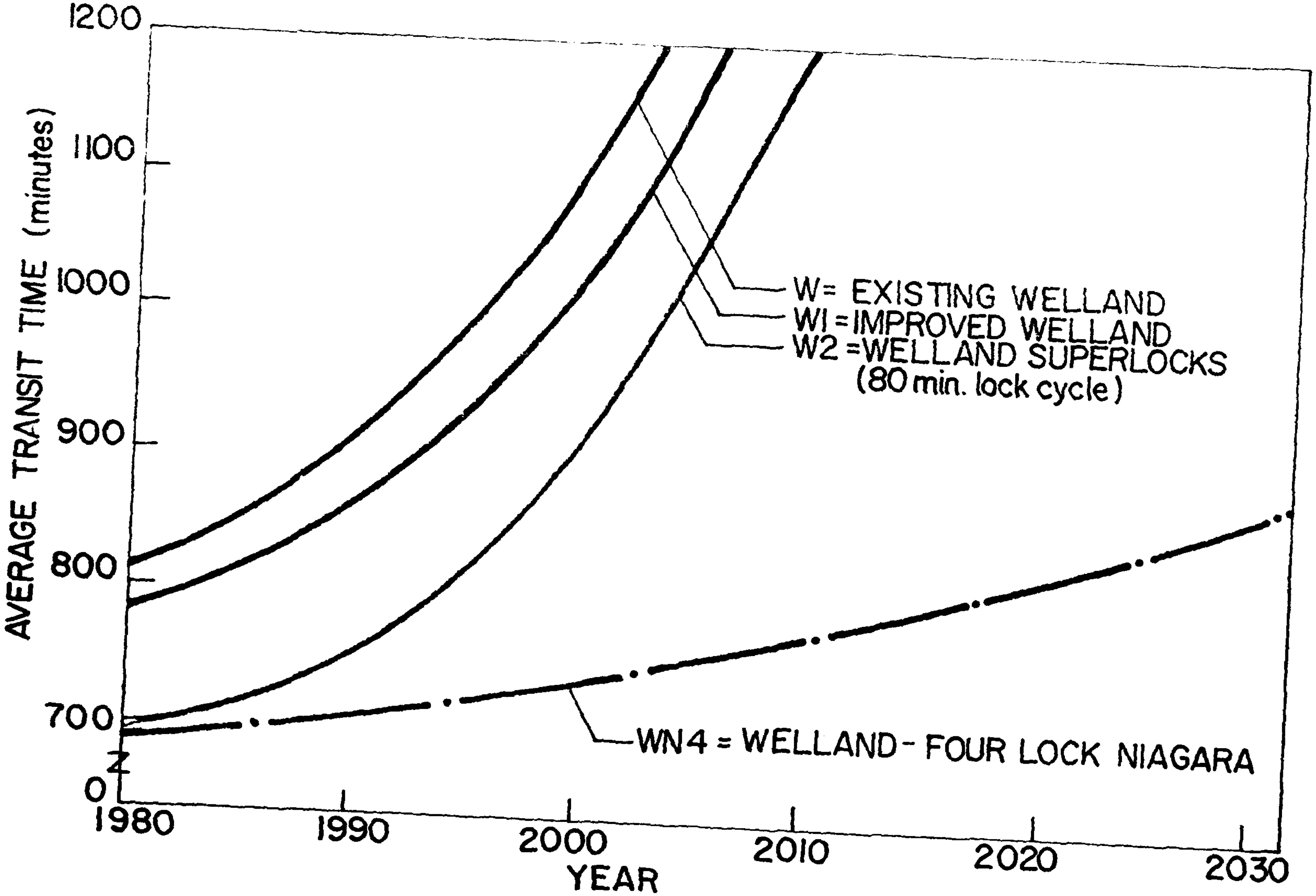

Figure 10. Transit Summary Under Traffic Level "B"

B. Great Lakes-St. Lawrence Waterway Simulation

1. Introduction

The validity of a simulatic⁻ is a measure of the extent to which it satisfies its design objectives. In the case of the NETSIM II-PROSIM model, the design objective was the development of a model with capabilities for comprehensive GL-SLS system simulations. Thus, assurance of validity requires the following:

(a) The model must be shown capable of simulating a "representative" configuration of the GL-SLS system consistent with the specified applications.

(b) The theoretical structure of the model including all the assumptions must appear reasonable in relation to the real world phenomenon being simulated.

(c) The model must be shown to measure what it purports to measure.

Since properties (b) and (c) of the simulation model are treated in the accompanying volume [3], this section will be restricted to a summary description of a simulation experiment of the GL-SLS system.

2. Simulation Methodology, Data and Results

The simulation encompassed a representative GL-SLS configuration consisting of 18 ports, 9 locks, 15 reaches (channels) and the five Great Lakes. Commodities in trade were grouped into seven categories. Vessels were aggregated into three types: dry bulk transporters, liquid bulk tankers and saltwater vessels. These principal entities in the simulation run are listed in Table 3.

TABLE 3. ENTITIES IN GL-SLS SIMULATION USING NETSIM II-PROSIM MODEL

a. Ports

1. Duluth, Superior, Port Arthur
2. Marquette, Sault Ste. Marie
3. Escanaba
4. Milwaukee
5. Chicago
6. Gary, Indiana Harbor
7. Muskegon
8. Alpena (Lake Huron)
9. Detroit, Windsor
10. Toledo
11. Cleveland
12. Buffalo
13. Inland Waterways
14. U. S. Coastwise
15. Hamilton
16. Toronto
17. Montreal
18. Atlantic (overseas)

b. Locks

1. St. Lambert
2. Cote Ste. Catherine
3. Upper and Lower Beauharnois
4. Snell
5. Eisenhower
6. Iroquois
7. Poe (at Sault Ste. Marie)*
8. Other Sault Ste. Marie locks represented as one lock*

c. Reaches

1. 15 connecting channels and rivers

d. Lakes

1. Superior
2. Huron
3. Michigan
4. Erie
5. Ontario

e. Welland Canal

*Formed a parallel lock system.

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f. Commodities

1. Grain (corn, soybeans, wheat, other grain)
2. Coal
3. Cement, stone, sand and gravel
4. Iron Ore
5. Other bulk (other ores, pulp and paper and other bulk)
6. Petroleum (fuel oil, gasoline, and other petroleum products)
7. General cargo (iron and steel, other primary metals, chemicals, food, transportation equipment, machinery, other manufactured goods)

The simulation was conducted for a one-month period beyond initial warmup time. A total fleet of 848 vessels including 720 bulk transporters was introduced into the system. A port-to-port origin and destination matrix of the seven types of commodity movements was arbitrarily constructed and introduced through ports as daily arrivals. The cargo input data summary is shown in Table 4.

TABLE 4. INPUT CARGO SUMMARY FOR THE GL-SLS SYSTEM SIMULATION

Cargo Type	Annual Tonnage	Average Monthly Tonnage
1. Grain	10,717,582	893,132
2. Coal	43,315,220	3,609,601
3. Cement, etc.	42,880,045	3,573,337
4. Iron Ore	80,530,977	6,710,915
5. Other dry bulk	6,967,027	580,586
6. Liquid Bulk	9,926,752	827,229
7. General Cargo	14,282,337	1,190,195
TOTAL	208,619,940	17,384,995

In addition to these data, all other data such as port turnaround time factors, locking distributions and reach and lake transit times were hypothetically constructed since a complete and accurate data base was not available at the time of the experiment.

The simulation results showed that the model was indeed performing as theoretically expected and that it was capable of accommodating a large, complex and diversified network. No output analysis, particularly an analysis of delays could be carried out, however, since the model's input data were hypothetical and since comparative real-world data on performance was also lacking. Such data can be obtained from various sources including the Corps of Engineers, the St. Lawrence Seaway Development Corporation, the St. Lawrence Seaway Authority, port authorities and waterway operators, and indeed their availability is a prerequisite to the use of the model.

Because of this problem more stable variables for which data are available, such as tonnage flows, must be used to compare simulation output with real-world data. This comparison may be of the form shown in Table 5 where the results from the uncalibrated simulation run are compared with the actual input data. The difference column indicates that the relationships balancing supply and demand incorporated in NETSIM II's structure produced tonnage flows which lay somewhere along the desired levels (based upon hypothetical data). With the benefit of an accurate data base, the model can be properly calibrated for the GL-SLS system and rigorous statistical tests can be used to analyze the output.

A number of output statistics can be used to aid the calibration process. Some calibration parameters are already built into the model as discussed previously in subsection E of Section II. Alternately, the model output might be statistically adjusted to reflect modeling error. Figure 11 shows some of the output statistics generated by the NETSIM II-PROSIM model and this also serves to illustrate the additional information provided by the extended model vis-a-vis its predecessor, NETSIM I.

3. Future Model Studies

Having outlined the type of output available from the GL-SLS simulation run, it is traditional to focus upon the limitations of the model and recommend further studies. In the case of the NETSIM II-PROSIM model, it it indeed crucial, in order to have meaningful applications, to gather real-world data not only on the model's input needs but also on some of the

TABLE 5. OUTPUT TONNAGE SUMMARY FOR GL-SLS SIMULATION RUN

Port	O-D Tons	Simulated Tons	Percent Change*
Duluth	5,200,883	5,094,500	2.0
Marquette	314,023	308,200	1.9
Escanaba	1,470,171	1,809,000	-23.0
Milwaukee	70,346	64,100	8.9
Chicago	1,124,133	1,401,100	-24.6
Gary	554,794	579,300	- 4.4
Muskegon	439,590	467,900	- 6.4
Alpena	2,904,255	3,433,500	-18.2
Detroit	101,862	95,400	6.3
Toledo	1,828,364	1,285,400	29.7
Cleveland	2,000,054	2,349,300	-17.5
Buffalo	37,587	33,200	11.7
Inland Waterways	16,112	0	100.0**
U.S. Coastwise	39,546	28,500	27.9
Hamilton	426,837	227,600	31.4
Toronto	555,540	361,700	34.9
Montreal	14,310	10,700	25.2
Atlantic (Overseas)	286,582	---	-- ***
Total (excluding Atlantic)	17,098,407	17,549,400	2.6

*Percent Change is difference from the true value.

**A shipment large enough to transport not available during most of the simulation.

***No statistics were gathered for Atlantic since the saltwater vessels were removed from systems upon arrival at the node.

Note: Error is large for ports with relatively high proportion of overseas cargo.

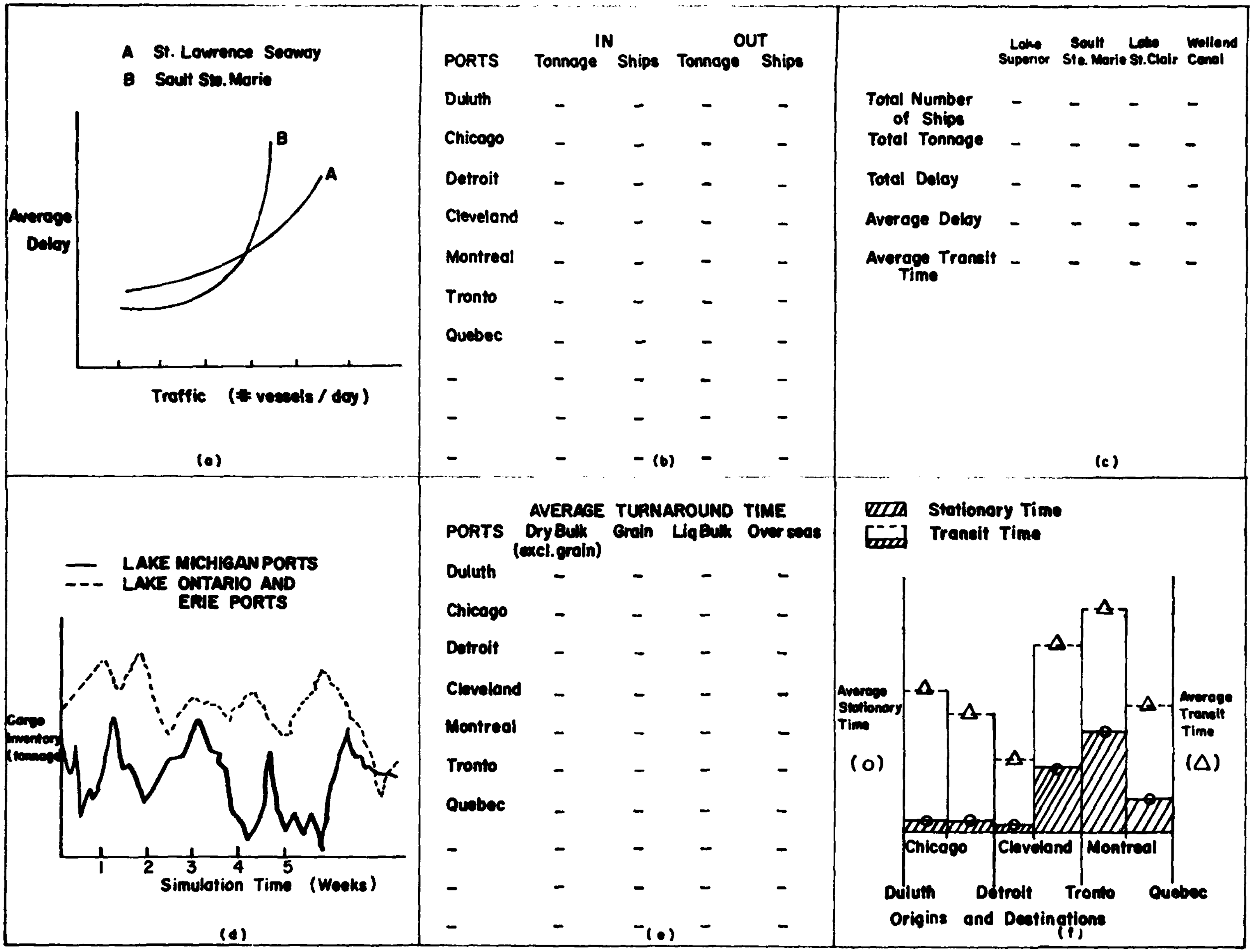

Figure 11. Representative Output From GL-SLS Run
Using NETSIM II-PROSIM Model

output parameters. These data should be used to validate further the model and also to calibrate it for the system of interest. A list of some of the relevant exercises follows.

With regard to validation:

a. steady state attainment for locks--i.e., how much warmup time is necessary for the locks to achieve a stable behavior?

b. steady state attainment for ports and other system elements,

c. output error analysis (tonnage and vessel flows, delays, transit times).

With regard to calibration:

a. handling of parallel lock systems such as at Sault Ste. Marie,

b. proper timing of bi-directional traffic,

c. timing cargo arrivals at ports,

d. determination of stable values for the model's built-in calibration factors,

e. port statistics analysis--how accurately must port facilities and their capabilities be represented?

f. vessel movement analysis.

The above suggestions are made in an effort to describe areas which may be improved to enhance the efficiency of the model. For example, in reference to steady state attainment, considerable time savings could be realized in repeated simulation experiments if the minimum warmup time for various system conditions could be statistically determined; however, such a determination is not a prerequisite to the use of the model. Again, the model's calibration factors could be set intuitively at "safe" levels; yet, this may be inefficient and unnecessary.

C. Other Potential Applications

The purpose of this section is to address the question of whether the NETSIM II-PROSIM simulation model can be used to analyze the characteristics of other waterway systems. Clearly, the model has been designed for the GL-SLS navigation system, whether it be the total system or a subsystem such as the Sault Ste. Marie locks. Can the model be applied then to other navigation systems such as the inland waterways?

If the question is whether the model can be applied as is to other waterways, the answer is definitely not. NETSIM II-PROSIM has been specifically tailored to the GL-SLS system and in fact, takes advantage of the system's specific characteristics in its program structure. Applying the model to a waterway system with different operating characteristics can only lead to erroneous results.

However, if the question is whether the model provides a basic capability for simulation studies of other waterways, then there is indeed much logic that is transferrable. The lock, reach, Monte Carlo Sampling and vessel handling logic could be used for a simulation on the inland waterways, for example, even though the vessel entity itself has a separate definition. Changing NETSIM II-PROSIM for other waterways is not a simple task and should be undertaken only after becoming thoroughly familiar with all aspects of the program.

VI. CONCLUSIONS

As stated in Section I, the objective of this entire simulation effort was the development of an analytical tool suitable for exploring the operating characteristics of the Great Lakes-St. Lawrence Waterway System. The preceding five sections of this report have served to document in summary form the data needs, structure and the output of the NETSIM II-PROSIM computer simulation model. Coupled with the previous works on the inland waterways at Penn State, this effort provides the Corps of Engineers with a set of shallow and deep draft navigation models which can be applied to a wide variety of waterway transportation problems.

The potential applications for the NETSIM II-PROSIM model involve primarily investigations into the impact of potential structural and nonstructural improvements. Typical issues that may be addressed by the model include:

- Given current and future traffic forecasts, what is the capacity of the waterway system? What and where are the constraints? What methods can be suggested to alleviate the constraints?
- What locks or lock subsystems need to be improved? In what manner? When? In what sequence? What are the benefits in terms of reduced delay and transit time?
- How can system efficiency be improved? Alternative locking rules? Artificial navigation aids? Channel deepening? To what extent can the fleet evolve to service a given flow of commodities within the existing system?
- How will changes in future fleet composition, commodity movements, different facility locations, ship scheduling procedures, dock strikes, etc., affect system parameters?

- How will season extension affect the pattern of cargo movements and facility and fleet utilization?
- What would be the effect of staging the closing of the season so individual ports, channels and lakes would close at substantially different times?
- How does channel depth affect ship cargo capacity, vessel speed and hence, the pattern of vessel movements?

To conduct research into some of the areas mentioned above might require modest changes in the model to fit the particular need. For example, investigations into the affects of various locking rules will necessitate insertion of the appropriate locking rule logic in the lock module. This is because the model could not possibly accommodate all possible investigations on a ready-to-go-basis. However, NETSIM II-PROSIM does provide the basic capability for general purpose simulations. It has been programmed in a modular fashion just for this purpose of providing flexibility so that incorporating different locking rules need not affect the logic for the port, reach, lake and support routines. This illustrates another major point about complex simulation models such as the current effort. Simulation capability for the GL-SLS system as for the inland waterways and any other case is a continuous undertaking since it would be folly to assume that the system interactions that are the object of simulation will forever remain static. There is an implied responsibility to reassess model parameters periodically and to evaluate the validity of the model in the future as the requisite data become available.

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