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AUG 81 M R HORNE, L A SHULTZ DACW35-80-C-0060

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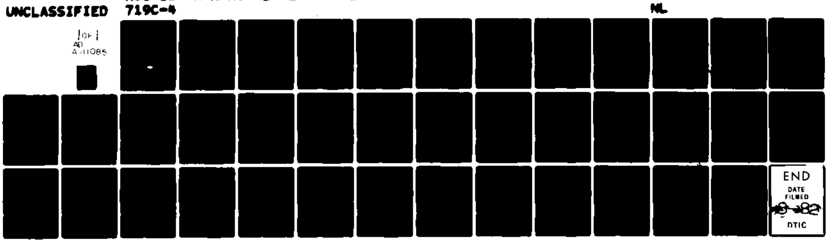

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Twelve lock capacity models were considered for use in the GL/SLS Regional Transportation Study. Primary criteria were expensive to run, program coverage of entire GL/SLS system and use of fortran language. The recommendation was to use the lock capacity study developed by the Corps of Engineers, developed in 1979 for the Navigation Season Extension Study.

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# EVALUATION OF LOCK CAPACITY MODELS FOR USE IN THE GREAT LAKES/ST. LAWRENCE SEAWAY REGIONAL TRANSPORTATION STUDY

TASK 8.1 Report of Great Lakes/St. Lawrence Seaway Regional Transportation Studies

Prime Contract DACW 35-80-C0060

August 1981

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Submitted to

Department of the Army
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# 1. SUMMARY

Twelve previously developed lock capacity models were considered for use in this GL/SLS Regional Transportation Study. A multi-phase screening process was used to determine which model should be recommended to the Corps of Engineers for this study. One model, the Welland Canal Lock Model, was dropped from further consideration primarily because the model is not available, but also because it is an extremely complex, multi-purpose model that is very costly to run.

Since the scope of work for the study requires that the lock capacity model be delivered upon completion of the study in standard ANSI FORTRAN, it was judged impractical, in terms of the time and financial constraints imposed upon the program, to redevelop a program written in some other language to FORTRAN. On this basis of programming language, the INSA LOKCAP and the Penn State MCDD, NETSIM I, and NETSIM/PROSIM models were eliminated from further consideration. Models which were developed for barge-tow applications rather than deep-draft systems were dropped from further consideration since extensive programming revisions would be required to adapt these models to the GL/SLS System. The models which were eliminated on this basis include the WATSIM Model, the LOKSIM Model, and the Bronzini, or LOKSIM II, Model.

Further screening of the remaining four models required a closer investigation of their internal characteristics. In very general terms, the SPAN Model, the Winter Rate Model, and the Sabin-Davis Model were judged to be more complex, and therefore more expensive to run, than is necessary for the purposes of the present study. This analysis, therefore, results in the recommendation that the Lock Capacity Model be used for the study of capacity improvement alternatives in this GL/SLS Regional Transportation Study. The major advantages offered by this model include:

- It is inexpensive to run ($5.00/run); a needed requirement for alternatives analysis.
- One program covers the entire GL/SLS System but does it in an individual manner at each set of locks without a loss of detail.
- It is written in a widely used language--FORTRAN.

- Output is extensive enough to make an independent decision, but not overloaded with extraneous detail.

- Input requirements are concise but cover the required detail.

- It views the locking times as functions of vessel class, direction, and constraining or nonconstraining for size of lock (Soo Lock).

- It permits the investigation of the impact of season extension on vessel and lock operation and lock capacity.

- It has an internal fleet mix model generator by commodity, which starts with a validated fleet mix and modifies it to take into account increases (decreases) in commodities, tonnages, new construction, shipbuilding constraints, and retirement of older ships. This fleet mix generator lends itself to modification as discussed in the Task 5 Report.

- It permits the redistribution of cargo commodities (within normal season and to extended season).

- It permits cargo tonnage to be input as a function of season extension.

- It permits the occurrence of required lockages for pleasure craft and ice lockages.

- It permits the investigation of the impact of vessel utilization on lock capacity.

- The programs are well-documented and have been validated against actual SOO, WELLAND CANAL, and ST. LAWRENCE RIVER locking records.

## 2. INTRODUCTION

The Great Lakes/St. Lawrence Seaway System (GL/SLS) provides a shipping link between the deep water of the Atlantic Ocean and ports 2400 miles inland on the American continent. In that distance there are sixteen sets of locks that lift ships from sea level to an elevation of 600 feet in Lake Superior. Figure 1 is a schematic cross-section of the GL/SLS System. Figure 2 shows the area covered by the system.

In very general terms, the GL/SLS System can be thought of as a series of locks, connecting channels, and harbors. Generally, for navigation systems equipped with locks, the traffic capacity, defined either in terms of annual tonnage or annual vessel transits, is constrained by the locks. Prior capacity studies of the GL/SLS System have indeed shown the locks to be the constraining element of this system. As the annual tonnage shipped on the GL/SLS navigation system continues to increase in the future, the demand for service at the locks will increase accordingly, and as the capacity limits of the system are approached, vessels will begin to experience long waiting times and long vessel queues at the locks.

Any transportation system interested in serving its customers over the long term must plan to provide an expanded capacity when the need for such capacity is required by the system's users. For a simple system having one major constraining component, the removal of the constraint at that one point removes the system constraint. For a more complex system, such as the GL/SLS navigation system, the multiplicity of locks, connecting channels, and harbors presents a more challenging assignment to the planners addressing the removal of system capacity constraints over the long term. An analysis of the entire system is required to ensure that removal of a constraint at one feature or location does not simply result in movement of the constraint to another feature or location with relatively little, if any, improvement in overall system capacity.

With such considerations in mind, the North Central Division of the U.S. Army Corps of Engineers initiated a study entitled, "Great Lakes/St. Lawrence Seaway Regional Transportation Studies," having as its primary objective the development of a sound documented working tool for use in analyzing GL/SLS regional transportation improvement alternatives. This report documents the work of Subtask 8.1 of this program, consisting of an evaluation of existing lock capacity models and the selection of a preferred model to be used as the working tool for evaluating non-structural and structural alternatives in terms of capacity expansion.

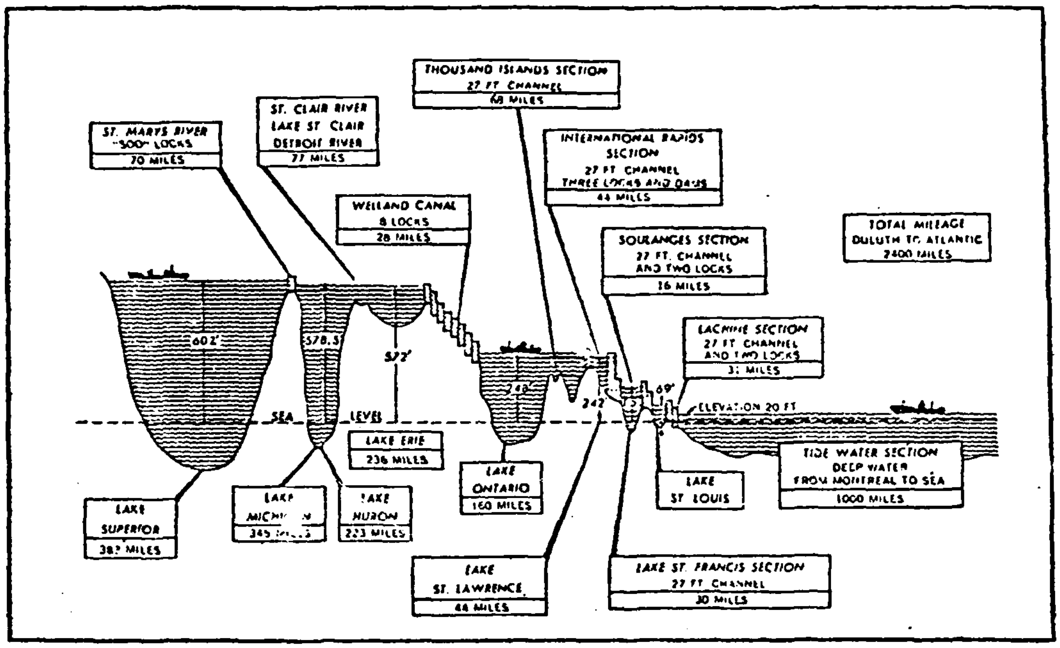


FIGURE 1. PROFILE OF GREAT LAKES-ST. LAWRENCE NAVIGATION SYSTEM

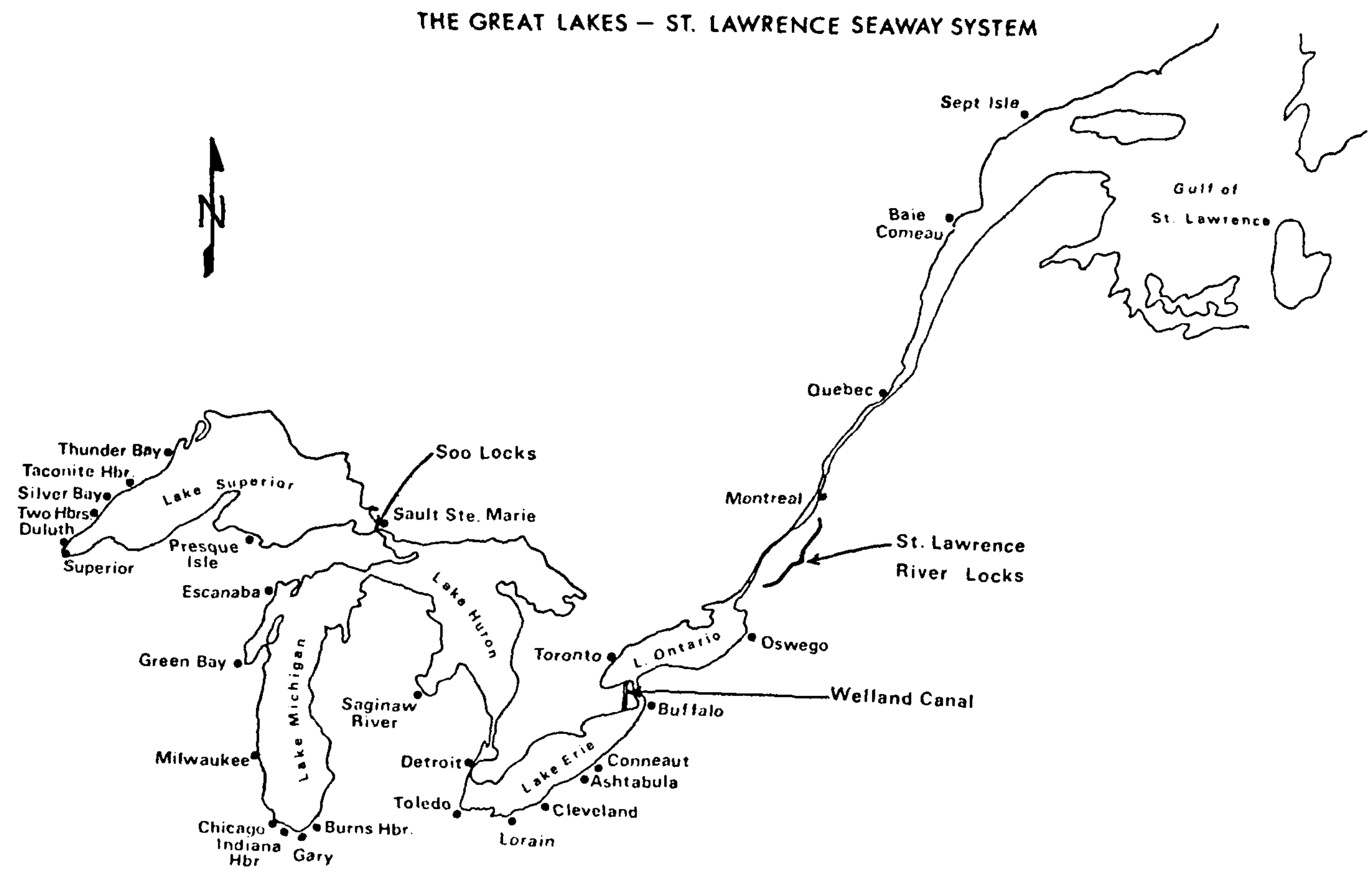


FIGURE 2. THE GREAT LAKES - ST. LAWRENCE SEAWAY SYSTEM

## 3. GENERAL COMMENTS ON COMPUTER SIMULATION

Computer simulation is a fast and efficient method of deriving some understanding of large complex systems that would be too cumbersome to model physically. Computer simulation models and the systems they simulate can be classified by a few parameters. Dynamic models have time dependent variables, whereas static models do not. On one end of a scale, deterministic models are analytical with unique-valued variables and solutions. On the other end of the scale, stochastic models have all variables defined by probability distributions. Most real systems fall between these bounds.

The problem of lock capacity is an unsteady queuing problem, which means the interarrival time of ships at the locks is a random distribution. Therefore, queues grow and shrink, and there is a nonzero probability that any ship will experience a delay time before being processed. This system, then, is a stochastic system, which is part of a broader class of dynamic systems of commodity flows through finite channels.

In general terms, there are two approaches to the development of a simulation which is applicable to this problem. One approach would be to, in essence, actually build the whole system in the computer, put ships in it, and keep a record of every event that happens. The second approach would be to derive equations, empirical or otherwise, which characterize the system. The first approach is called the discrete event approach because every event is recorded as a separate piece of data. Events cause the status of the system to change at a discrete point in time. These system changes occur when there is a change in the state of an entity such as a vessel or lock. An entity is said to be in a particular state when its attributes have specified numerical values, such as position or draft. These events occur instantaneously; i.e., in zero simulated time. This approach usually rests heavily on the Monte Carlo technique which uses psuedorandom number sampling of the statistical distribution of a particular variable. This frees the user from the task of developing and inputing large lists of such things as fleets and interarrival times, but still can effectively generate the randomness as well as the proportionality of different inputs. The advantage of discrete event simulation is that it can be as complex, and take into account as many factors, as wanted. One disadvantage is that computational time has to be long enough to allow the simulation to warm up and ready steady-state and also give a good distribution in the steady state period. Until this warm up time is completed, the transit times or other simulated values will be inaccurate and show large variations.

Compilation warm up time for large system simulations can run on the order of 10 minutes. Memory storage requirements can be considerable. One particular system simulation with 22 ports, 12 commodities, 1000 total vessels, 10 locks, 50 route branch points (nodes), and 15 reaches requires 241K bytes of storage.

The raw data produced by discrete event simulation typically consists of an event log that must be statistically analyzed before any meaningful output is generated. This can be done by a processor module in the program, or a separate post-processing program developed specifically for that purpose. Note that the example system storage requirement above does not include the post-processor. To run that particular system and that particular model post-processor requires 242K bytes of storage.

Discrete event simulation is better suited for large, complex network systems that can't be analyzed any other way, or simulations where all known factors are accounted for and what is required is a sensitivity analysis for minute variable changes. Another point to consider is that the model, since it uses statistical data, is no better than the data base, regardless of model complexity. So in many cases the question to ask is why use a large, complicated model to bludgeon the problem when the data might be lacking?

The second approach, queuing theory, is related to the discrete event approach in that it also accounts for statistical distributions of variables. One way of looking at the relation between the two methods is that the equations developed in the queuing theory characterize the queuing data generated by discrete event simulation. For a very brief introduction to queuing theory, these equations, which focus on unsteady arrival rates, delay time, and length of queues, are derived from two important concepts; Little's Result and Conservation of Flow. Little's Result, the validity of which has been established, states that the average number of customers in a queuing system is equal to the average arrival rate of customers to that queuing system times the average time spent in that queuing system. Conservation of Flow states that the flow into a system must equal the flow out of a system; i.e., nothing can be created or destroyed. If one studies a system where the interarrival times and exit times are exponentially distributed and there is only one server, one finds, analytically, that for average interarrival times greater than or equal to the rate at which customers can be processed, queues and the time spent waiting in the queue become infinite; but for average interarrival times less than the processing rate, the average waiting time approaches infinity as average interarrival times approach the processing rate. This bit of background illustrates that what we know through the personal experience of waiting in line can be modeled by, and derived from, the equations of queuing theory.

Therefore, for modeling the same system, queuing theory would be much faster and consequently cheaper to run than discrete event simulation. Discrete event run computer costs are typically over 100 dollars, while queuing theory runs are typically under 10 dollars. For problems where long range forecasting is needed, which means many runs and a lot of variable changes, queuing theory is a better choice. Another advantage with queuing theory modeling is that Monte Carlo techniques can still be used. As was said before, queuing theory just deals with the queuing, so that if some random variable distribution would be better generated rather than input, Monte Carlo techniques are still applicable.

In terms of the operational aspects of computer simulation, there are several simulation languages that can be used. Some languages, such as FORTRAN, SIMSCRIPT, and GPSS are independent languages having their own compiler. Other languages are based on one of the independent languages. For example, GASP is a set of FORTRAN subroutines.

The advantage of using FORTRAN or any FORTRAN based language is that FORTRAN is a standardized, general purpose language that is widely used and taught. Also, if a program is written in a standard version of FORTRAN, it is largely machine independent. However, there are always some problems moving a program from machine to machine. FORTRAN is more flexible than other languages because programming can be done without regard to the type and level of detail of the flowcharting. Also, the number of library programs or subroutines is only limited by the size of memory available.

SIMSCRIPT and GPSS have the advantage of being developed specifically for simulation purposes, however they were also originally designed for use on specific computers.

# 4. DESCRIPTION OF THE LOCK CAPACITY MODELS

This section of the report contains a general description of each of the twelve models evaluated.

## 4.1 Penn State Waterways Simulator - WATSIM

WATSIM is a computer simulation model written in the FORTRAN programming language whose purpose is to provide a general simulation capability for any inland waterway subsystem. WATSIM, therefore, deals with barge traffic and its characteristics are distinctly different from models developed for deep draft systems.

WATSIM operates in conjunction with another program, TOWGEN (for tow generation), in an effort to aid investigation of system operating characteristics as a function of traffic volumes, service times, and other system variables. The model was developed for use by the U.S. Army Corps of Engineers as a portion of a total waterway systems analysis study.

The actual simulation is carried out via a main scheduling mechanism which processes each individual tow, on a chronological event basis, as it proceeds from origin to destination. Required inputs consist of:

- Tow list (from TOWGEN)
- Frequency distributions for locking time components
- Description of the waterway system
- Waterway transport equipment characteristics
- Run parameters

The output produced by the model is displayed on twelve tables, and deals with many aspects of waterway operation:

- The number of barges and towboats originated and terminated at ports by equipment type
- At each lock within the simulation system, the total tows and barges processed as well as tonnage, delays, process times, queue lengths, and lockages by type

- Frequency distributions of delays and headways

- Summaries of equipment usage, total equipment usage, and overall system delays.

Particular emphasis is placed upon system-wide displays on both a tow and facility basis.

Finally, flexibility exists in the modular design of the model. This modular design allows for the insertion or removal of any program segments necessary to provide a desired simulation capability.

## 4.2 Penn State Lock Simulator - LOKSIM

LOKSIM is a computer simulation model written in the FORTRAN language which simulates a single inland waterway lock. The model is capable of simulating a multiple chamber system of up to three separated or adjacent chambers which serve both commercial tow and pleasure craft traffic. LOKSIM is a very general program which is intended to be used to investigate lock operating characteristics as a function of traffic volume, service times, and queue disciplines. The model was developed for use by the U.S. Army Corps of Engineers as a portion of a total waterway system analysis program.

Simulation is performed by selecting a vessel for service based on some predesignated selection procedure, assigning it to a chamber according to a variable assignment logic and computing a processing time based on a Monte Carlo sampling from locking time distributions. Changes in all three steps are permitted because of the modularization of the program into subroutines.

The input to LOKSIM consists of six main data groups:

- Tow list
- Pleasure craft list
- Run parameters
- Desired queuing disciplines
- Lock chamber information
- Tow codes.

Tabular output consists of:

- Numbers of tows, barges, and pleasure craft processed
- Number of lockages of each type
- Lockages consisting entirely of tows or pleasure craft (multiple vessels of mixed type occur per lockage)
- Delay means and variances
- Maximum delays and queue lengths
- Delay frequency distributions.

## 4.3 Penn State Multiple Channel Deep Draft Model - MCDD

Performance data generated by computer simulation experiments can be used as the basis for comparative evaluation of alternative multiple channel, deep draft navigation facilities. MCDD, a generalized, discrete state, computer simulation model was implemented for studies of the St. Lawrence River and the proposed Niagara Canal paralleling the existing Welland Canal. A ship-event orientation is used with GPSS 360 to simulate two-way movements through canal reaches under a no-passing rule, and through locks which are modeled in terms of eight distinct elemental operation times. A unique "Assignment Map" technique is used to control ship movements through a network of multiple locks and reaches. Equations for predicting transit times through alternative canal branches are formulated by statistical analysis based on an "Experience Data Bank".

The five primary inputs are:

- Separate system arrival rates for upbound and downbound arrivals
- Reach transit time distributions for each reach
- Lock time element distributions for each lock (regardless of vessel class)
- Assignment or travel direction decision rule to control the channel choice at the branch points
- Fleet mix.

These inputs are either randomly sampled in the program (Monte Carlo) or are functions of the randomly sampled variables. Output contains lock utilization, queue lengths, and transit times.

## 4.4 Penn State - NETSIM/SHIP

NETSIM is a computer simulation model written in the SIMSCRIPT programming language whose purpose is to provide a general simulation capability for any network composed of links and nodes. The current use of NETSIM in multiple channel deep draft navigation systems has been designated as NETSIM/SHIP. The model was developed for use by the U.S. Army Corps of Engineers with applications on the Great Lakes.

Ships are handled in NETSIM/SHIP on a chronological event basis as they engage in their journey from origin to destination. Simulation of ship processing at system facilities (such as locks and reaches) is carried out through the use of distinct link modules. Channel choice decisions where alternative routes exist are handled by a decision-making mechanism based on the calculation of expected transit times for each route.

Required inputs consist of:

- Run parameters
- System size parameters (number of ports, lakes, locks, etc.)
- System entity descriptions (descriptions of ports, lakes, reaches, locks, and vessels; locking time distributions take into account only 3 vessel classes)
- Network configuration descriptions (map of network configuration).

The output produced by the model consists of data for the formulation of the channel choice mechanism in the first form, and an event by event description of the actual simulation in the second form. The latter form provides a permanent data base from which exactly tailored statistical reports can be generated.

## 4.5 Penn State - NETSIM II/PROSIM

NETSIM II/PROSIM was developed to study the operating characteristics of the Great Lakes and St. Lawrence Seaway navigation system. 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 non-structural 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.

The input to NETSIM II is made up of the following basic data groups:

- Commodity arrival list at ports*
- Vessel fleet data*
- Description of navigation facilities - lakes, reaches, locks, and ports
- Description of navigation network
- Run parameters.

Two of the support programs can be used to generate the starred items. The third support program generates the itinerary for the vessels. The fourth support program processes the experience data base (EDB) which becomes the channel choice mechanism for the final simulation.

PROSIM processes the event log produced by NETSIM II and can produce fifteen different tables detailing performance results for locks, ports, lakes, and reaches. This output comprises both accumulated event tabulation and calculated output such as lock utilization.

## 4.6 COE Sabin-Davis Lock Model

The function of this model is to provide a simulation capability for the analysis of delays at the Soo Locks. This model consists of:

- A set of event programs that describe the system's operating rules
- Lists and matrices that store data
- An executive routine that directs the flow of information and control within the model.

These form an operating program whose performance reflects that of the simulated system. The final element, the executive routine, is a group of FORTRAN subroutines that are collectively referred to as GASP II subroutines.

The only exogenous events, events fed to the model externally, in the model are the arrivals of the first vessels in the upbound and downbound direction. There are many endogenous events, events generated within the program, in the model such as future arrivals, lockings, queuings, and lock selections.

The input data that define the operating environment for the events and program consist of:

- Run parameters
- Vessel data
- Tonnage and route data
- Lock data
- Vessel lock preference.

Of the above data, random number streams sample the following specific distributions:

- Vessel class upbound
- Vessel class downbound
- Empty upbound

- Empty downbound
- Loaded upbound
- Loaded downbound
- Interarrival time upbound
- Interarrival time downbound.

Locking time components are a function of vessel class and direction. The interarrival rate distributions are Poisson distributions about a mean calculated from cargo projections.

The output consists of:

- Lock transits and delays
- Lock delay distributions
- Estimated monthly tonnage flow
- Estimated monthly delays and cost
- Lock utilization.

### 4.7 SLSDC SPAN Lock Model - SPAN

This program is a dynamic simulation that is capable of predicting individual movements of all ships in the St. Lawrence River at any given time and the influence of various improvement concepts and levels on those movements.

The model keeps track of each ship as it passes through the St. Lawrence River. Consequently, statistics such as time spent waiting for locks, waiting for visibility to improve, waiting for high winds to die down, waiting at anchor due to nightfall, and being stuck in the ice are available, as well as the time a ship requires to transit each subreach and the entire St. Lawrence River.

The input data for this model is rather extensive. Briefly, it consists of:

- Run parameters - length of simulation, weather update times, ice update times, number of reaches, etc.

- Subreach array - mileage, speed limits, passing, widths, lock parameters, etc.
- Ship class array
- Anchorage array - location, type, capacity, etc.
- Hullform coefficients - for calculating ice-breaking resistance
- Lock equipment array - deicing equipment
- Ship arrival list
- Historical data (5 years) on navigation aid removal, weather parameters, ice type, and coverage.

Extensive output is also produced:

- Vessel traffic control records
- Voyage statistics by Class
- Ships per day statistics
- Subreach statistics
- Hydraulic conditions
- Ice conditions
- Lock transit records for each lock.

## 4.8 COE Winter Rate Lock Model

The computer programs which comprise the simulation that was developed for the WINTER RATE STUDY are:

(1) Transit Time Generation Model

(2) Ship Processing Model

(3) Freight Rate Model.

Since the input of each of these programs is rather extensive, only the operating characteristics plus the output data have been outlined below.

Transit Time Generation Model: The Transit Time Generation Model converts the open water and raw ice conditions data, and ship class data, into transit times for each ship class in each connecting reach. These reaches were selected to form the major domestic and world-wide trade routes on the Great Lakes-St. Lawrence Seaway System, including 13 overseas "world areas".

Ship Processing Model: The Ship Processing Model, using the transit times generated by the Transit Time Generation Model, simulates the movement of ships and cargo within the system and to and from the overseas ports. It compiles statistics for each class of ship operating on each route for use by the Freight Rate Model. In simulating these movements, the model incorporates the interactions between ships and the system, and between the ships themselves, such as:

- Increased transit, lockage, and port times due to the presence of ice (extended season)

- Port and lock limitations and constraints

- Draft limitations

- Speed limits

- Daylight only navigation

- Queues forming, expanding, and diminishing at lock and port facilities

- Ships getting stuck and having to wait for icebreaker assistance.

Freight Rate Model: The Freight Rate Model translates the statistics generated by the Ship Processing Model, along with vessel data, into the following route-by-route vessel operating cost and performance measures:

- Total tonnage
- Time underway (domestic and world-wide)
- Time stopped (domestic and world-wide)
- Number of trips (total and broken into ships with bow thrusters and ships that are self-unloaders)
- Crew costs
- Maintenance and repair costs
- Stores and supplies costs
- Insurance costs

- Overhead costs
- Towing costs
- Lay-up charges
- Fuel costs
- Gallons of fuel consumed
- Tolls
- Total operating costs
- Operating cost per ton
- Operating cost per hour
- Operating cost per ton-mile
- Revenues per ton-mile
- Taxes per ton-mile
- Depreciation per ton-mile
- Profit per ton-mile
- Required freight rate
- Per-unit required freight rate (normalized to the normal season value)
- Revenue ton-miles (ton-miles on which cargo was carried)
- Total miles with cargo
- Total miles backhaul
- Dollar-miles (the value of the cargo times distance moved)
- Average transit time per trip
- Average transit time per ton-mile
- Average length of haul (miles).

## 4.9 Welland Canal Simulation

The Welland Canal Simulation is an interactive discrete event simulation which requires a large amount of storage (300K) and is relatively expensive to run ($100/run for a 120 day simulation). As part of the basic operating characteristics of the model, the demand factors: vessel arrival characteristics, arrival numbers and arrival patterns and the selected scheduling decisions, are input into the model. The model then performs the discrete event simulation with knowledge of the following Canal characteristics:

- Geography of locks
- Geography of reaches
- Human variation
- Day/night differences

- Effect of draft/beam, etc.

- Lockage interactions.

The model output consists of service times including canal transit times, canal delay times, and waiting turns. These operating characteristics are developed specifically for the Welland Canal from existing data collected at the Canal.

The model is basically similar in approach to other discrete event simulations in that it starts with the operating characteristics of the system, introduces a demand on that system via vessel arrival patterns and characteristics, and develops service times. The vessel characteristics and arrivals are not internally generated from cargo projections but are pseudorandomly generated within a predefined distribution (Monte Carlo technique).

The output of the model consists of lockages/day, round trip waiting turn time, and round trip transit time.

## 4.10 INSA Lock Model - LOKCAP

The Lock Capacity Function Generator (LOKCAP) is a computer program that determines delay times through a double chamber lock. The program computes the parameters of a hyperbolic function that returns the delay incurred at a lock as a function of the daily traffic volume that passes through the lock. LOKCAP has been designed to consider double chamber locks where the interference between chambers is explicitly taken into account in determining the parameters. LOKCAP may also be used to obtain information about the individual chambers including the chamber function parameters and the probabilities of various approach/exit combinations.

LOKCAP was developed for an inland waterway lock and is, therefore, most applicable to barge and tow traffic rather than deep draft vessel traffic.

LOKCAP requires input as follows:

- System descriptions

- Locking time components (not a function of vessel size, i.e., barges)

- Tow and barge parameters

- Run parameters.

LOKCAP produces three types of output reports: echo report, chamber report, and lock delay report. The echo report plays back all the input. The chamber report covers all the separate chamber statistics such as queue sizes and delay interarrival time, and traffic volume. This is without regard to interference effects between chambers. The third report includes all the output that is modified by considering the interference effects.

## 4.11 COE Lock Capacity Model

The Great Lakes/St. Lawrence Seaway (GL/SLS) Lock Capacity Model was used as a planning tool to determine if, or when in time, the Soo, Welland, and St. Lawrence River Lock Systems can be expected to reach capacity as a function of:

- Cargo traffic projections
- Vessel fleet projections
- Vessel operating characteristics and locking times
- Lock operating characteristics
- Length of navigation season
- Available operating time (weather delays, lock malfunction delays, daylight-only navigation)
- Pleasure craft and non-commercial vessel locking requirements
- Winter vessel and lock operating procedures.

Overall, the GL/SLS Lock Capacity Model can be described as a queuing model which analyzes steady-state lock operations and vessel-lock interaction. For a given set of the above-listed data and a specific year, the GL/SLS Lock Capacity Model generates the following output for 14 separate time periods (10 months plus early and late April, and early and late December):

- Cargo transported by commodity and direction
- Vessel operating fleet

- Yearly vessel transit demand by vessel class, commodity, and direction

- Daily vessel transit demand by vessel class and direction

- Lock cycle time by direction (mean and standard deviation)

- Average vessel waiting time by direction

- Average vessel queue length by direction

- Lock utilization

- Vessel delay costs.

Using this output, an independent decision can then be made as to whether or not a capacity condition has occurred based on a prescribed capacity criteria such as average vessel waiting time, average vessel queue length, and lock utilization. The model is very inexpensive to run, costing approximately $5.00 per run for a single run submitted in batch, and approximately half of that amount if a series of runs are submitted in batch.

### 4.12 Bronzini Model - LOKSIM II

The single lock simulator called "LOKSIM II" was initially developed for a single lock chamber. Dual chamber locks are analyzed by combining the results of separate single chamber analyses in a manner similar to that used in LOKCAP. The total traffic using such a lock is preassigned to the two chambers. Interactions between this assignment and the chamber simulations are necessary in order to balance the chamber delays.

LOKSIM II makes use of a preprocessor to generate a tow list containing the commercial barge traffic to be locked through. This preprocessor has features similar to those in the TOWGEN model.

Input consists of:

- Run data

- Lock data

- Chamber class data

- Tow data
- Recreational vessel data
- Light boats
- Commodity codes.

In the chamber data there are 41 locking time distributions that deal with several types of barge lockages.

Output includes:

- Input playback
- Traffic and delay summary
- Queuing statistics
- Commodity summary.

## 5. SELECTION OF THE PREFERRED LOCK CAPACITY MODEL

As stated in the scope of work for the project, the objective of this subtask is to evaluate existing lock capacity models in terms of their attributes, capabilities, and limitations. In order to reach this objective a multi-phase screening process was used to determine which of the twelve lock capacity models summarized in the previous section of this task report is to be recommended to the Corps of Engineers as best meeting the needs of the GL/SLS Regional Transportation Study.

The availability and completeness of information obtained on the twelve lock capacity models investigated varies widely. The results of a search for information on the models is summarized in Table 1. In searching for information on lock capacity models it was determined desirable to have six specific sources of information for each model consisting of a report on the model, documentation, a program listing, a user's manual, sample input files, and sample output displays. As summarized in Table 1, this complete listing of information is not available for any of the twelve models investigated. The two models coming closest to having a complete availability of information are the SPAN Model and the Lock Capacity Model, both of which are complete except for a detailed user's manual. Obviously, any lack of information on a particular model makes that model less desirable for use in the program, since more time and effort would be required to make that model operational for use in this study.

As the search for information on the lock capacity models progressed, the opportunity presented itself to discuss the advantages and disadvantages of the models for the purposes of this study with many of the individuals most familiar with the workings of the models at the present time. The individuals who provided a substantial amount of help in this regard are identified in Table 2. While not specifically identifying comments with individuals, the evaluation procedure developed in the following paragraphs incorporate the views of these individuals as related to the application of the model to the present project.

Table 3 summarizes the major features and characteristics of the twelve lock capacity models evaluated for use in this program. The models are organized in the table according to the approximate year in which the model was developed. The models are then evaluated in terms of methodology, application, the viewpoint of the model, the relative cost per run, the programming language used, whether or not the model is currently operational,

TABLE 1. SUMMARY OF THE AVAILABILITY OF INFORMATION ON THE LOCK CAPACITY MODELS INVESTIGATED.

| MODEL | REPORT | DOCUMENTATION | LISTING | USERS MANUAL | INPUT FILES | SAMPLE OUTPUT |
|---|---|---|---|---|---|---|
| Penn State Models | A | Incomplete | NA | Incomplete | Incomplete | NA |
| Sabin-Davis | A | Incomplete | A | Incomplete | A | A |
| SPAN | A | A | A | NA | A | A |
| Winter Rate | A | Incomplete | A | NA | A | A |
| Welland Canal | Paper | NA | NA | NA | NA | NA |
| INSA LOKCAP | A | Incomplete | A | NA | Incomplete | A |
| Lock Capacity | A | A | A | NA | A | A |
| Bronzini-LOKSIM II | Paper | NA | A | NA | A | A |

A - Available
NA - Not available

TABLE 2. INDIVIDUALS INTERVIEWED IN THE MODEL EVALUATION PROCESS.

| INTERVIEWEE | AFFILIATION |
|---|---|
| J. Carrol | The Pennsylvania State University |
| L. Daggett | Corps of Engineers, WES |
| J. Lane | Corps of Engineers, Ft. Belvoir |
| B. McCleod | St. Lawrence Seaway Authority |
| D. Robb | St. Lawrence Seaway Development Corporation |
| D. Ward | Corps of Engineers, NCD |

TABLE 3. COMPARISON OF MAJOR FEATURES AND CHARACTERISTICS OF TWELVE LOCK CAPACITY MODELS

| | WATSIM | LOKSIM | MCDD | NETSIM I | NETSIM/ PROSIM | SABIN | SPAN | WINTER RATE | WELLAND | LOKCAP | LOCK CAPACITY | BRONZINI (LOKSIM II) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR DEVELOPED | 1971 | 1971 | 1971 | 1972 | 1973 | 1975 | 1975 | 1975 | 1976 | 1978 | 1979 | 1980 |
| METHODOLOGY | DE | DE | DE | DE | DE | DE | DE | QT | DE | QT | QT | DE |
| APPLICATION | BT | BT | DD | DD | DD | DD | DD | DD | DD | BT | DD | BT |
| VIEWPOINT | SY | SI | SY | SY | SY | IN | IN | SY | IN | SI | IN | SI |
| RELATIVE COST PER RUN | HI | HI | HI | HI | HI | HI | HI | HI* | HI | LO | LO | HI |
| LANGUAGE | F | F | G | S | S | F | F | F | G | S | F | F |
| CURRENTLY OPERATIONAL | Y | N | N | N | N | Y | N | N | Y | Y | Y | N |
| VARIABLE DETERMINATION | | | | | | | | | | | | |
| LOCKING TIME | DIM | DIM | DIM | DIM | DIM | DIM | COM | IP | DIM | DI | DI | DIM |
| ARRIVAL TIME | IP | IP | IP | IP | IP | DIM | IP | COM | DIM | COM | COM | IP |
| FLEET MIX | IP | IP | IP | IP | IP | DIM | IP | IP | DIM | IP | DI | IP |
| VALIDATED | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

* Due to factors other than logic.

KEY:
F - FORTRAN
G - GPSS
S - SIMSCRIPT
Y - Yes
N - No
BT - Barge & Tow

DD - Deep Draft
QT - Queueing Theory
DE - Discrete Event
HI - High
LO - Low
SI - Single Point

SY - System
IN - Intermediate, covers a part of the System larger than one lock
IP - Input
DIM - Distribution input, Monte Carlo sampling
DI - Distribution input, but not Monte Carlo sampled
COM - Computed

how the major variables of locking time, arrival time, and fleet mix are determined, and whether or not the model has been validated.

Under methodology, the table indicates whether the model is based upon a queuing theory approach or a discrete event approach. As indicated in a previous section of this report, the methodology used has a major impact upon the applicability of the model to the problem of concern in this project and, in addition, in general terms determines the relative cost of running the program.

Under application, the table summarizes whether the model was originally developed primarily for inland waterway use concerned with barge and tow traffic, or whether the original development of the program was oriented towards deep draft vessels, such as are the concern in the present program.

Under viewpoint, the table indicates whether the model takes a single point or system approach to the problem. In a system where the constraining element that determines capacity is known, it is generally not necessary to model the entire system. On the other hand, a single point model applicable to only one lock system might be too restrictive in terms of application to several lock systems, and too detailed in terms of complexity and running time to be practical for use in the present program. What is desirable for use in the present program is a model that takes into account the important factors at each lock system and which can be used individually for each lock system, rather than requiring separate models to be developed for the Soo, Welland Canal, and St. Lawrence River Locks.

The determination of the relative cost per run for each model was based upon an evaluation of the modeling technique used in the development of each model and, in addition, comments obtained from the interviewees during discussions of the suitability of each model for the present project. The computer language in the programming of each model is very important since the work statement requires that the model selected be delivered to the Corps of Engineers in standard ANSI FORTRAN. Whether or not the model is operational on some computer at some location was also judged to be a major evaluation factor. Major differences also exist in the various models in terms of how the fleet mix is determined, how the locking time is determined, and how the arrival time for ships arriving at the locks is determined. In some cases, these factors are simply treated as input data, while in others they are computed in the program, while in still others they are treated as a distribution input with Monte Carlo sampling.

The final feature included in the table is that of validation. The standard procedure for determining whether or not a model accurately predicts events is to compare model results obtained for a case for which data already exists. Model validation is generally a two step process where the first step is concerned with a determination of whether or not the model is internally correct in terms of language, syntax errors, and data input, for example. The second step of the validation orocess is to compare the prediction developed by the model with existing data for a hindcast situation. All of the models considered in this program have been validated at one time or another, although in some cases the extent of the validation is not readily discernable from the available documentation.

The screening process resulting in the recommendation of a model for use in the present study was a three step process. The first step of the screening process considered major external factors such as availability, programming language, and the original application for which the model was designed. As indicated in Table 1, the Welland Canal Model developed by the Canadian St. Lawrence Seaway Authority is not available. Representatives of the St. Lawrence Seaway Authority qualified the unavailability of information by stating that complete documentation exists for the model, but it has not been prepared in publishable form. It was also pointed out that the model is a very large model requiring 300K units of storage in an IBM 370 computer, and is very expensive to run, on the order of $100 per run. The model is not just a capacity model but also covers system economics, and has capabilities for being used in training traffic controllers. There is no user orientation available for the program, and SLSA representatives stated that it takes them one full month to bring their own staff up-to-speed on the operation of the program. For these reasons, the Welland Canal Model was eliminated from further consideration for use in the present program.

The second external factor used in the screening process was that of programming language. Since the work statement for this project requires that the program be delivered in standard ANSI FORTRAN, it was judged impractical in terms of the time and financial constraints imposed upon the program, to redevelop a program written in some other language to standard ANSI FORTRAN. This eliminates the INSA LOKCAP Model and tnree of the Penn State Models, MCDD, NETSIM I, and NETSIM/PROSIM.

A third external factor is the original purpose of the development of the model, or the application of the model. Models that were originally developed for barge and tow traffic include numerous features that would be incorrect, inoperable, or unnecessary when the model is intended for use with deep draft vessels on the Great Lakes/St. Lawrence River System. Since other models are available which have been originally developed for deep draft navigation systems, it was determined that expending the major reprogramming effort to adapt barge and tow systems to deep draft systems was inadvisable. This resulted in the elimination from further consideration of the WATSIM Model, the LOKSIM Model, and the Bronzini (LOKSIM II) Model.

In the second screening phase, a closer investigation was made of the internal characteristics of the remaining models, which include the Sabin-Davis Model, the SPAN Model, the Winter Rate Model, and the Lock Capacity Model. The SPAN Model can be eliminated for a number of reasons. It was designed specifically for the analysis of extended season operations on the St. Lawrence River. It therefore includes ice routines and historical weather data that are not required in this level of detail for the capacity study of the GL/SLS System. The fleet mix is input as an arrival list, which means that for every cargo projection a new fleet mix must be hand calculated. Also, being a discrete event simulation, it includes ship interaction and transit statistics that are unnecessary for a capacity analysis. It is also an expensive model to run; a disadvantage for looking at the many alternatives required in the final task of this program.

The Winter Rate Model can be eliminated for some of the same reasons. This model considers every element in the system, not just the constraining elements; i.e., the locks. Therefore, it has much unnecessary detail in terms of the present program, which makes it expensive to run (≈$200 per run). Also, a new fleet mix must be hand calculated for each cargo projection, and at least one calibration run made to fine tune the fleet mix to ensure that the estimated fleet can carry the projected tonnage.

The Sabin-Davis Model is a discrete event simulation and is, therefore, relatively expensive to run. The Sabin-Davis Model was "clearly tailored to the unique specifications of the Soo Locks. The end product...is rather specific in nature, however, with minor adjustments, it may be applied to general parallel locking facilities studies". This model would require a significant level of modification in order to be used on a serial system, such as the Welland Canal or the St. Lawrence River, for which it was not designed. These reasons are sufficient to swing the final decision away from the Sabin-Davis Model and to the Lock Capacity Model.

As a further consideration, it is conceivable to use a combination of models, such as the Sabin-Davis Model for the Soo Locks, the SPAN Model for the St. Lawrence River Locks, and the Welland Canal simulation for the Welland Locks. Even beyond the substantial complications associated with running three models, these models have costs per run that are an order of magnitude larger than the cost of running the Lock Capacity Model. Also, the external costs would be increased because the Welland simulation would have to be run by SLSA personnel on their equipment.

The model recommended to the Corps of Engineers for use in this study as a result of this analysis is therefore the Lock Capacity Model. The major advantages offered by this model include:

- It is inexpensive to run ($5.00/run); a needed requirement for alternatives analysis.
- One program covers the entire GL/SLS System but does it in an individual manner at each set of locks without a loss of detail.
- It is written in a widely used language--FORTRAN.
- Output is extensive enough to make an independent decision, but not overloaded with extraneous detail.
- Input requirements are concise but cover the required detail.
- It views locking times as functions of vessel class, direction, and constraining or non-constraining for size of lock (Soo lock).
- It permits the investigation of the impact of season extension on vessel and lock operation and lock capacity.
- It has an internal fleet mix model generator by commodity, which starts with a validated fleet mix and modifies it to take into account increases (decreases) in commodities, tonnages, new construction, shipbuilding constraints, and retirement of older ships. This fleet mix generator lends itself to modification as discussed in the Task 5 Report.

- It permits the redistribution of cargo commodities (within normal season and to extended season).

- It permits cargo tonnage to be input as a function of season extension.

- It permits the occurrence of required lockages for pleasure craft and ice lockages.

- It permits the investigation of the impact of vessel utilization on lock capacity.

- The programs are well-documented and have been validated against actual SOO, WELLAND CANAL, and ST. LAWRENCE RIVER locking records.

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