COMPUTER SIMULATION - QUEUEING STUDY

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COMPUTER SIMULATION OF RAW MATERIAL RECEIVING FACILITY - QUEUEING STUDY

By

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ABSTRACT:

A computer simulation model was developed to simulate the receiving of raw materials at a dock for an integrated steel plant on the North shore of Lake Erie. The model was formulated to study queue build-up, berth waiting time and the effect of various unloading conditions on dock efficiency. A financial analysis, using present value techniques, was then applied to the model results in order to recommend an optimum berth staging plan under various economic conditions.

Historical data on raw material receiving at Hilton Works, Hamilton, were collected and used to develop mathematical functions to describe the random nature of vessel arrivals and berth times. It was determined from this data that vessel arrivals are described by a Poisson distribution and berth times are described by an Erlang distribution. The computer model simulates the dock operation by generating random numbers according to these distributions (Monte Carlo Simulation.) Coal and ore vessel arrivals are merged and respective service times

generated. Interferences occur and queues grow and diminish as the facility is simulated through the shipping seasons throughout its expected life.

Various unloading rates and vessel tonnages are simulated for a single and double berth operation and the associated waiting times and queue lengths are recorded for each alternative. An economic analysis is performed on the alternatives using present value techniques. The economic analysis indicated that the optimum time to expand the dock to a double berth occurs at a tonnage level of 15 million (coal + ore). To reach this level unloading rates of 10,000 TPH for ore and 8,000 TPH for coal would have to be achieved with an average vessel tonnage of 39,000 metric tonnes.

Reducing the unloading rates or average vessel tonnage would move forward the required construction of a double berth and would increase the present value for that alternative. This expansion date will also depend on future economic factors such as cost of capital and escalation rate.

The other important conclusion drawn from the economic analysis was that the receiving facility should be expanded in minimum feasible increments because of uncertain economic conditions. This concept dictates that conveyors be installed at minimum capacity, i.e. - belt width and drive size, to handle the first stage tonnage only with provision in the equipment to increase capacity by replacing narrow belts with wider ones and adding additional drive units. The timing for the stages is predicted on several factors, such as: life of the initial belt, tonnage forecast, ship delay costs, and most importantly future economic conditions. For example, it would be advantageous to increase the unloading capacity with a wider belt at the time the initial belt is worn out. Belt and drive staging will take place before the expansion to a second berth in order to defer the capital investment as long as possible. The conveyor system for the second berth can be similarily staged.

The study indicated that a good planning strategy would be to initially install a 1.8 m wide belt on 2.0 m wide machinery with 3 - 1,000 H.P. drives. This system would unload ore at approximately 7,000 t/hr. and coal at approximately 5,000 t/hr. This capability could be increased to 10,000 t/hr. for ore and approximately 8,000 t/hr. for coal by adding a 2.0 m wide belt and 1 - 1,000 H.P. drive unit. These rates would be compatible with the expected unloading rates of the future fleet. The decision to increase capacity should be considered when the initial belt is worn out or when delay costs and future economics dictate expansion before that time.

The study also indicated that it is poor strategy to design the second berth/conveyor system to be restricted to coal receiving only. The Computer simulation indicated ship delay time for the restricted berth to be approximately three times that for a system with capability to receive ore and coal equally at both berths on either conveyor and either stacker. It indicates that ore receiving is the most important capability and should not be restricted. Even though ore pellets unload more quickly the ore tonnage required is twice that for coal. Therefore, it is recommended to design a completely flexible system with full provision for expansion to higher unloading rates and larger vessels (850 ft.) and with provision to unload equally from either berth to either conveyor and to have the ability to transfer material between converyors at the head end of the stacker conveyor.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. A.A. Smith of the McMaster University Civil Engineering Department for his guidance and patience during the course of the study and preparation of this project report.

In addition, I thank the many knowledgeable Engineers at the Steel Company of Canada for their assistance.

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CHAPTER I

INTRODUCTION

Raw material receiving and storage is the 'life-line' of any steel making facility. This is especially true when the 'life-line' is a slender pier into the exposed and treacherous waters of Lake Erie.

The 'life-line' must receive sufficient raw materials during the shipping season to maintain the steel plant production for 12 to 13 months. For example, at a plant capacity of 12 million metric tons (steel-in-ladle) per year, it is necessary to receive approximately 2-39,000 metric ton ships per day, on the average, and unload each in the average time of 7 hours.

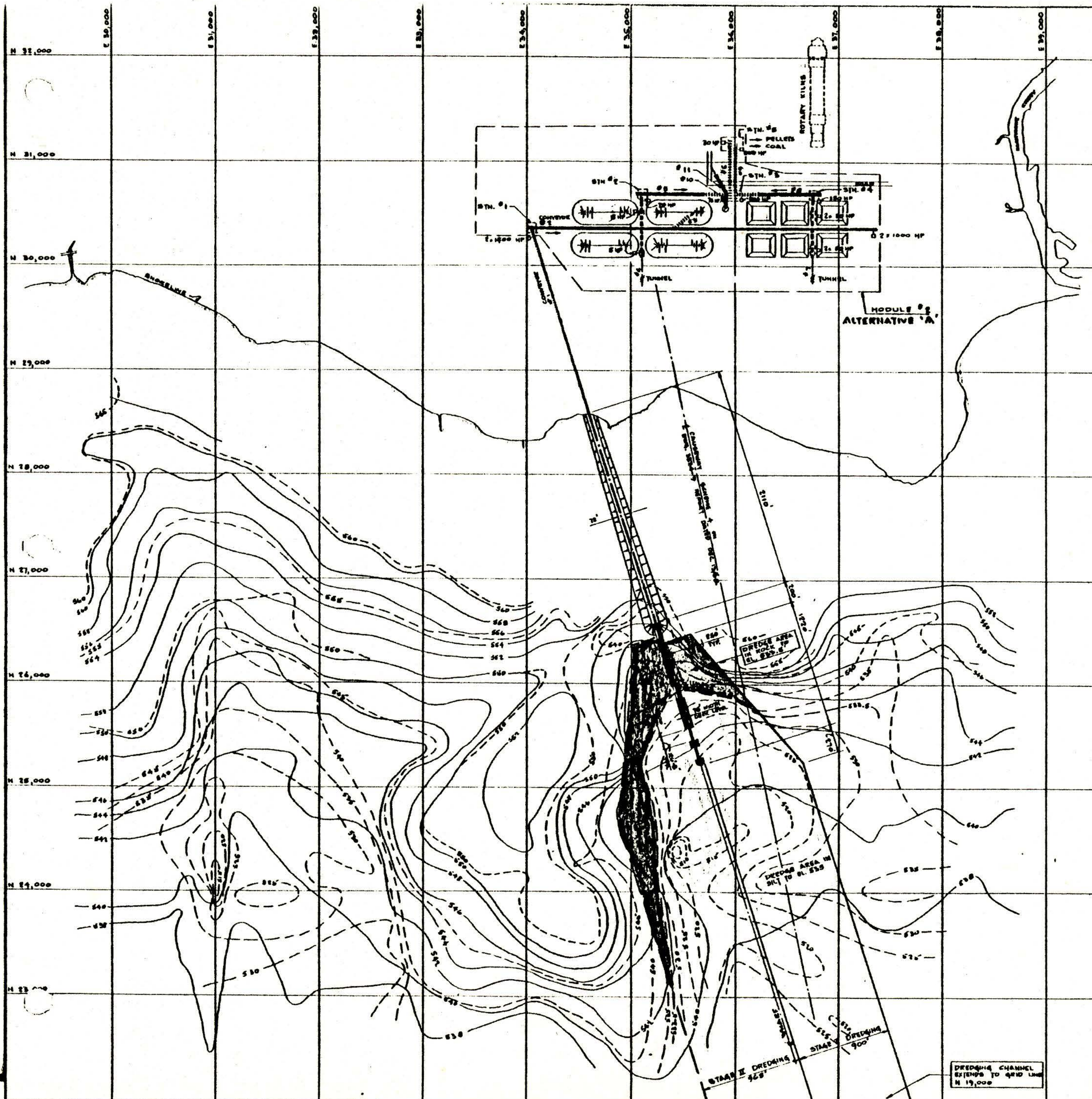
The efficiency of receiving raw materials will be affected by many factors, such as, weather, mechanical breakdowns and shipping interferences at the dock. Interferences will occur due to the fact that ship arrival and unloading times, although scheduled to meet production levels, are random in nature. Interferences result in reduced dock efficiency and increased operating cost due to ship delay.

The purpose of this project is to develop a computer model to simulate the receiving of raw materials at Stelco's new dock facility at Nanticoke, Lake Erie, based on raw material receiving history at Hilton Works, Hamilton. (See Fig. I-1). The model results will be used to predict berth utilization as a function of production level, waiting time costs, queue build-up and the effect of different unloading conditions on berth efficiency.

A present value analysis of different unloading options is used as a decision tool in planning berth and conveyor staging. Predictions are set in perspective by determining the sensitivity of the planning decisions with respect to the main variables.

The initial dock feasibility studies were performed by FENCO in 1968 at which time several types of dock configuration were considered. It was concluded that a 'finger-type' dock with rockfill causeway and crib-wharf was the most economical. In 1971 FENCO carried out further studies of the material handling aspects of the dock facility. (See Fig. I-2). This study included consideration of the possible ship delay costs and berth staging. The predictions made at this time were based on a simplified analytical approach assuming Poisson arrival distribution and uniform berth service times. Also, a good attempt was made to account for ship time lost due to weather.

In 1973, a further study was carried out by Stelco which finalized the alignment of the dock in a North-South direction (as built) based on dock and material handling economics, and also on property and environmental considerations. (See Fig. I-3). In 1974, further studies were undertaken by FENCO to refine design and assess environmental impact. Construction started Spring 1975. (See Fig. I-4). In 1974, Stephens-Adamson and Stelco studied optimum



NOTE

1) INFORMATION ON OFFSHORE BOTTOM CONTOURS COMPILED FROM HYDROGRAPHIC AND SEISMIC SURVEYS BY HUNTEC LTD. DATED MARCH 1968 AND BY H.O. GOLDER AND ASSOC. DATED SEPT. 6, 1968.

2) SHORELINE OUTLINE OBTAINED FROM COMPOSITE PLAN OF NANTICOKE SITE. DRAWING NUMBER K 56785-X.

3) ELEVATIONS REFER TO CHART DATUM FOR LAKE WHEN CANADIAN HYDROGRAPHIC SERVICE GAUGE AT PORT COLBORNE READS 568.6 FT. LOW WATER CHART DATUM = EL 568.6

4) LOCATION OF ROTARY KILNS TAKEN FROM STELCO DRAWING PD 686-X (FACILITY CODE NO. 01-0167-11-086.)

5) MODULE #1 CONSISTS OF OFFSHORE FACILITIES AND CONVEYOR SYSTEM TO TRANSFER STATION NO. 1.

6) MODULE #2 CONSISTS OF ON-SHORE RAW MATERIALS HANDLING AND STORAGE FACILITIES.

7) FOR DETAILS OF MODULE #1 STRUCTURES REFER TO PLAN DWG. NO. 3334-9 FENCO REPORT ON PORT FEASIBILITY STUDY DEC. 1968

LEGEND OF LAND OPERATIONS

- STN. # — TRANSFER STATION
- DEWS LOCATIONS
- PELLETS STOCK PILE
- COAL STOCK PILE
- PELLETS FINE STOCK PILE
- CONVEYOR AT GRADE
- CONVEYOR UNDERGROUND
- CONVEYOR IN GALLERY (12 FT. OR GREATER CLEARANCE)
- CONVEYOR IN GALLERY (10 FT. CLEARANCE)

LEGEND

- SILT BOTTOM CONTOUR
- ROCK BOTTOM CONTOUR
- CAUSEWAY
- ROCK DREDGE AREA STAGE I
- ROCK DREDGE AREA STAGE II

P.G.
FEB. 1971
K.P.

THE STEEL COMPANY OF CANADA LIMITED
HAMILTON ONTARIO

LAKE ERIE DEVELOPMENT
STEELMAKING STUDY

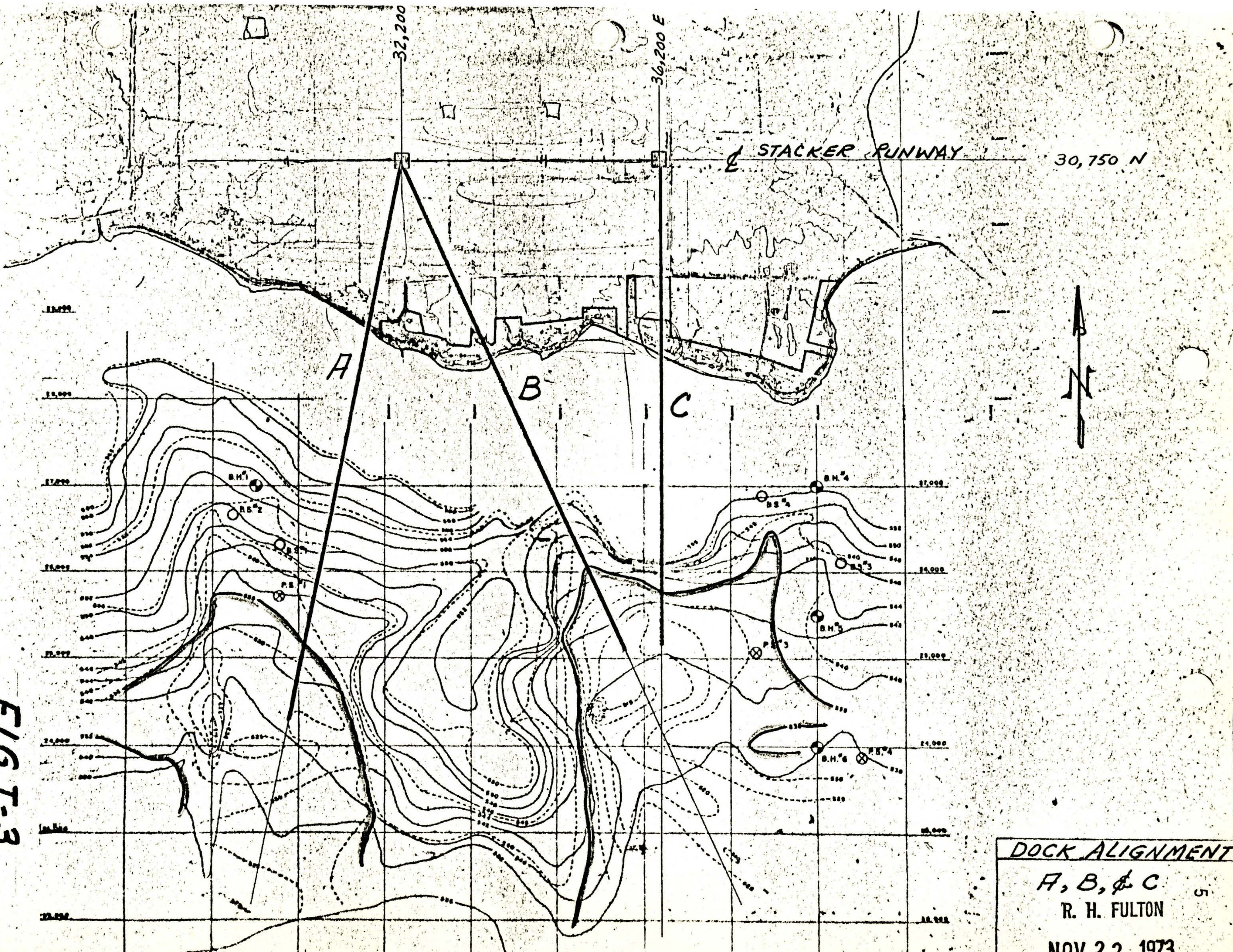
WHARF AND RAW MATERIALS HANDLING AND STORAGE FACILITIES

GENERAL ARRANGEMENT
MODULES #1 AND #2

Foundation Of Canada Engineering Corporation Limited FENCO

3334-1-1

FIG I-2



DOCK ALIGNMENT
A, B, & C
R. H. FULTON
NOV 22 1973

5

FIG I-3

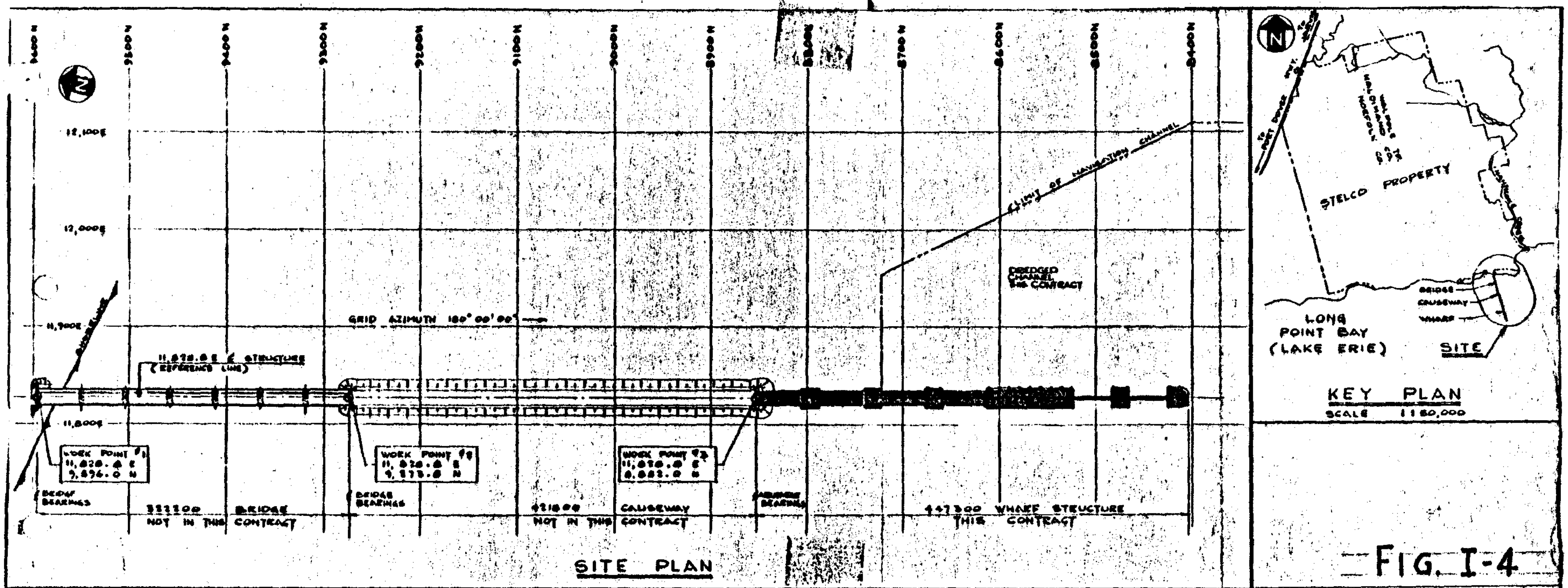

GRID AZIMUTH 180° 00' 00"
11,878.8 E ℄ STRUCTURE (REFERENCE LINE)
WORK POINT #1 11,828.4 E 9,596.0 N
WORK POINT #2 11,828.8 E 9,273.8 N
WORK POINT #3 11,828.8 E 8,882.0 N
BRIDGE BEARINGS
BRIDGE NOT IN THIS CONTRACT
CAUSEWAY NOT IN THIS CONTRACT
WHARF STRUCTURE THIS CONTRACT
LIMIT OF NAVIGATION CHANNEL
DREDGED CHANNEL THIS CONTRACT
SITE PLAN
STELCO PROPERTY
LONG POINT BAY (LAKE ERIE)
BRIDGE
CAUSEWAY
WHARF
SITE
KEY PLAN
SCALE 1:50,000

FIG. I-4

conveyor design including unloading rates, optimum belt and drive sizes, future staging and storage. However, this study was not integrated with all the aspects of possible ship delay times associated with each of the unloading options.

The present study is confined mainly to the planning aspects of raw material receiving, specifically in the area of predicting ship delay time with a computer model. It is hoped that the results of this computer modelling study will shed more light on the interface between shipping and receiving.

Several unloading alternatives (i.e. belt and drive sizes) were considered with the associated capital and operating cost including ship delay costs generated from the computer model.

The following is a summary of the steps taken to develop this study:

(a) Theory, Chapter II: Relevant queueing theory is outlined and various functions formulated to provide some degree of control over the computer model so that possible deviations can be rationalized. The model in this case is further complicated by the fact that there are two different unloading rates from more than one berth. Therefore, four different probability distributions are involved which makes a manual analytical approach rather complicated since these distributions must be manipulated and merged to measure the interference at the dock. It was decided, therefore, to use Monte Carlo computer simulation. The manually developed queueing functions are used only to provide a rough check on the computer results.

(b) History, Chapter III: Data from the present raw material receiving facilities at Hilton Works, Hamilton, were collected and used to determine probability distributions to describe the manner in which ships arrive, berth and unload. The materials shipped to Lake Erie will be comparable to those presently shipped to Hamilton, although the route to Lake Erie is generally shorter and does not involve the negotiation of the Welland Locks or the lift bridge at Hamilton Harbour. The arrival distribution at Lake Erie may be affected by ship traffic to Ontario Hydro Generating Station and Texaco Refinery at Nanticoke, not to mention the local fishing fleets. Arrivals will be further affected by more difficult navigation and manoevering in the somewhat restricted approach channels and shoal areas at Lake Erie, coupled with wind and current. The service time distributions at Lake Erie will be more affected by receiving equipment, weather (being more exposed) and properties of the material. For example, coal produces a much greater variance in berth time distribution than ore pellets because of associated unloading difficulties such as packing and sticking in bins and chutes. This will have more affect at Lake Erie because of the more extensive receiving system, whereas at Hamilton, ships unload directly to the storage area. Also at Lake Erie, ships will unload into a relatively small hopper on the wharf which could produce, at times, greater spillage especially in rough weather, forcing the operators to unload more slowly.

All the above points must be considered, however, it is felt that the distributions derived from history at Hilton Works are adequate to simulate the arrivals and service at the Lake Erie dock.

(c) Computer Model Development, Chapter III: Using the distribution obtained from history at Hilton Works, mathematical functions are derived to describe these distributions in order that they may be incorporated in the computer model. The various parameters and their effect on the distributions are studied. These functions are used to develop a Monte Carlo algorithm for the facility, which generates random numbers to be used in conjunction with the arrival and service functions referred to above. Having generated random arrivals and service times of ore and coal vessels according to their respective distributions, the arrivals are merged to represent a true sequence of operation, and then queued into the wharf to unload according to randomly generated service times. Concurrently, waiting times as a result of ship interferences are measured as queues build-up and diminish. Berth times and berth utilization factors for various tonnage levels are also recorded. The true value of the model is in being able to adjust any or all of the parameters to simulate any situation at the dock, i.e. (unloading rates, vessel tonnage, conveyor combinations, mechanical breakdowns, etc.) and thus measure the effect on delay costs and queues.

(d) Calibration and Application of the Model, Chapter IV: This chapter deals with the accuracy of the model, number of simulations required, data accuracy, adjustment and sensitivity of model parameters, seed values for random generation, and monitoring of model using analytical techniques.

(e) Econometrics of the Model, Chapter V: The various alternatives simulated on the model are evaluated economically by using well known Present Value techniques. For example, if a higher unloading rate is proposed, this variable would be adjusted in the model and the resulting delay costs measured. In this case, it would result in lower delay costs and queue build-up, however, it would involve higher capital cost to provide the equipment. The delay and capital costs would be discounted to the present so that the alternative can be compared and predictions can be made on berth staging.

Also, the effect of escalation (inflation) rate and cost of capital onthe present value is studied.

(f) Results, Recommendations and Future Applications are presented in the last three chapters.

CHAPTER II

QUEUEING THEORY DEVELOPMENT

The objective in this chapter is the analytical development of a queueing model based on general queueing theory adapted to this particular application.

The analytical approach must of necessity be limited to a rather simple distribution because of the complexity of the expressions, but will serve to get an understanding of the variables and distributions involved. The theoretical study serves also as a check on the Monte Carlo computer simulation used for this model and which is developed in Chapter III. Discussion is presented on the theoretical significance of parameters such as the ratio of ship waiting time to berth time (TW/TB) an important parameter in describing the general performance of a dock facility. Queue build-up and utilization factors are also studied. All these parameters are later compared to the results of the computer simulation.

Queueing

Several examples of queueing or waiting-line problems can be found in the technical and commercial world. In transportation systems, airplanes wait for an open runway or berth, automobiles queue for a ferry or toll-gate, ships wait for a dock and freight trains wait to be serviced in a yard.

The examples mentioned above are all subject to many uncertainties and delays. Scheduling in these cases is usually not accurate enough to eliminate the waiting-line problem since the delays are usually a result of random or chance occurances such as weather, mechanical breakdown, labour slowdowns or simply the mood of the server.

Whenever queues occur there is loss of productivity, and disruption which reduces the total effectiveness of the system. The reason for studying queueing problems in detail, especially in industry, is to minimize operating costs.

In this particular study, the queueing problem is one of ships arriving at a dock facililty to be unloaded. Although there is scheduling to meet the average arrival rate compatible with production levels, there is still variance about these means due to chance occurances, such as weather, ship traffic, seaway locks and channels. It can be shown further that ships arrive and are serviced in a random manner according to certain probability distributions which can be approximated from previous experience. The average rate of arrivals can be altered to suit the production tonnage requirements; the distributions remaining unchanged because they describe the nature of the random process.

In this study the average rate of ship arrivals is denoted as λ, the reciprocal $^1/\lambda$ being the mean time between successive arrivals.

In a similar manner it is known that service times (unloading) are independent random variables having a certain probability distribution derived from past history. The randomness in service times is caused by several factors such as weather, ship approach to the wharf, mooring procedure, receiving equipment reliability, ship unloading equipment reliability, and the types of material handled. The average unloading or service rate is denoted by μ and is a function of the material receiving equipment. The average time to complete service is the reciprocal $^1/\mu$. In every case it is assumed that ships are serviced on a first-come, first-serve basis.

Due to the randomness of arrivals and services, and the inability to schedule out this randomness, interferences occur at the dock. Ships are therefore forced to form a waiting-line or Queue. In the case under study the queue length is dependent on tonnage levels and receiving rates, and may comprise only one or zero ships for lower tonnage levels increasing to perhaps 3 or 4 as the tonnage builds up to ultimate levels.

In order to increase service rate, and thus reduce ship waiting time, it is necessary to increase the capacity of the material receiving systems which would increase the operating costs or cost of service. In reality the cost of service would have to take into account the cost of the initial capital investment and the staging alternatives involved with increasing the service rate. This is investigated in Chapter V using a "present-value" analysis. In practice the analysis is further complicated by the fact that the ship delay charge is variable and usually subject to negotiation between the shipping companies and the users based on the previous years record. In this study, a constant cost per hour for ship delay is assumed.

Calling Population

In this case the calling population is the fleet of ships specifically commissioned to service production demands. Therefore, it is a finite population increasing with production (see Appendix 2). It is assumed here that the arrival rates are not affected by the depletion in the population caused by those units in the queue and in service, since the maximum number in the queue is expected not to exceed 3 or 4 and, therefore, will not affect arrivals in a fleet of 18 or 20 at ultimate production levels.

State of the System

The total number of vessels being serviced or in queue will be referred to as the 'state of the system". In general, concern is with the long term, average behavior of the system in equilibrium and not during short-term transient conditions. The system is not studied as a function of time but of the probability of the system being in a certain state at a randomly selected time, after the transient condition has passed.

With the above as guide lines, consideration is given to the single service channel and later expanded to multiple channels.

Assume that service times and interarrival times are exponentially distributed. Thus:

$So(t) = e^{-\mu t}$ (Service time distribution)

$Ao(t) = e^{-\lambda t}$ (Arrival time distribution)

Where μ = mean service rate (services/hour)

λ = mean arrival rate (arrivals/day)

It will be shown that an equilibrium state can be reached only if $\lambda/\mu < 1$. The time dependent state probabilities are defined by Pn(t), such that;

Pn(t) = Prob (there are n units in the system at time t, 1 in service and (n-1) in the Queue.)

The steady-state probabilities are Pn, where Pn = lim Pn(t) as $t \to \infty$. The limit is reached at a rate depending on μ and λ. The possible state probabilities would be;

Po, P1, Pn-1, Pn, Pn+1, subject to the condition that

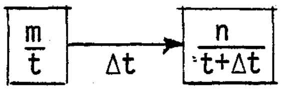
$$\sum_{j=0}^{\infty} Pj = 1.0$$

The probability that there are n units in the system at some selected moment in time is the sum of probabilities associated with state changes leading to state n. The following expression represents a system of n equations.

$$P_n(t+\Delta t) = \sum_m P_m(t) \cdot T_{mn}(\Delta t) \qquad (2.1)$$

where $P_m(t)$ = Prob. system is in state m at time t.

Tmn(Δt) = Prob. of a transition from state n in Δt/ given that the system is in state m at time t, diagramatically,



The above system of equations can be simplified by using interarrival and service times which are exponentially distributed, i.e. [$Ao(t) = e^{-\lambda t}$; $So(t) = e^{-\mu t}$], this makes possible the following statements;

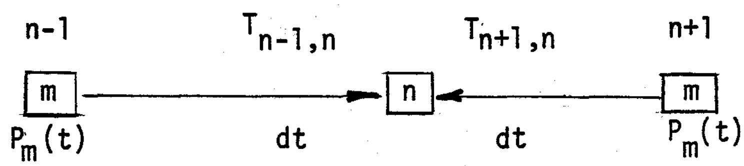
(i) The probability of arrival in time dt is λdt

(ii) The probability of service completion in time dt = μdt

(iii) The probability of more than one arrival or service in time dt is infinitesimal.

Thus in Egn 2.1 as $\Delta t \to 0$

$$P_n(t+dt) = \sum_{m=n-1}^{n+1} P_m(t) . \; T_{mn}(dt) \tag{2.2}$$



The domain of this summation is restricted to the above since $T_{mn}(dt) \approx o$ for $n-1 > m > n+1$.

Three different transitions may be identified, leading to a value of T_{mn}. These are as follows:

(i) $T_{mn}(dt)$ = prob. of no arrivals or service completion during time dt.

(ii) $T_{n-1,n}(dt)$ = prob. of an arrival during time dt X prob. of no service completed during time dt.

(iii) $T_{n+1,n}(dt)$ = prob. of no arrivals during dt X prob. of one service completion during dt.

Using the above definitions the following expressions can be derived for the transition probabilities

$$T_{nn}(dt) = A\ (dt) \cdot S_0(dt)$$

$$= e^{-(\lambda+\mu)}dt$$

$$= 1 - \frac{(\lambda+u)dt}{1!} - \frac{(\lambda+\mu)dt^2}{2!} \quad ,$$

Using series expansion $e^x = 1 + \frac{x}{1!} + \frac{x}{2!} +$ and ignoring second order terms,

$$T_{nn}(dt) = 1 - (\lambda+\mu)dt \qquad (2.3)$$

$$T_{n-1,n}(dt) = A_1\ (dt) \cdot S_0\ (dt)$$

$$T_{n-1,n}(dt) = \lambda dt \cdot (1-\mu dt) \simeq \lambda dt \qquad (2.4)$$

$$T_{n+1,n}(dt) = (1-\lambda dt) \cdot \mu dt$$

$$= \mu dt - \lambda\mu dt^2$$

$$T_{n+1,n}(dt) \simeq \mu dt \qquad (2.5)$$

Using equations 2.3, 2.4, 2.5, equation 2.2 becomes;

$$P_n(t+dt) = P_{n-1}(t) \cdot \lambda dt + P_n(t)\ [1-(\lambda+\mu)dt] + P_{n+1} \cdot \mu dt$$

or

$$d[\frac{Pn(t)}{dt}] = \lambda P_{n-1}(t) + \mu P_{n+1} - (\lambda+\mu) \cdot P_n(t) \qquad (2.6)$$

By the definition of the derivative as t becomes large $\frac{d}{dt}[P_n(t)] = 0$ which indicates that the rate of change of state probabilities becomes small when steady state conditions are reached. P_n is independent of time*. Equation 2.6 then becomes; $\lambda P_{n-1} + \mu(P_{n+1}) - (\lambda-\mu)P_n = o$ (2.6a)

Equation 2.6a represents the balancing of transitions between states for the system in equilibrium, i.e. the transition probabilities are equal. Considering the special case when n = o, since no service completion can occur equation 2.6a becomes;

$$\lambda P_{-1} + \mu P_1 - \lambda P_o - \mu P_o = o,\ n > o,\ \text{Since } \lambda P_{-1} \text{ is not defined}$$

for $n < o$. Now $\mu P_o(t) = o$, since no service completion occur. Therefore, Equation 2.6a reduces to $\mu P_1 - \lambda P_o = o$ or $P_1 = (\lambda/\mu) \cdot P_o$. Carrying this argument through for n terms

$$P_n = (\lambda/\mu)^n \cdot P_o = \rho^n \cdot P_o \tag{2.7}$$

where $\rho = \lambda/\mu$ is called the utilization factor of the system. Now if λ increases or μ decreases, (i.e. the rate or intensity of arrivals increases or service time $(1/\mu)$ increases) the dock or server utilization will increase and ships will have longer waits. If $\rho \geq 1$ the steady-state condition would not be reached and theoretically the queue would grow without bound. Using the fact that

$\sum_{n=o}^{\infty} P_n = 1.0$ and substituting into equation 2.7 yields $\sum_{n=o}^{\infty} [\rho^n P_o] = 1$

and, thus $P_o = \dfrac{1.0}{\sum_{n=o}^{\infty} \rho^n}$

---

* this holds true only when transitition probabilities follow an exponential process and when μ and λ are independent of time -- as assumed in this study.

Then using a geometric series for the denominator

$$Po = \frac{1.0}{1 + (\rho) + (\rho)^2 + (\rho)^3 + \dots \rho^n}$$

This converges only if $\rho < 1$ with a sum $= \frac{1}{1-\rho}$. Thus $Po = 1-\rho$ for $\rho < 1$ Substituting for P_o equation 2.7 becomes $P_n = \rho^n(1-\rho),\ n \geq o$, (2.8)

Using the above basic definitions of the system, several parameters can be derived which describe the behaviour of the system.

1. Number in system (Queue and Wharf) - (L). L is the expected value of the random variable n having distribution Pn

$$L = E(n) = \sum_{n=o}^{\infty} n \cdot P_n$$

$$L = \sum_{n=o}^{\infty} n \cdot \rho^n(1-\rho)$$

Expanding, the series yields; $L = \rho(1-\rho) + 2\,\rho^2\,(1-\rho) + \dots$

$$L = \rho + \rho^2 + \rho^3 + \rho^4 \dots$$

$$L = \rho[1+\rho+\rho^2+\rho^3+ \dots]$$

The expression in brackets is a geometric series convergent for $\rho < 1$ with $\lim_{n\to\infty} Sn = \frac{1}{1-\rho}$

$$\therefore L = \rho[\frac{1}{1-\rho}]$$

$$L = \frac{\rho}{1-\rho} \qquad (2.9)$$

2. Probability of a number n in the system being less than a given number x

$$P(n \leq x) = \sum_{n=o}^{x} P_n = \sum_{n=o}^{x} \rho^n (1-\rho)$$

$$= 1 - \rho + \rho(1-\rho) + \rho^2(1-\rho) + \rho^3(1-\rho) \ldots \rho^x(1-\rho)$$

$$= 1 - \rho + \rho - \rho^2 + \rho^2 \ldots\ldots -\rho^x + 1$$

$$P(n \leq x) = 1 - \rho^{x+1} \qquad (2.10)$$

3. The expected number in the queue (m) say Lq.

$$E(m) = o \cdot P_o + o \cdot P + \sum_{m=1}^{\infty} m \cdot Pm + 1$$

Since there is one in service, there are m + 1 in the system.

$$\text{Expanding; } \sum_{m=1}^{\infty} m \cdot P_m + 1 = \sum_{m=1}^{\infty} m \cdot \rho^{m+1} (1-\rho)$$

$$= \rho^2 + \rho^3 + \rho^4 + \rho^5 \ldots \rho^{m+1}$$

$$= \rho^2(1+\rho+\rho^2+\rho^3)$$

$$= \rho^2 \left[\frac{1}{1-\rho}\right]$$

$$Lq = \frac{\rho^2}{1-\rho} \qquad (2.11)$$

4. Given that there is a queue (m>o), the expected value of m would be;

$$E(m/m>o) = \frac{P(m\ m>o)}{P(m>o)} = \frac{E(m)}{P(m>0)}$$

$$= \frac{\frac{\rho^2}{1-\rho}}{\sum_{n=2}^{\infty} \rho^n(1-\rho)} = \frac{\frac{\rho^2}{1-\rho}}{\rho^2(1-\rho)+\rho^3(1-\rho)} = \frac{\frac{\rho^2}{1-\rho}}{\rho^2}$$

$$E(m/m>o) = \frac{1}{1-\rho} \tag{2.12}$$

5. The total time in the system, a random variable (v) has the probability distribution, as given by T. L. Saaty (1)

$$f(v) = (\mu-\lambda)\ e^{-(u-\lambda)v} \quad v \geq o \tag{2.13}$$

From this the mean time in the system (W) can be determined as follows;

$$W = E(v) = \int_o^{\infty} v \cdot f(v)\ dv = \frac{1}{u-\lambda}$$

$$W = \frac{L}{\lambda} \tag{2.14}$$

6. The waiting time in the queue is also a random variable (w) with probability distribution (1)

$$g(w) = \begin{matrix} 1 - \rho \text{ for } w = o \\ (1-\rho)\lambda \quad e^{-(\mu-\lambda)\ w} \cdot \text{ for } w \geq o \end{matrix}$$

The mean waiting time is given by

$$Wq = E(w) = o(1-\rho) + \int_o^{\infty} w(1-\rho)\lambda e^{-(\mu-\lambda)w}\ dw$$

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)} \tag{2.15}$$

The mean waiting time for those vessels in a queue is given by;

$$E(w/w>o) = \frac{1}{\mu+\lambda}$$

The probability of having to wait is 1 - prob (queue > o) = 1 - P(w = o) and from Equation 2.7, $1 - \rho^{o}(1-\rho) = \rho$. Using equation 2.11 and substituting yields, Lq =

$$\frac{\rho^2}{1-\rho} = \frac{\left(\frac{\lambda}{\mu}\right)^2}{\frac{\mu-\lambda}{\mu}} = \frac{\left(\frac{\lambda}{\mu}\right)}{(\mu-\lambda)} \cdot \lambda$$ Substituting into Equation 2.15 yields:

$$Wq = \frac{Lq}{\lambda} \qquad (2.16)$$

i.e. Mean waiting time in queue equals the expected number in queue/mean arrival rate.

Also, $W = \frac{1}{\mu-\lambda} = \frac{\lambda}{\mu(\mu-\lambda)} + \frac{1}{\mu}$

$$W = Wq + \frac{1}{\mu} \qquad (2.17)$$

i.e. Mean waiting time in system equals mean waiting time in queue plus mean service time.

Following this presentation of the basic theory for a single service channel, the theory for more than one service channel may be developed. Exponential interarrival and berth service times will be assumed because non-exponential distributions become very complex and impractical to apply. The simulation of non-exponential distributions is best handled by Monte Carlo methods, the procedure used in this study, described later. However, exponential simulations will be sufficient to check bounds for the Monte Carlo computer simulations.

In the case of the dock facility it is assumed that the length of queue does not affect the arrival frequency distribution, although in the case being considered, the max queue should be practically limited to 3 or 4 vessels because of available anchorage beside the channel. (See Fig. III-7). As in the single channel derivations, the state equations must be derived in order to derive the state probabilities (i.e. the probability that the system will contain n vessels). The objective is to develop an expression for TW/TB in order that an approximate check may be applied to the results of the Monte Carlo computer simulation. If the number of berths is given by M, then;

When $n \leq M$ there is no queue

When $n > M$ there is a queue $(n-M)$ long.

The probability that there are n units in the system at some time t is the sum of the probabilities associated with state changes leading to state n as given by Ruiz et al (2), as follows,

$$P_n(t+dt) = \lambda dt \cdot P_{n-1}(t) + (n+1) \cdot P_{n+1}(t)\mu dt + (1-\lambda dt) \cdot (1-\mu n dt) P_n(t) \text{ for } n = 1,2,3,\ldots M-1 \quad (2.19)$$

i.e. prob of going from state n+1 to n, one arrival if the state is n-1, one service when state is n+1, and no services or arrivals if state is n.

$$P_n(t+dt) = \lambda dt \cdot P_{n-1}(t) + (M\mu dt) P_{n+1}(t) + [1-\lambda dt] \cdot [1-M\mu dt] \cdot P_n(t), \text{ for } n = M, M+1 \quad (2.20)$$

Note: Prob. of more than one channel completing service in time dt is negligible.

Manipulating and using the definition of derivative results in the following differential equations;

$$P'_o(t) = \mu \cdot P_1(t) - \lambda P_o(t),\ n = o \tag{2.21}$$

$$P'_n(t) = \lambda P_{n-1}(t) - (\lambda - n\mu) \cdot P_n(t) + (n+1) \cdot \mu P_{n+1}(t),\ n = 1,2 \ldots M-1 \tag{2.22}$$

$$P_n'(t) = \lambda P_{n-1}(t) - (\lambda + M\mu) P_n(t) + (M\mu) P_{n+1}(t) \quad n = M, M+1 \tag{2.23}$$

The steady state may be found by setting $P'_n(t) = o$ which results in;

$$\mu P_1 - \lambda P_o = 0,\ n = o \tag{2.24}$$

$$\lambda P_{n-1} - (\lambda + n\mu) \cdot P_n + (n+1)\mu \cdot P_{n+1} = o;\quad n = 1,2,\ldots M-1 \tag{2.25}$$

$$\lambda \cdot P_{n-1} - (\lambda - M\mu) \cdot P_n + M\mu \cdot P_{n+1} = o;\quad n = M, M+1 \tag{2.26}$$

By successive solution of these equations starting at n = o, yields;

$$P_n = \frac{\phi^n}{n!} \cdot P_o,\quad n = o,1,2,\ldots M$$

$$P_n = \phi n \cdot P_o / M^{n-M} M!,\quad n = M+1, M+2$$

where $\phi = \frac{\lambda}{\mu}$ and $\rho = \frac{\lambda}{M\mu} = \frac{\phi}{M}$ the "utilization factor", which is the mean fraction of berths being utilized. By using the expression

$\sum_{n=o}^{\infty} P_n = 1$, and solving for Po the following expression is derived:

$$P_o = \frac{1}{\sum_{n=o}^{M-1} \frac{\phi^n}{n!} + \frac{M\phi^M}{M!(M-\phi)}} \tag{2.27}$$

Since $\rho < 1$ for equilibrium, the mean number of vessels (m) in the queue Lq can be expressed as;

$$Lq = E(m) = 0 \cdot P_o + 0 \cdot P_1 \ldots \sum_{m=1}^{\infty} m \cdot P_m + M$$

By expanding this expression similar to the procedure used for the M = 1 case, the following expression is derived;

$$Lq = \frac{\rho}{(1-\rho)^2} \cdot \frac{\phi^M}{M!} \cdot P_o \qquad (2.28)$$

P. M. Morse (3) has defined functions to aid in the manipulation of these formulas. These are given in Appendix 3.

However, for the purposes of this study, the basic form given by Equation 2.28 will be used to derive a function for TW/TB, the ratio of ship waiting time (TW) to berth time (TB). The waiting time in the queue is given by Equation 2.16, $Wq = Lq/\lambda$, then the ratio $TW/Tb = \frac{Wq}{1/\mu} = \frac{Lq}{\lambda} \cdot \mu = \frac{Lq}{\phi}$, $\frac{1}{\mu}$ being equal to the average berth service time Tb. Using Equation 2.28, $\frac{TW}{TB} = \frac{\rho}{(1-\rho)^2} \cdot \frac{\phi^M}{M!} \cdot \frac{1}{\phi} \cdot P_o$

$$\frac{TW}{Tb} = \frac{\rho}{(1-\rho)^2} \cdot \frac{\phi^M}{M!\phi} \cdot \frac{1}{\sum_{n=o}^{M-1} \frac{\phi^n}{n!} + \frac{M\phi^M}{M!(M-\phi)}}$$

By expanding and manipulating, the above ratio is reduced to the form;

$$\frac{TW}{Tb} = \frac{\phi^M}{M \cdot (1-\frac{\phi}{M}) \cdot \phi^M + M \cdot M! \ (1-\frac{\phi}{M})^2 \cdot (1 + \frac{\phi}{1} + \frac{\phi^2}{2!} + \frac{\phi^3}{3!} + \ldots \frac{\phi^{M-1}}{(M-1)!})}$$

In deriving this function, the state equations are based on the assumption that the interarrival and service times are exponential.

By setting K = 1 the Erlang distribution for berth service times reduces to the exponential. A value of $K = \infty$ implies constant berth times. If the ratio TW/Tb is plotted against Berth Occupancy, (i.e. B.O. = $\phi \times 100/(M)$ the results of the Monte Carlo simulation may be compared as shown in Fig. III-8). The Monte Carlo simulation results are plotted as solid lines and the theoretical values calculated by the above function for TW/TB are shown dotted. The results compare favorably. The simulated curves fall within the bounds set by the calculated curves for the extremes of K = 1 and $K = \infty$, as expected, since the simulated curves are a composite of Ko = 11 and Kc = 6. The simulated curves, of course, take into account the true distributions for arrivals and berth times as determined from previous history, (Fig. III-1 through Fig. III-4). They also reflect the real interference at the dock for a composite of arrival and berth times for coal and ore vessels. Having demonstrated that the computer simulation is rational and compares well with theoretically determined bounds, assuming exponential distributions, the analysis may be carried a step further in order to predict if and when the facility should be expanded.

In the present case, a practical limit of 3 or 4 exists for the queue length and the unloading rates have upper values of approximately 8000 t/h for coal and 11,000 t/h for ore.

Basically two options for expanding the facility are available:

(a) increase the unloading rate for the single berth,

or

(b) add a second berth in parallel with the same unloading rate.

The advantage of adding the second berth is that it reduces the size of the queue and thus the mean delay time in queue. Also, it enables the facility to operate nearer to full utilization ($\rho \to 1$) before the queues become excessive. However, the disadvantage is that it does not reduce service time for the individual berth. In other words, the provision of two parallel berths is an advantage to the operator of the dock and a disadvantage to the shipping company, (which of course, will be reflected in the future rates). Perhaps the following plots will help to illustrate these relationships.

From Equations 2.27 and 2.28;

$$Lq = \frac{\rho}{(1-\rho)^2} \cdot \frac{\phi^M}{M!} \cdot \frac{1}{\sum_{n=o}^{M-1} \frac{\phi^n}{n!} + \frac{M \cdot \phi^m}{M!(M-\phi)}}$$

Also, $L = Lq + \rho M$, $\rho = \frac{\lambda}{M\mu} = \frac{\phi}{M}$ and as defined previously $W = L/\lambda$ and $Wq = Lq/\lambda$. Thus plots may be obtained of Lq vs ρ and L vs ρ as shown in Figs. II-1 and II-2.

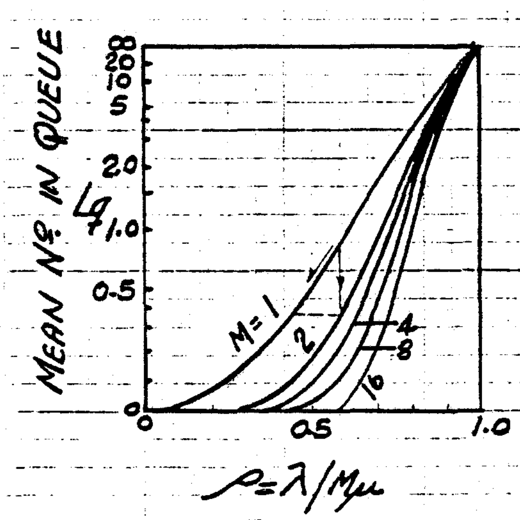


FIG II-1

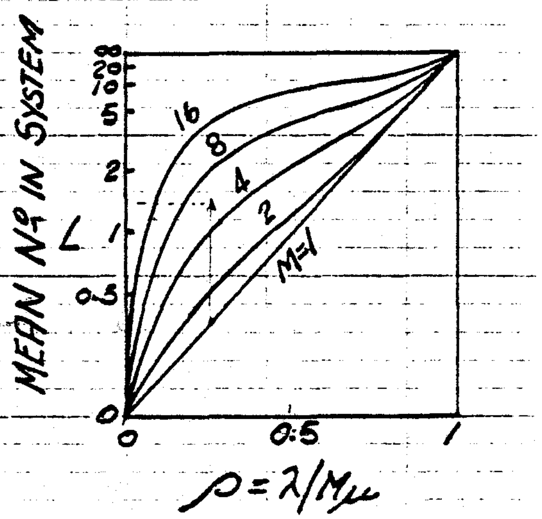


FIG II-2

These plots indicate that for a given value of ρ, an increase in M, increases L and decreases Lq. In order to lower the mean number in the queue (see Fig. II-1) one can either move down the M = 1 curve by increasing μ (unloading rate) or drop from the M = 1 curve to the M = 2 curve keeping ρ constant. For values of ρ around o.5 the unloading rate would have to increase by 40% to achieve the same decrease in Lq by changing from M = 1 to M = 2. To increase the unloading rate to the practical limit, one must not only consider the extra power required but also the increased capital expenditure for larger conveying equipment, therefore, the decision between options a and b must be based on a present value analysis, described in Chapter V.

To determine when and if the practical queue limit of 3 or 4 will be exceeded at the facility, the probabilities of the queue length Lq exceeding a limit (say N) can be investigated as follows;

$$PQ_{M+N} = \sum_{n=o}^{\infty} P_{M+N} \quad , \qquad n > M + N$$

where PQ_{M+N} is the probability of the queue length exceeding N. Using Equations 2.27 and 2.28 the following expression for PQ_{M+N} is derived;

$$PQ_{M+N} = \frac{\rho^N}{(1-\rho)} \cdot \frac{\phi^M}{M!} \cdot \sum_{n=o}^{m-1} \frac{1}{\frac{\phi^n}{n!} + \frac{M \cdot \phi M}{M! \ (M-\phi)}}$$

Expanding yields;

$$PQ_{M+N} = \frac{\rho^N}{(1-\rho)} \cdot \frac{\phi^M}{M!} \div \left[\frac{1}{1 + \phi + \frac{\phi^2}{2!} + \frac{\phi^3}{3!} + \ldots \frac{\phi^{M-1}}{(M-1)!} + \frac{M \cdot \phi^M}{M!(M-\phi)}}\right]$$

Fig. II-3 shows curves of PQ_{M+N} against ρ for various values of M and N. Considering Fig. II-3 for a dock with single berth (M = 1) and at a utilization of 80% ($\rho = 0.8$) the probability of exceeding a queue length of 4 is 33%. Considering a double berth dock (M = 2) with $\rho = 0.8$, the probability of exceeding a queue of 4 is 28%, which is close to the single berth case but would represent twice the dock capacity.

Considering equal tonnage levels for M = 1 and M = 2, with $\rho_1 = 0.80$ and $\rho_2 = 0.40$. the probability of exceeding N = 4 for a single berth is 33% and for a double berth is 0.1%.

Again, by means of Fig. II-3, if it is planned to expand the dock from a single to a double berth at $\rho = 0.50$ (approx. 15×10^6t per year level) the probability of exceeding the limiting queue of 4 (N = 4) is only 1%. Note that this percentage increases very rapidly beyond 50% utilization ($\rho \doteqdot .50$).

The foregoing general predictions are compared with the computer simulation results in Chapter VI.

PROBABILITY OF QUEUE EXCEEDING GIVEN NUMBER N FOR VARIOUS VALUES OF ρ & M

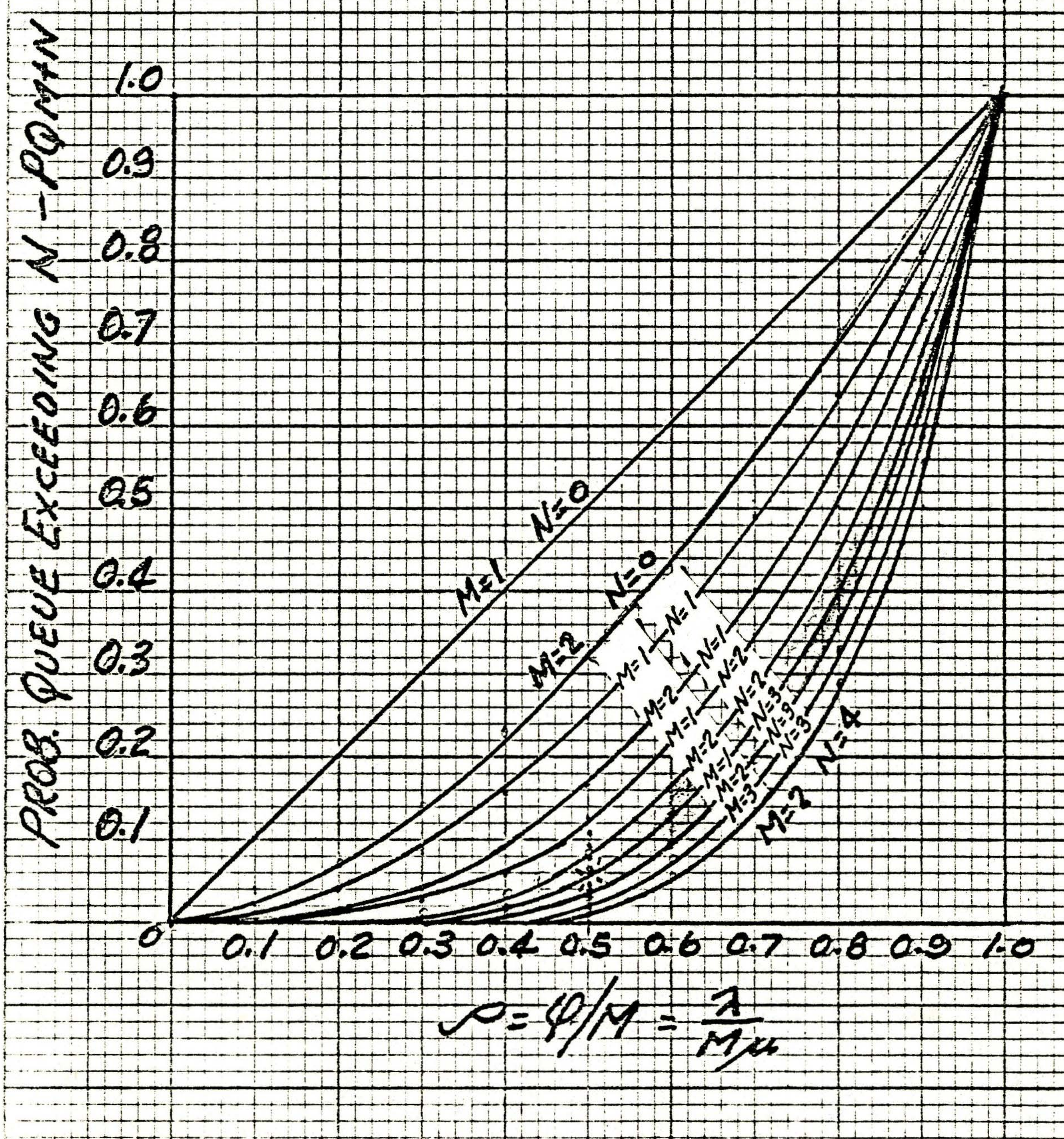


FIG II-3

CHAPTER III

HISTORICAL DATA

DEVELOPMENT OF COMPUTER SIMULATION MODEL

Probability Distributions For Arrivals and Berth Times

In order to simulate arrival and berth service times at the new dock facility it is necessary to study data collected from existing facilities and to develop from this data distribution functions to describe the random variability of ship arrivals and berth times. A sample of two years of actual historical data is tabulated in Appendix 6.

From these distributions a computer algorithm may be used to generate random arrivals and berth times conforming to the properties (shape, variance, etc.) of the known distributions.

Berth Service Time Distribution

The data collected at Hilton Works for ore and coal berth times is plotted as shown on Fig. III-1 and Fig. III-2. The curves closely follow an Erlang distribution with K factor = 11 for ore and 5 for coal. The Erlang or Hypoexponential curve has a lesser variability than the exponential distribution and properly describes the unloading operation of ore and coal vessels.

The shape parameter K of the Erlang distribution is the measure of the randomness of the variable t - the unloading time. By

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SPECIFY TRACING OR DRAWING PAPER

GRAPHIC CONTROLS CANADA LTD.
MADE IN CANADA

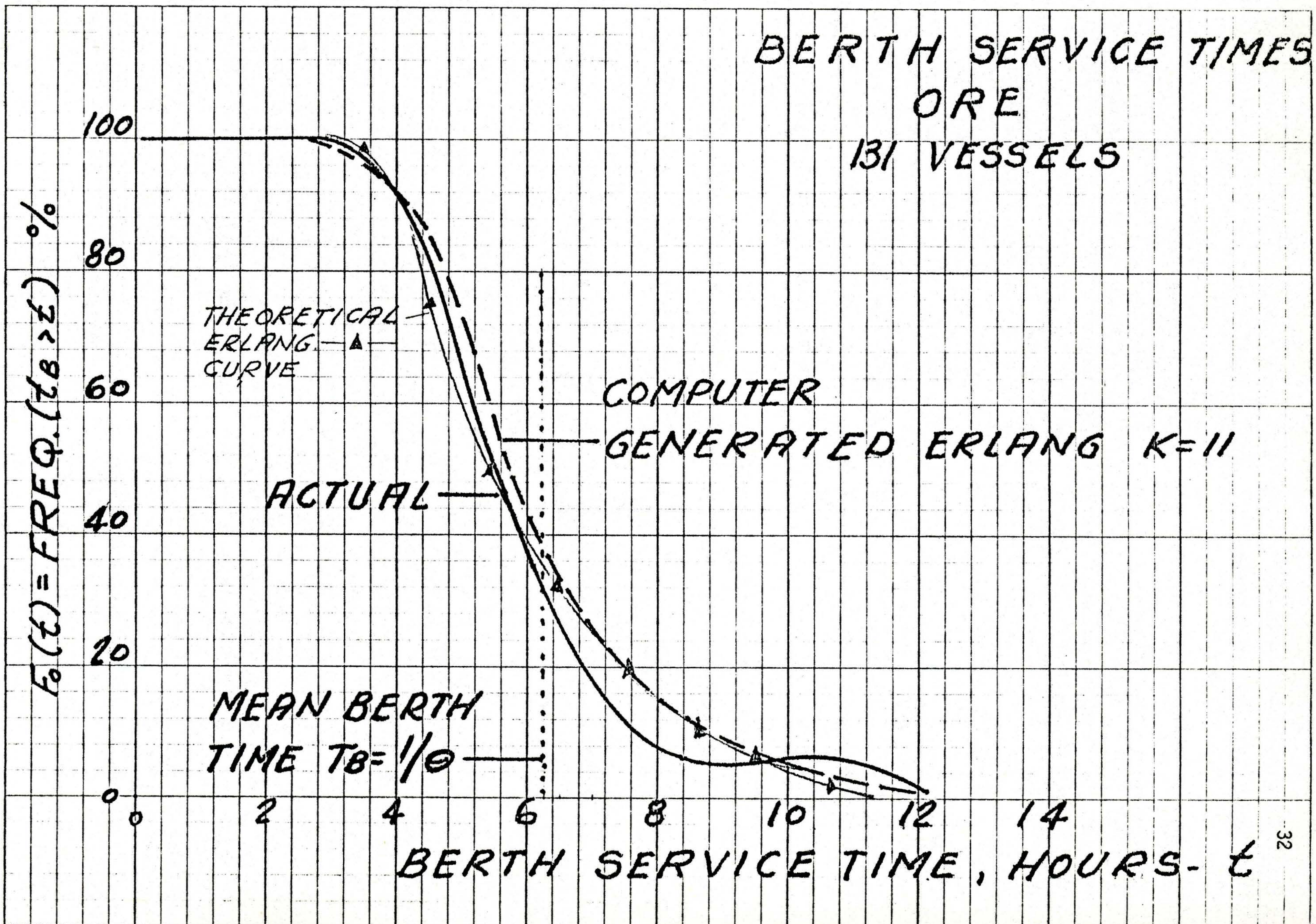


FIG III - 1

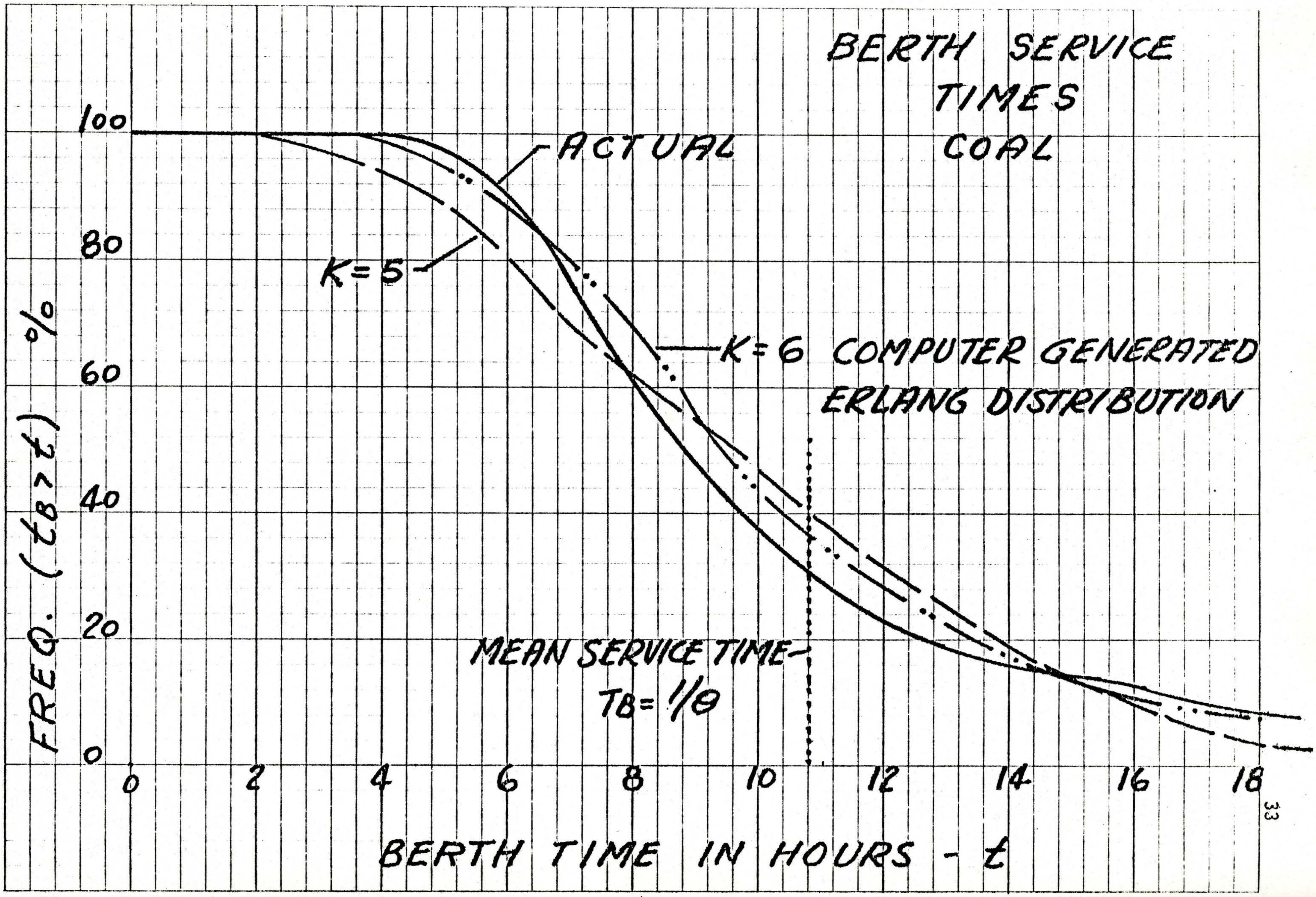

BERTH SERVICE
TIMES
COAL
ACTUAL
K=5
K=6 COMPUTER GENERATED
ERLANG DISTRIBUTION
MEAN SERVICE TIME
TB= 1/θ
FREQ. (tB>t) %
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
BERTH TIME IN HOURS - t

FIG. III-2

varying K an infinite 'family' of Erlang distributions can be generated. As K increases toward infinity the unloading times become constant, shown on Fig. III-1 and 2 as a vertical line which is the mean berth service time - $\frac{1}{\theta}$. A Small K value indicates more randomness with K = 1 reducing to the exponential distribution $(e^{-k\theta t})$.

The K parameter for coal unloading times indicates more randomness (K = 5) compared to that for ore (K = 11) which is closer to constant (K = ∞) coal being more difficult to unload because of sticking in bins and excessive spillage.

In the following section a derivation is given of the Erlang distribution as it applies to this model.

<u>Berth Service Time - Derivation</u>

The Erlang distribution or Hypoexponential distribution of the time t required for a unit to pass through the berth (service channel) is considered to be the sum of the individual times for several (K) different operations during unloading (pseudo-channels) each of which takes time -tj. (j = 1,k).

$$t_1 + t_2 + t_3 \text{--------} t_k$$

The unit must pass sequentially through the K operations or pseudo-channels before unloading is completed. Each channel has an exponential distribution of holding time with parameter kθ and mean holding time of ($^1/k\theta$). The K pseudo-channels simulate a single channel. Total time t is a random variable such that $t = t_1 + t_2 + t_3 \ldots t_k$.

The variables tj are independent random variables with exponential distribution;

$$g(tj) = (k\theta)\, e^{-k\theta t}\ , \quad tj \geq o \qquad j = 1,2,3\ldots k$$
$$= o \qquad\qquad , \quad tj < o$$

The mean time to pass through the service channel, (berth) is given by

$$E(t) = E(t_1) + E(t_2) + \ldots\ldots\ldots E(tk)$$

$$= k \cdot \left(\frac{1}{k\theta}\right) = \frac{1}{\theta} \quad \text{since for exponential density}$$

$$E(t) = \int_o^{\infty} t \cdot \theta e^{\theta t}\, dt = {}^1/\theta$$

The variance of time through the service channel is $V(t) = \frac{1}{k\theta^2}$ and the standard deviation $= \frac{1}{\theta\sqrt{k}}$. The mean time to pass through service is $\frac{1}{\theta}$ which is independent of k.

The standard deviation takes on values ranging from $^1/\theta$ to o for k = 1,2,3... since the standard deviation $= {}^1/_{\theta\sqrt{k}}$. For a specific value of the mean, $\frac{1}{\theta}$, k can be varied to reduce the variation in t and thus fit a particular Erlang distribution.

If k = 1, mean = $^1/\theta$ and standard deviation = $^1/\theta$ which corresponds to the exponential distribution; as $k \to \infty$, $t \to {}^1/\theta$ a constant.

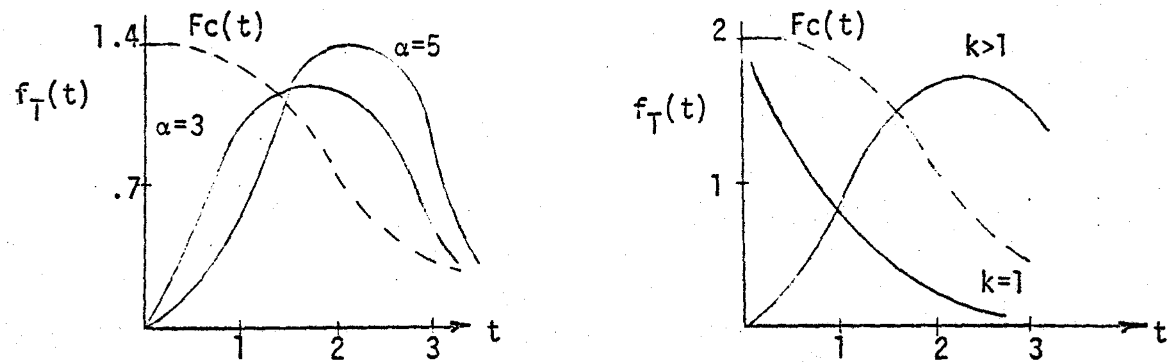
The probability density function (pdf) of t is called the 'Erlang density'

$$f(t) = \frac{k\theta}{(k-1)!}\,(k\theta t)^{k-1}\, e^{-k\theta t} \quad \text{for } t > o$$
$$= \quad o \qquad\qquad\qquad \text{for } t \leq o.$$

The corresponding distribution function is given by:

$$Fc(t) = \int_{o}^{\infty} f(t)\ dt = e^{-k\theta} \sum_{n=o}^{k=1} \frac{(k\theta t)^n}{n!}, \quad t > o \tag{3.1}$$

The derivation for this function is presented in Appendix 4. The quantities $\alpha = k\theta$ and k in the Erlang Pdf are the scale and shape parameters, respectively, α affects only the scale of the curve, whereas k varies the general shape. The plots shown in Fig. III-3 demonstrate the effect of these 2 parameters on scale and shape.



k = 3 Fig. III-3 α = .1

Arrival Time - Distribution

In studying berth service times a distribution was developed which is hypoexponential - i.e. less variable than exponential. However, arrival times are influenced by a larger number of chance factors (e.g. weather, traffic, etc.) than affect berth times. Thus the arrival times come closer to being random in the sense that they are exponentially distributed.

Fig. III-4 and III-5 show the plot of arrival frequencies for ore and coal in 3-day intervals throughout the shipping season. These

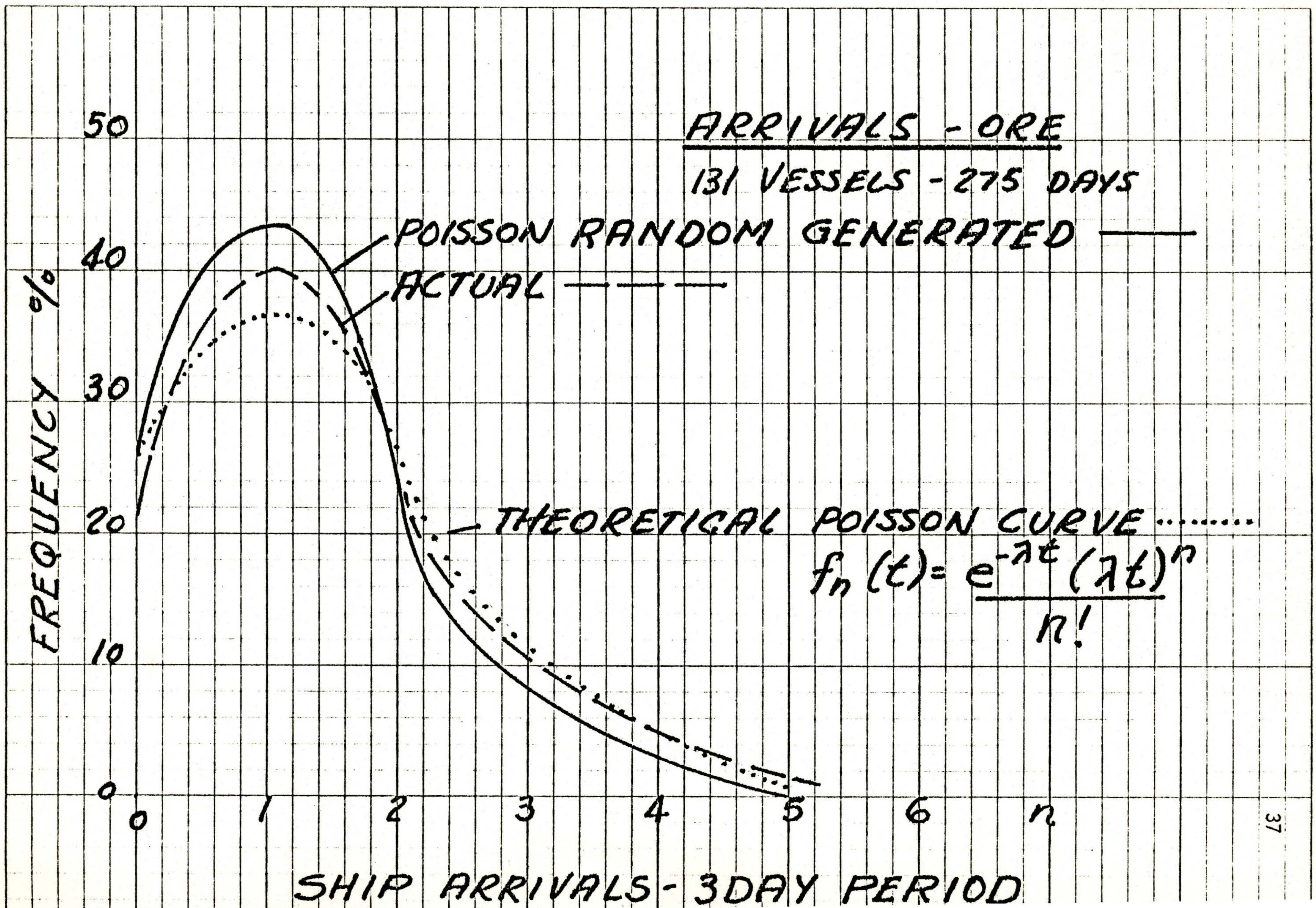

ARRIVALS - ORE
131 VESSELS - 275 DAYS
POISSON RANDOM GENERATED
ACTUAL
THEORETICAL POISSON CURVE
$f_n(t) = \frac{e^{-\lambda t}(\lambda t)^n}{n!}$
FREQUENCY %
50
40
30
20
10
0
0
1
2
3
4
5
6
n
SHIP ARRIVALS - 3DAY PERIOD

FIG III - 4

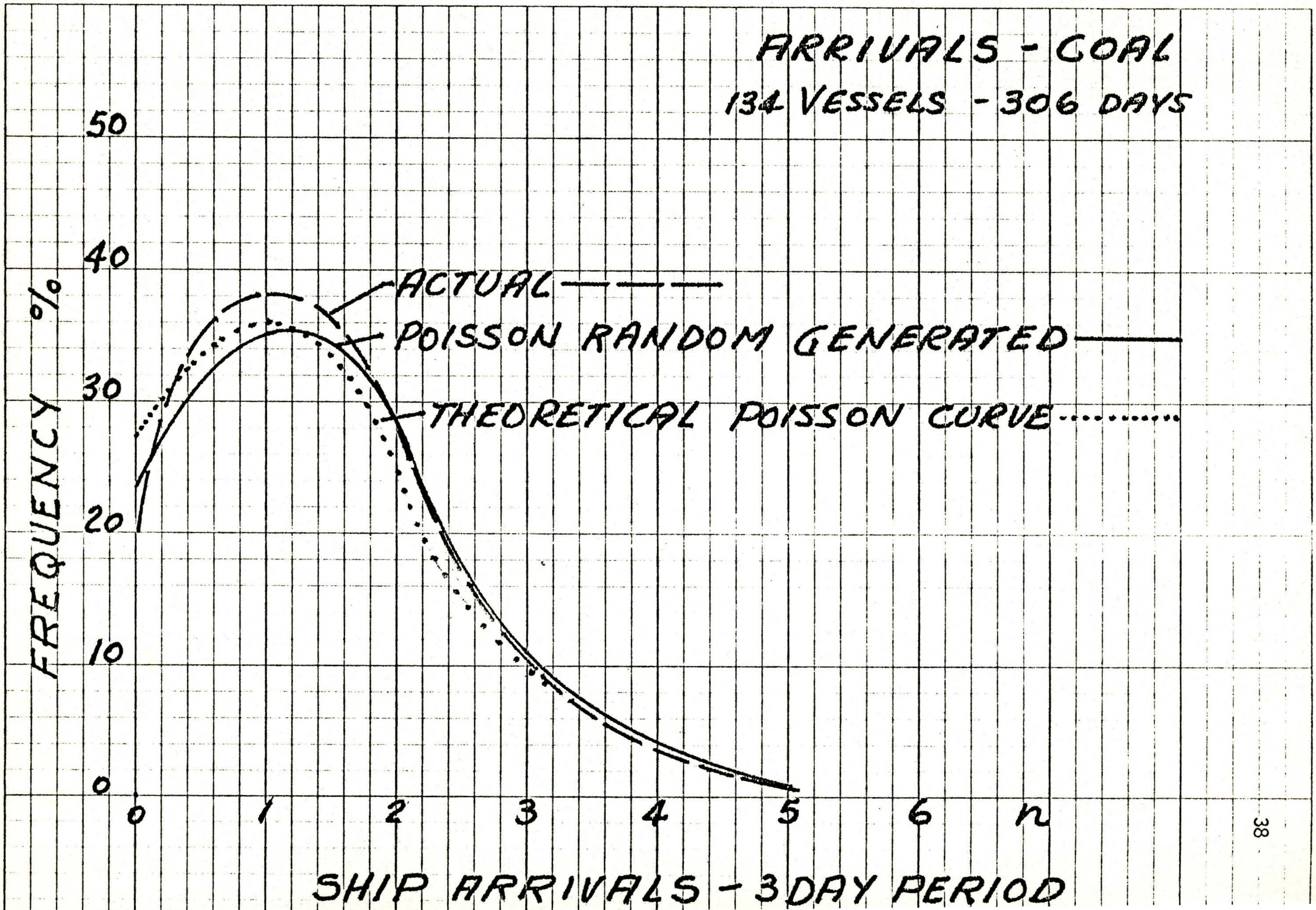

ARRIVALS - COAL
134 VESSELS - 306 DAYS
ACTUAL
POISSON RANDOM GENERATED
THEORETICAL POISSON CURVE
FREQUENCY %
50
40
30
20
10
0
0
1
2
3
4
5
6
n
SHIP ARRIVALS - 3 DAY PERIOD

FIG III-5

plots follow the Poisson distribution with only one parameter, λ, the mean frequency (rate) of arrivals (ships per 3-day period). It will be shown later that if the arrivals follow a Poisson distribution then the interarrival times (times between ship arrivals) follow an exponential distribution with a mean frequency λ. This distribution will be used to generate the arrival times for the model.

Inter Arrival Times - Derivation

The time t between ship arrivals is a random variable and follows an exponential density distribution; $\lambda e^{-\lambda t}$, where λ = arrival rate (ships/hr.). If the arrivals are random and not a function of size of population of arriving vessels then the complement of the probability distribution function of t can be described as follows;

$$Fc(t) = 1 - \int_0^t \lambda e^{-\lambda t} dt = e^{-\lambda t}$$

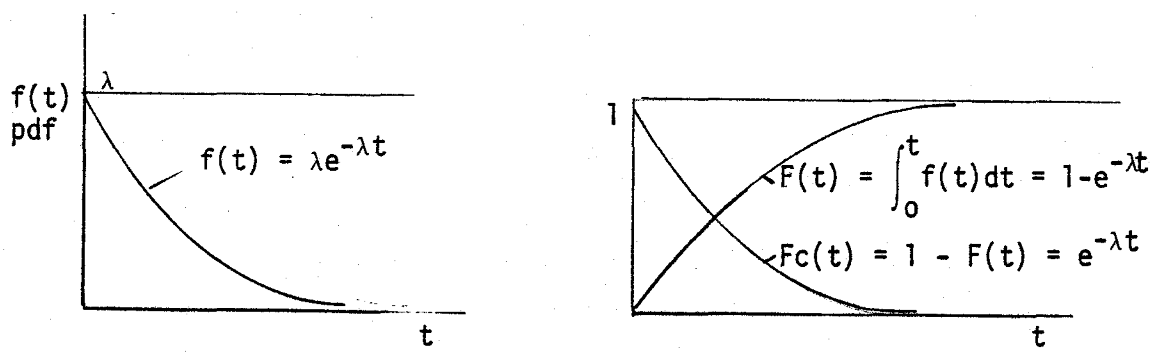


Fig. III-6

When the interarrival times follow an exponential density curve then the distribution of arrivals follows the Poisson distribution given by;

$$Fn(t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \tag{3.2}$$

where n = number of arrivals in time t

λ = mean arrival rate

The derivation of this distribution function is presented in appendix 5. The relationship between the various functions is shown in Fig. III-6.

Monte Carlo Simulation

Having developed probability distributions which describe the arrival and berth times of ships at the existing facilities these distributions may now be used to simulate arrivals and berth times at the Lake Erie dock. It is assumed that the same randomness exists at the new site and that the mean arrival rates (ships/yr. or tonnes/yr.) are those necessary to meet production levels and berth times compatible with conveyor receiving rates and estimated time for approach and departure.

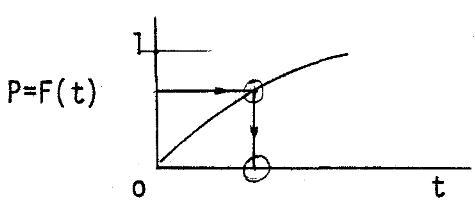
Computer techniques are to be used to simulate the dock operations because of the complexity of the model. This complexity arises because consideration must be given to both coal and ore arrivals and services with different and rather complex distributions. The coal and ore vessels arriving with different Poisson distributions must be merged in the order that they arrive to be queued into either a single or double berth dock. The berth service times are generated at the same time according to the Erlang distribution.

With vessels arriving and being serviced randomly according to the distribution developed previously, interference will occur and queues will grow and diminish. By recording waiting times due to this interference, berth time, queue length and frequency, the efficiency and cost of operation of the system can be predicted, further, the model parameters can be altered easily to determine the effect on the system.

Monte Carlo simulation in this model simply involves generating times for arrivals conforming to a Poisson distribution and berth times conforming to an Erlang distribution.

In general, we have a probability distribution $P = F(t)$ with range of $o < F(t) \leq 1$ and domain consisting of the admissible values of t, $t > o$.

Mathematically $t = F^{-1}(p)$ is evaluated using the inverse function of F(t).



Monte Carlo sampling simply reduces to using random numbers (uniform random density function; $o < (RN) \leq 1$) to enter the ordinate scale and values are read from the t scale. Analytical methods can be used to evaluate $F^{-1}(P)$ for the distributions being used.

Arrival Time Distribution (Poisson)

To simulate arrival times interarrival times are generated with t exponential with parameter λ (mean arrival rate) and density $f(t) = \lambda e^{-\lambda t}$. Accumulating these times gives the time of arrival of each vessel; the resulting frequency conforms to a Poisson distribution, Equation 3.2, which is the probability that n vessels will arrive in time period t.

Using the exponential interarrival times with density $f(t) = \lambda e^{-\lambda t}$ and the functions; $F(t) = 1 - e^{-\lambda t}$ and $Fc(t) = e^{-\lambda t}$ (see Fig. III-6) the following expression for t can be derived;

$t = (-\frac{1}{\lambda}) \ln[Fc(t)]$, or,

$$t = (-\frac{1}{\lambda}) \ln (p) \qquad (3.3)$$

where $p = Fc(t)$.

In order to generate a sequence of values according to density $\lambda e^{-\lambda t}$ random numbers are sequentially assigned to p and equation 3.3 is evaluated.

Berth Time Distribution (Erlang)

For berth service times, t is to have an Erlang distribution with parameters θ and k where $^1/\theta$ is the mean service time (hrs./ship) and k is the shape parameter. Recall that the Erlang random variable can be expressed as a sum of k independent random variables, each having density $g(tj) = (k\theta)\ e^{-k\theta t}$ so that $t = t_1 + t_2 + \ldots t_k$. To generate a sequence of t values, the inverse for the exponential distribution is used k times with $\mu = (k\theta)$. Summing for each value of t, yields

$$tj = - (\frac{1}{k\theta}) \ln (P) \tag{3.4}$$

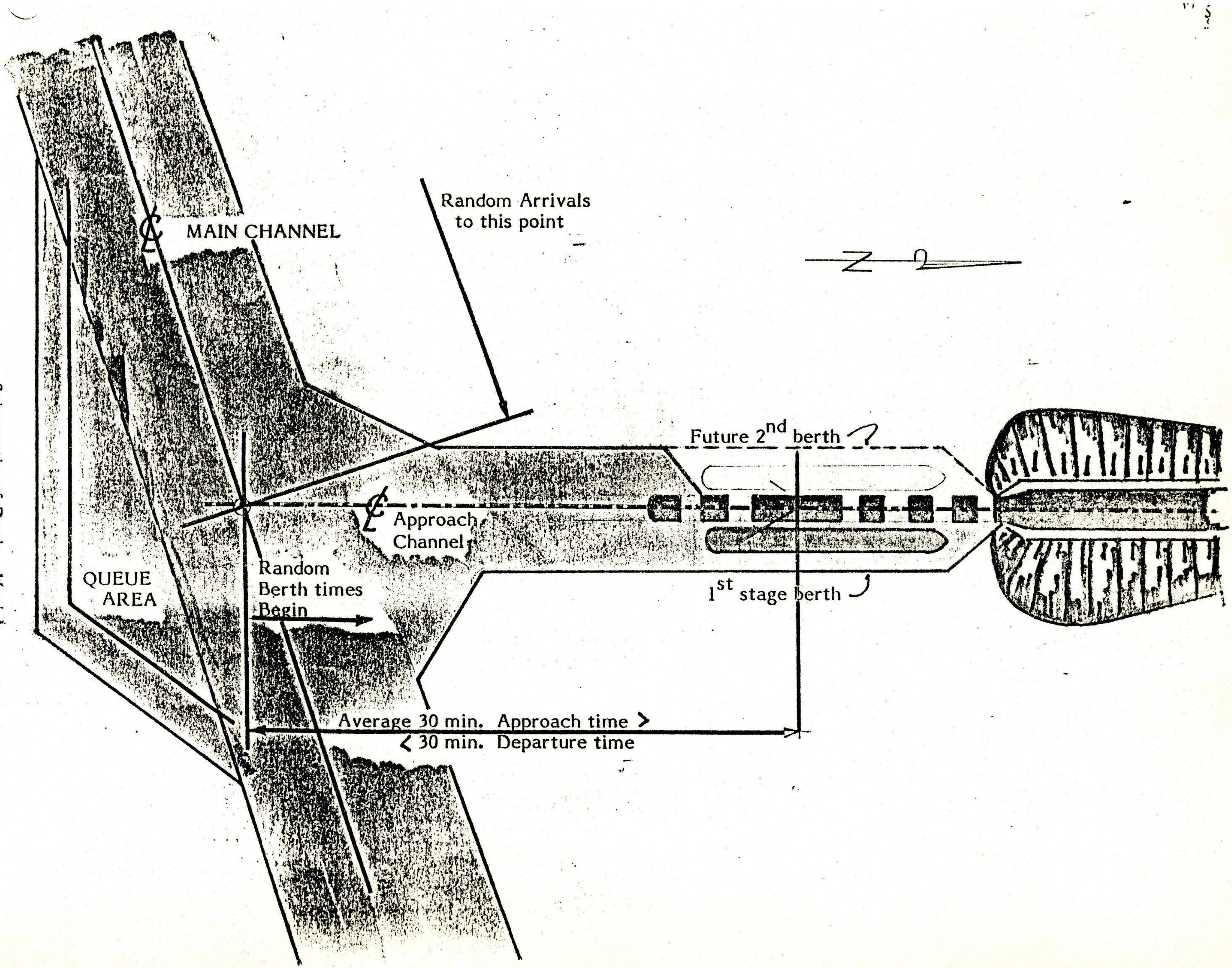
Considering the present case, for example with k = 5, 5 random numbers are used, evaluating equation 3.4 with each and summing to determine a value of t. Repetition of this procedure results in a sequence of values t which conform to the Erlang density.

Simulation of Dock

Now that a method has been developed for generating random arrivals and berth times conforming to distributions based on historical data a model can be constructed which simulates the dock operation itself.

The following physical description will help clarify the model: Fig. III-7.

Ore and coal ships arriving randomly at the approach channel queue up in the order of arrival or approach the dock if a berth is free. If a queue exists the arriving vessel takes its place in the queue and the first vessel in the queue approaches the dock when berth and approach channels are clear. The time for service in berth for each vessel is generated randomly, conforming to previously developed distributions. The total berth time is the sum of the approach and departure times and the random berth service time. The



Schematic of Dock - Model

FIG III-7

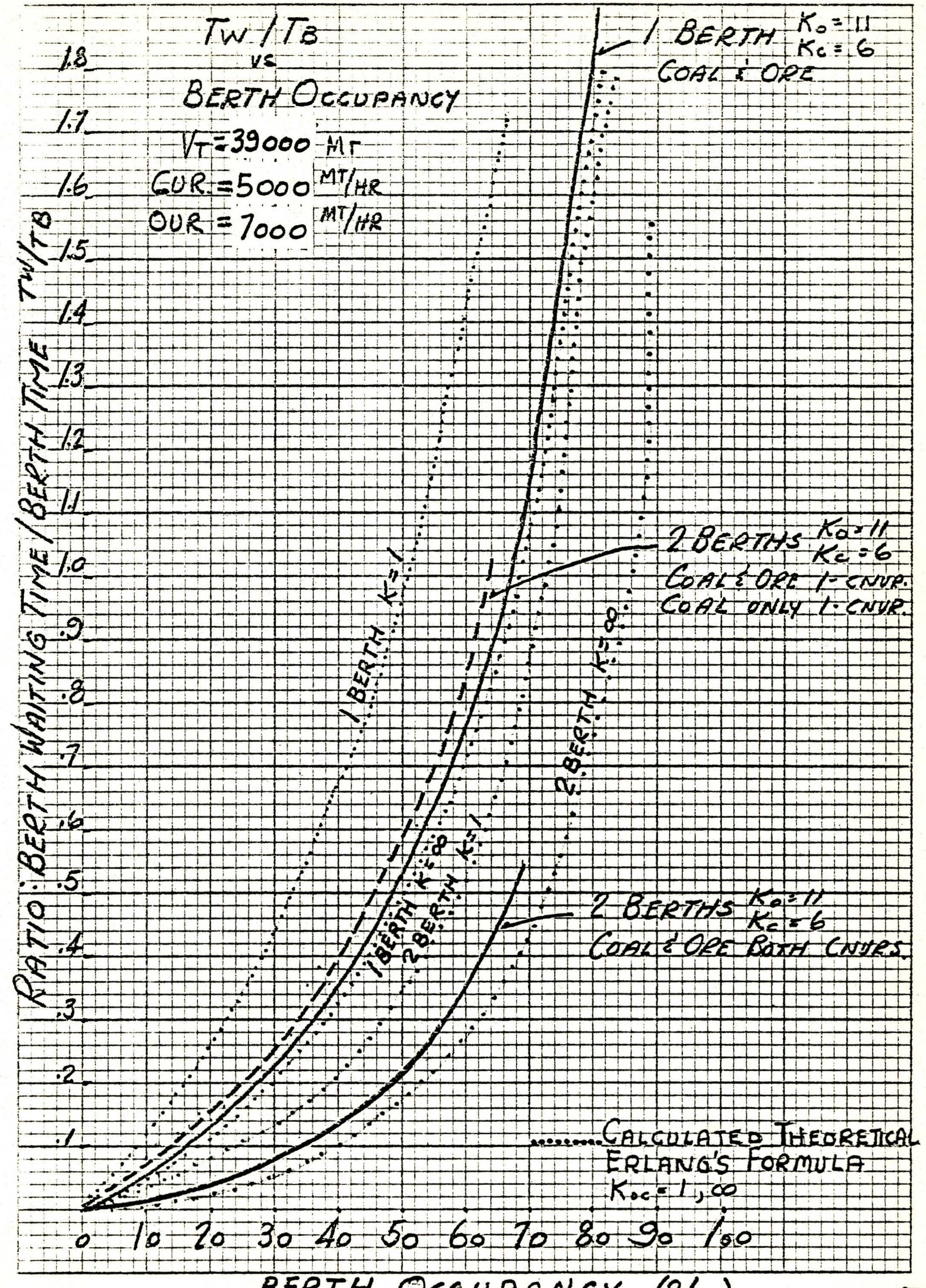

Tw / Tb vs BERTH OCCUPANCY
V_T = 39000 MT
CUR = 5000 MT/HR
OUR = 7000 MT/HR
1 BERTH Ko = 11 Kc = 6 COAL & ORE
2 BERTHS Ko = 11 Kc = 6 COAL & ORE 1-CNVR. COAL ONLY 1-CNVR.
2 BERTHS Ko = 11 Kc = 6 COAL & ORE BOTH CNVRS.
1 BERTH K = 1
1 BERTH K = ∞
2 BERTH K = 1
2 BERTH K = ∞
.........CALCULATED THEORETICAL ERLANG'S FORMULA Koc = 1, ∞
RATIO: BERTH WAITING TIME / BERTH TIME Tw/Tb
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
10
20
30
40
50
60
70
80
90
100
BERTH OCCUPANCY (%)

FIG III-8

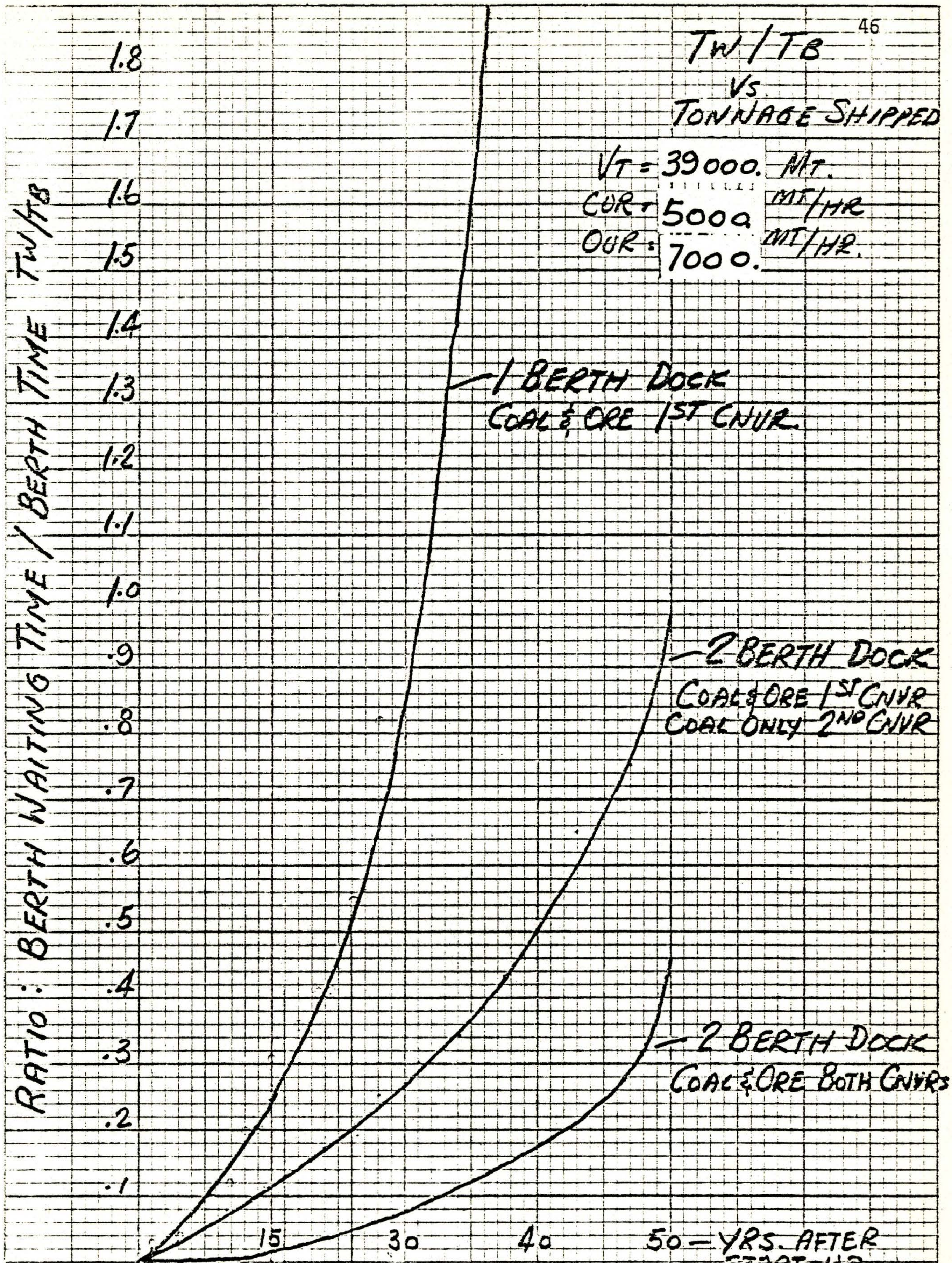

TW / TB
VS.
TONNAGE SHIPPED
VT = 39000. MT.
COR = 5000. MT/HR
OUR = 7000. MT/HR.
1 BERTH DOCK
COAL & ORE 1ST CNVR.
2 BERTH DOCK
COAL & ORE 1ST CNVR
COAL ONLY 2ND CNVR
2 BERTH DOCK
COAL & ORE BOTH CNVRS
RATIO: BERTH WAITING TIME / BERTH TIME TW/TB
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
15
30
40
50 — YRS. AFTER START-UP
10
20
30
40
TOTAL TONNAGE SHIPPED (MT × 10⁶)

FIG III-9

approach and departure times (taken from centerline of the main channel or queue area) are also random depending on weather, traffic, currents and time of day. This randomness is accounted for by the random berth time distribution.

Following the above logic, queue waiting time and length are recorded to give a measure of interference, shipping delay costs and maximum queue size expected.

A useful ratio to record is the ratio of waiting time to berth time, TW/TB. This can be plotted against berth occupancy as a % to give a measure of dock efficiency.

Fig. III-8 shows the difference in waiting time between a 1 berth and 2 berth dock. It can be seen that with proportionately similar delays (for example, TW/TB = o.1) the single berth can be operated at only 16% occupancy while each of the two berths can be operated at 34% occupancy. With equal handling rates the combined capacity of the pairs of berths is therefore about 4 times that of a single berth for a constant TW/TB.

Although a two berth dock is more efficient, it also involves a higher initial capital cost. Therefore, the economics of deferring this additional capital cost for a double berth and operating with a single berth with higher operating costs must be investigated. This investigation will be the subject of Chapter V.

Fig. III-9 shows the ratio TW/TB against tonnage levels for 3 alternatives to demonstrate the effect of restricting the 2nd berth to coal receiving only. For example, at the 20×10^6 tonne level the

TW/TB ratio is 3.25 times higher when the 2nd berth is restricted to coal only.

Fig. III-10 illustrates the delay costs as a function of tonnage level for various unloading rates and vessel sizes. These curves demonstrate that for low tonnage levels (less than 2×10^6 MT) the curves converge, indicating little difference in the alternatives. The curves also demonstrate that vessel size has a smaller affect on delay costs than unloading rates. It is obvious that the largest affect on delay costs is due to the number of berths.

The lowest present value at which a second berth is economical is indicated and shows that, if the higher unloading rates are used, then construction of the second berth can be deferred from the 11 million tonne level to the 15 million tonne level. This relationship will be explained in more detail in the present value analysis of Chapter V.

Fig. III-11 compares the delay cost of a single berth, double berth and restricted double berth. It emphasizes the impact on delay costs if the second berth is restricted to receiving coal only. The delay costs of a restricted berth approach those of a single berth. This demonstrates that ore receiving is the most important capability and must not be restricted.

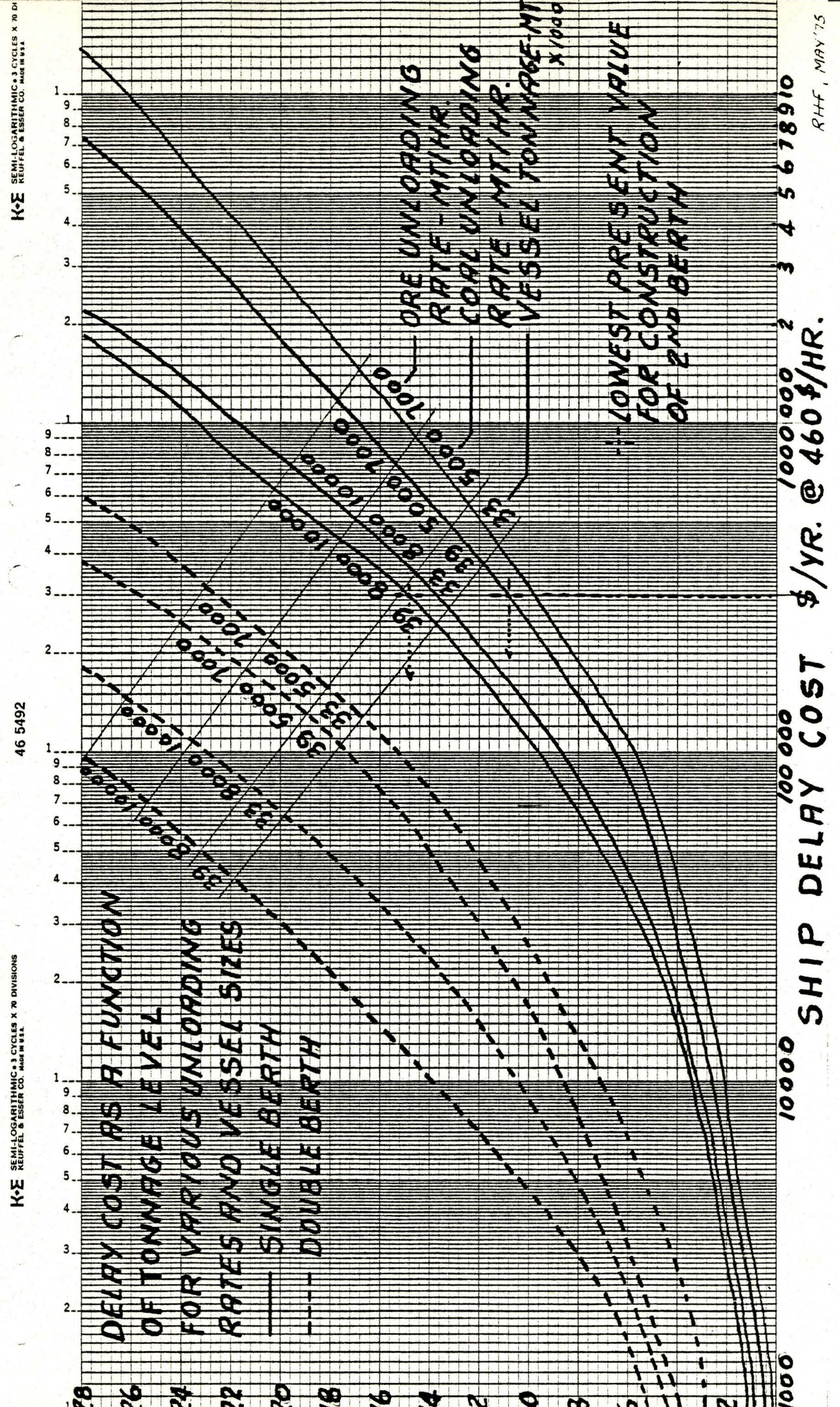
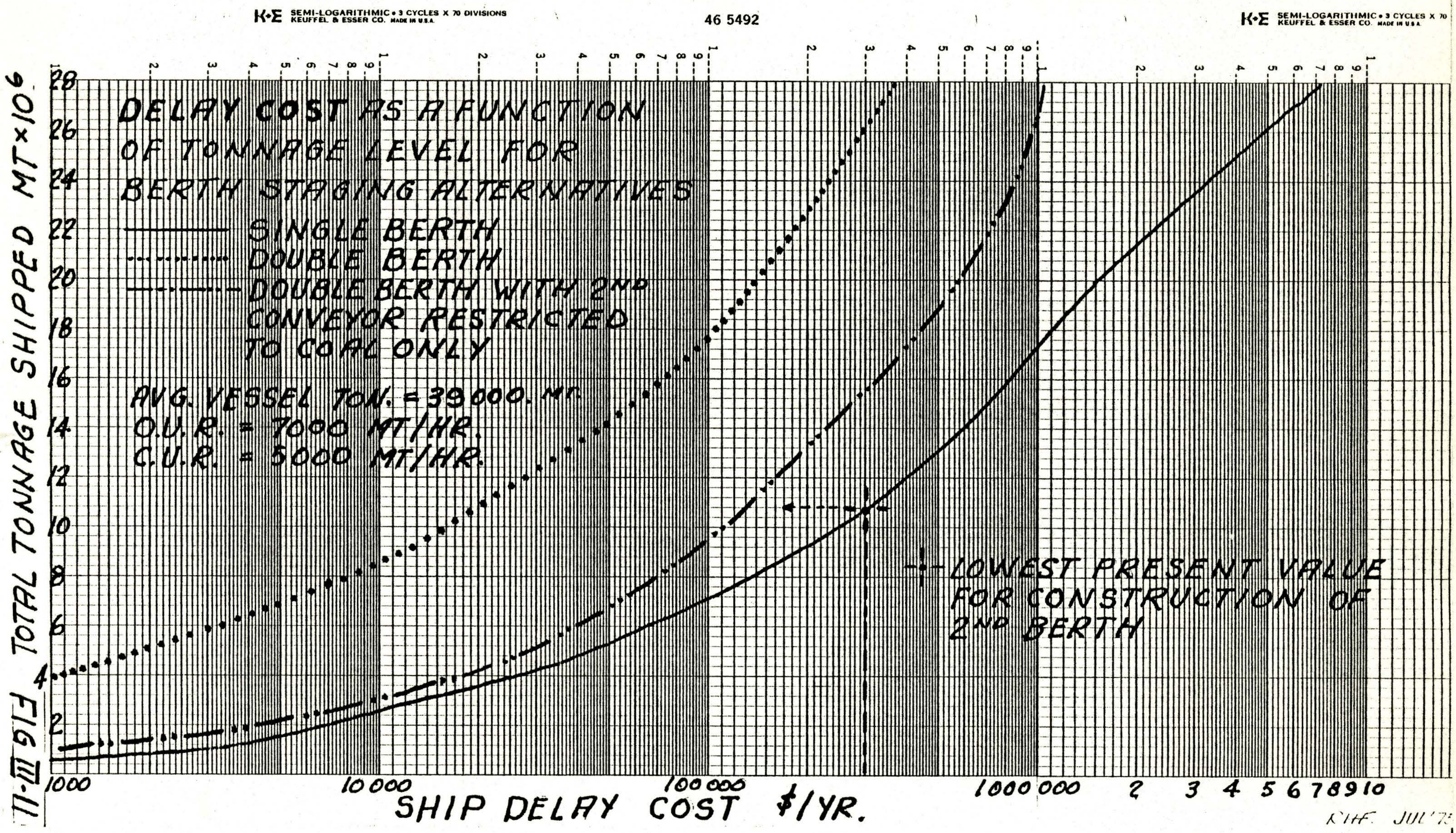

DELAY COST AS A FUNCTION
OF TONNAGE LEVEL
FOR VARIOUS UNLOADING
RATES AND VESSEL SIZES
—— SINGLE BERTH
- - - - DOUBLE BERTH
ORE UNLOADING
RATE - MT/HR.
COAL UNLOADING
RATE - MT/HR.
VESSEL TONNAGE-MT
X 1000
LOWEST PRESENT VALUE
FOR CONSTRUCTION
OF 2ND BERTH
SHIP DELAY COST $/YR. @ 460 $/HR.
TOTAL TONNAGE SHIPPED MT×10^6
RHF, MAY '75

FIG III-10



K·E SEMI-LOGARITHMIC • 3 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 5492
DELAY COST AS A FUNCTION
OF TONNAGE LEVEL FOR
BERTH STAGING ALTERNATIVES
SINGLE BERTH
DOUBLE BERTH
DOUBLE BERTH WITH 2ND
CONVEYOR RESTRICTED
TO COAL ONLY
AVG. VESSEL TON. = 39000. MT.
O.U.R. = 7000 MT/HR.
C.U.R. = 5000 MT/HR.
LOWEST PRESENT VALUE
FOR CONSTRUCTION OF
2ND BERTH
TOTAL TONNAGE SHIPPED MT×10^6
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1000
10 000
100 000
1000 000
2 3 4 5 6 7 8 9 10
SHIP DELAY COST $/YR.
RHF JUL'7

FIG III-11

CHAPTER IV

CALIBRATION AND APPLICATION OF MATHEMATICAL MODEL

This chapter considers the necessary adjustments or calibration of the model parameters and the input data in order to obtain some indication of model accuracy.

Historical Data Input

Historical data was collected at Hilton Works and used for estimating the distribution of arrivals and berth times. (See Appendix 6). The number of arrivals and unloading times were then grouped into time intervals, a 3-day interval for arrivals and a 1/2 hour interval for berth times, thus forming histograms. The resulting distributions are described in Chapter III. The time intervals were selected assuming a steady-state situation existed in that interval. Several different years of operation were checked to insure that the data used was taken from a steady-state interval. A non-steady-state might have occurred for instance after a shipping strike or major breakdown or if the seaway was late in opening due to extended bad weather.

In order to insure that the data used is statistically independent the 'runs up and down' technique was used. This technique is described by Hald (4).

Sample interarrival times from the Hilton works historical data are used with n = 25, and $x_i \ldots\ldots x_n$, n - 1 differences are taken $x_{i-1} - x_i$, i = 1, ...n - 1.

The sequence of consecutive plus signs is a run up and minus signs a run down.

Then if ri = number of runs of length i

$$R_k = \sum_{i=k}^{n-1} ri \quad = \text{number of runs of k or more}$$

$$R = \sum_{i=1}^{n-1} ri \quad = \text{total number of runs}$$

If the observed times are statistically independent then the distribution for r^i, R^k and R can be derived and compared.

Assuming that all n! possible arrangements of the n numbers are equally likely, leads to the following result;

$$E(ri) = \frac{2}{(i+3)!}\left[n(i^2 + 3i + 1) - (i^3 + ei^2 - 4)\right] \quad i < n - 2$$

$$E(Rk) = \frac{2}{(k+2)!}\left[n(k + 1) - (k^2 + k - 1)\right] \quad k \leq n - 1$$

$$E(R) = {}^1/_3(2n - 1)$$

Using the Historical Data from Appendix 6, the analysis yields the result shown in Table III-1(a) and Table III-1(b). The estimates and measurements of ri, Rk and R are compared in Table III-1(b). This comparison indicates that the data are statistically independent to a reasonable degree.

Interarrival times	Sign	Berth times	Sign
45		6.6	-1
137	+	5.5	+1
183	+2	6.0	-1
8	-1	5.5	+
54	+	5.8	+2
102	+2	6.6	-
98.5	-	5.7	-
88	-3	5.6	-
80	-	4.8	-4
160	+1	4.7	+
51	-	4.9	+2
7	-2	5.6	-1
20	+	4.9	+
111	+2	6.5	+2
51	-1	7.8	-
69	+1	6.9	-
48	-1	6.7	-3
82	+1	5.6	+1
66	-	8.5	-1
16	-2	4.8	+
60	+1	5.5	+
17	-1	6.5	+3
50	+	6.7	-1
185	+2	6.6	+1
71	-	7.0	-1
20.5	-2	4.8	+
93.7	+1	5.9	+2
92	-1	8.8	-
125	+1	8.5	-2
n = 29		7.7	+1
		8.9	-
		6.8	-2
		4.9	+1
		9.8	-1
		7.6	+1
		n = 35	

Table III-1(a)

"Run-up - Run-down Analysis"

SUMMARY COMPARISON

	STATISTIC	OBSERVED	EXPECTED FROM THEORETICAL DISTRIBUTION IF STATISTICALLY INDEPENDENT
INTERARRIVAL TIMES	r1	11	12
	r2	7	5
	r3	1	1.4
	R1	19	19
	R2	8	7
	R3	1	1.75
	n = 29		
BERTH TIMES	r1	12	14.6
	r2	6	6.2
	r3	2	2.0
	r4	1	.4
	R1	21	23
	R2	9	8.3
	R3	3	2.2
	R4	1	.43
	n = 35		

Table III-1(b)

Comparison of run-up, run-down parameters

The data, after being plotted from the interval groupings into frequency histograms suggested a Poisson distribution for arrivals and an Erlang distribution for the berth service times (see Figs. III, 1,2,4,5.) Using these hypothesized distributions the observed and hypothetical model distributions may be compared for goodness of fit using the Chi-square test with level of significance of o.ol.

Testing Goodness of Fit; Chi-square Test

The following theorem was invoked:

Given a set of observed frequencies, f1,f2, ...fk and a corresponding set of expected frequencies, $e_1, e_2, \ldots e_k$ for k possible outcomes of an experiment consisting of n trials, then, as $n \to \infty$

$x^2 = \sum_{i=1}^{k} \frac{(fi-e_i)^2}{ei}$ will approach the Chi-square distribution with (k-1) degrees of freedom.

Given the distribution of arrival times for coal as a Poisson process (see Fig. III-5), then,

$$x^2 = \sum_{i=1}^{6} \frac{(19-27)^2}{27} + \frac{(38-36)^2}{36} + \frac{(28-24)^2}{24}$$

$$\frac{(9.5-10.5)^2}{10.5} + \frac{(4.5-3.5)^2}{3.5} + \frac{(1.5-.75)^2}{.75}$$

$x^2 = 4.28$, $k-1 = 5$ degrees of freedom.

Now using the Chi-square distribution to test significance of .01

$P(x^2 > 15.09) = .01$ (Tables)

15.09 is the critical value and since the calculated value 4.28 < 15.09 the fit is acceptable at a significance level of .01.

Similar tests were carried out on the Poisson distribution for ore, Fig. III-4, which indicated an acceptable fit, see Appendix 6.

Berth Times: Erlang - Chi-Square Test

Given the distribution of berth times for ore as an Erlang distribution (Fig. III-1), with the following parameters; mean

$^1/\theta = 5.67$

$\theta = .1763$

$k = 11,\ k\theta = 1.94$

Erlang distribution $f(t) = \frac{1.94}{10!} \cdot (1.94t)^{10} \cdot e^{-1.94t}$,

then, $x^2 = 18.3$, as derived below.

Berth Service Time t-Hrs.	Observed frequency	Erlang frequency	$x^2 = \frac{(fi-ei)^2}{ei}$
3	2	9	5.4
4	18	23	1.08
5	46	30	8.50
6	32	27	.925
7	14	18	.89
8	11	10	.10
9	2	4	1.0
10	1	2	.50
	126	123	18.3
	$\frac{1}{\theta} = 5.67$	$\frac{1}{\theta_e} = 5.60$	

$P(X^2 < 18.48) = .01$ level of Significance. Since the calculated value of 18.3 is less than the critical value, 18.48, the Hypothesis that the observed distribution conforms generally to an Erlang distribution is accepted.

The above test compared the observed data against a theoretical Erlang distribution. The cumulative plot, Fig. III-1 indicates a closer fit than that indicated by the Chi-Square test at .01 level of significance. This is due to a tendency for a cumulative plot to smooth out small deviations between the two frequency curves.

By adjusting the distribution parameter k the fit could be improved. This would require several more trials. The k parameter can also be adjusted to try and account for a possible difference in randomness at the new facility (k decreasing for greater randomness).

However, k should increase at the new facility due to a more modern fleet which will not be prone to as much uncertainty. The weather factors will tend to reduce k i.e. more randomness being a more exposed facility and more dependent on receiving equipment.

In accepting data the relationships between the mean arrival and service times should be checked against the time of day to determine if the parameters are independent of the time of day. This could be done by means of regression analysis or the cumulative sum chart. In this case, the berth time will certainly be affected to some degree if the ship approaches the dock and unloads at night. However, this effect should already be accounted for by the random nature of the data from which the distributions were developed, therefore, this possible affect will not be considered further.

Based on the above analysis and reasoning it is felt that the arrival and service time data can be adequately represented by the selected distribution, within the accuracy required for this study.

Calibration of MonteCarlo Simulation Model

The Monte Carlo simulation method has frequently been applied to queuing problems to obtain numerical solutions. In this study it provides a very flexible and powerful tool to generate, combine and manipulate very complex distributions. It also allows the distribution parameters to be changed in order to examine the effects on the process. (See Chapter III for Monte Carlo application.)

In implementing the Monte Carlo method random numbers are generated and used to select values from the probability distributions which describe the random process being simulated (in this study the Poisson and Erlang distributions were used). The probability distributions can be any type provided they describe the randomness of the process correctly. It is more convenient for manipulation purposes if the distribution can also be represented by a mathematical function; however, a graphical representation may also be used.

The accuracy* of the Monte Carlo method improves approximately as $\sqrt{N}$ where N is the number of trials or replications. Also, the

* Since the procedure employs statistical sampling, the accuracy may be more precisely described as reduction in variance around the expected value.

accuracy is directly proportional to the reliability of the historical data used.

To demonstrate how the smoothness of the results is affected by the number of replications several simulations were made and the results averaged. The effect of the number of cycles on the variance or smoothness of the results is shown in Fig. IV-1. Based on this it was decided to use 5 cycles for the simulation process.

Since the Monte Carlo simulation provides only an approximate numerical solution, upper and lower bounds on the results would constitute valuable information on the accuracy of the method. To this end an analytical approach was useful in providing solutions at the boundaries as described in Chapter II and plotted with dotted lines in Fig. III-8. This plot indicates that the computer simulation results (solid lines) are within the bounds set by the analytical approach for the extremes of the Erlang distribution $K = 1$, exponential berth times and $K = \infty$, for constant berth times.

Check on Random Number Generation

One final check should be made on the generation of random numbers used in the Monte Carlo simulation to ensure that the results are not affected by the starting or "seed" values used in the generation process.

During the Monte Carlo simulation successive random numbers are called for from the computer sub-routine RANDU (IX, IY, P). Each value of P is equally likely to be selected, as if being drawn from a uniform random density function, ($o < RN \leq 1$). The value is then used to generate a Monte Carlo sample by evaluating the appropriate inverse function as described in Chapter III. The 'seed' value Ix is input to start the process and the last random integer generated, IY, is saved for the next use of the generator.

Fig. IV-2 indicates that the 'seed' value has no affect on the simulation results, within the accuracy of this study.

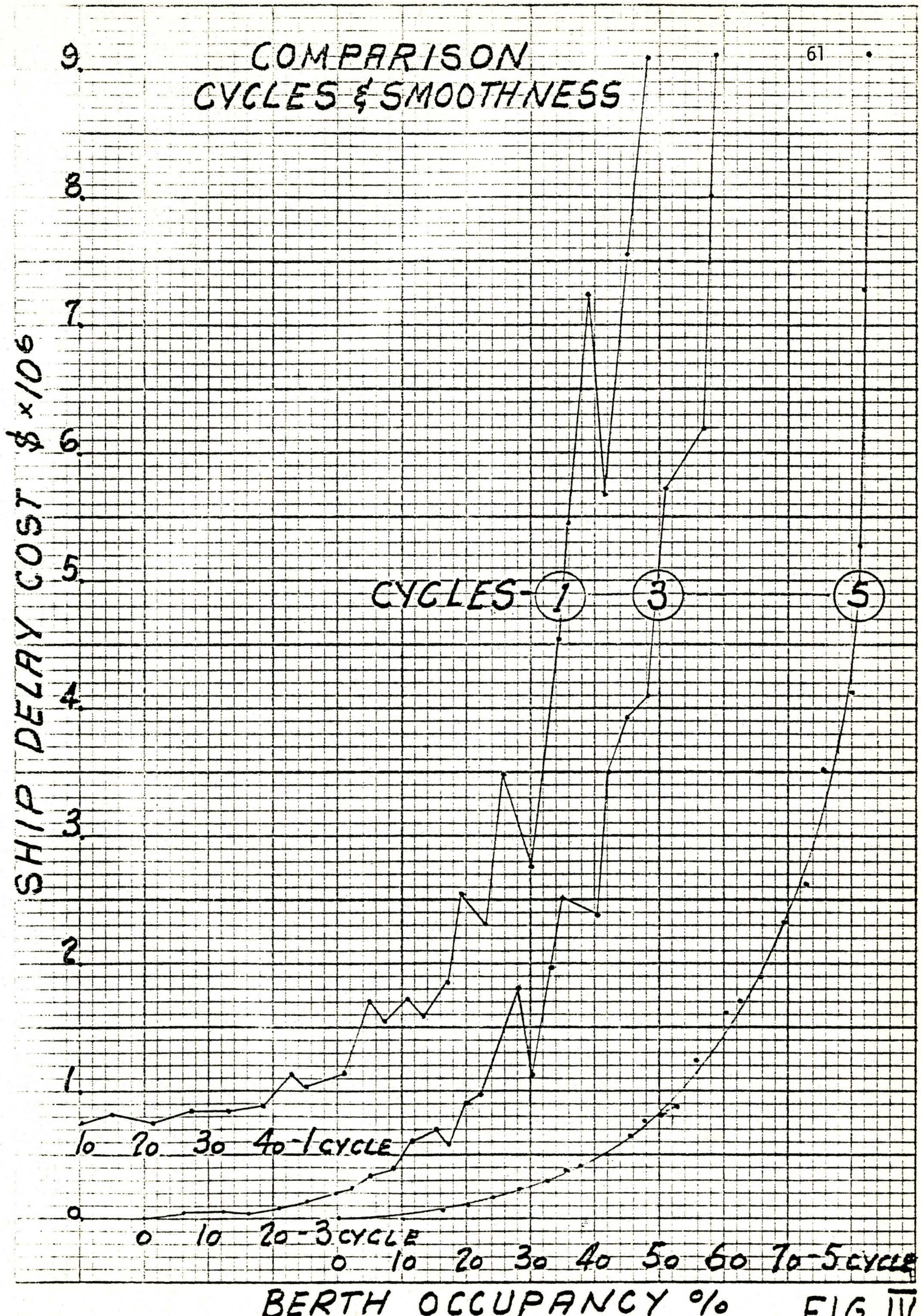

COMPARISON
CYCLES & SMOOTHNESS
SHIP DELAY COST $ ×10⁶
9.
8.
7.
6.
5.
4.
3.
2.
1.
0
CYCLES- 1 3 5
10 20 30 40-1 CYCLE
0 10 20-3 CYCLE
0 10 20 30 40 50 60 70-5 CYCLE
BERTH OCCUPANCY %

FIG IV-1

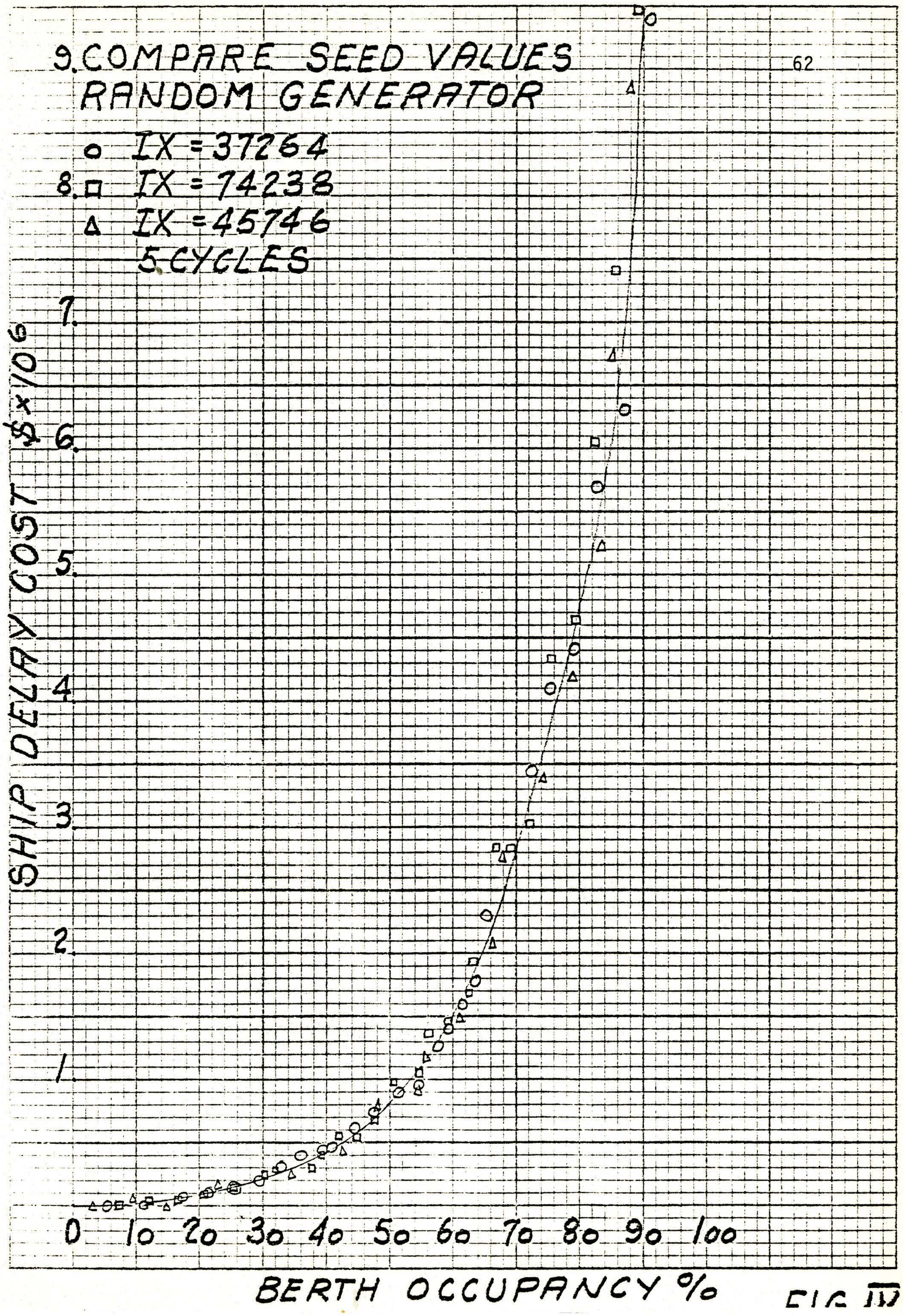

9. COMPARE SEED VALUES
RANDOM GENERATOR
o IX = 37264
□ IX = 74238
Δ IX = 45746
5 CYCLES
SHIP DELAY COST $ x 10^6
1.
2.
3.
4.
5.
6.
7.
8.
9.
0
10
20
30
40
50
60
70
80
90
100
BERTH OCCUPANCY %

FIG IV

CHAPTER V

ECONOMETRICS OF MODEL

The ship delay costs generated by the model are discounted using present value technqiues to evaluate the various alternatives to berth expansion and material receiving.

Before developing the present value approach used in the computer model it is appropriate to examine the economic balance between ship delay cost and service costs. This comparison will indicate the optimum unloading rate.

The case of ore pellet receiving at the dock with a single berth will be considered first. Ore arrives in 39000 Metric ton (t) vessels at a rate of λ vessels per hour. The arrival rate parameter λ increases as the production level increases, however, the question here is, at what rate should the vessels be unloaded at the dock? Vessels obviously must be serviced faster than they arrive to maintain a steady-state system, i.e. $\rho = {}^{\lambda}/\mu < 1$ where μ is the service rate as previously defined. The utilization factor $\rho = {}^{\lambda}/\mu$ must be less than 1, but how much less is economical? The service rate can be increased by installing larger equipment and more power to service vessels more quickly. This will increase service costs and reduce ship delay costs.

The service cost curve may be estimated as shown by Fig. V-1. This curve indicates how costs increase with increasing rate of service. These curves indicate a smooth transition between various conveyor combinations which provide the unloading capacity. However, in practice conveyor capacities would follow a stepwise increase as drives are added and belts widened to provide extra capacity.

Assuming the ship delay times or the mean wait per service at the dock is as defined by equation 2.15, then it follows that

$Wq = \frac{\lambda}{\mu} \cdot [\frac{1}{\mu-\lambda}]$ which indicates that as μ increases, Wq decreases and $\rho = \frac{\lambda}{\mu}$ decreases. It should also be noted that the berth idle time $(1-\rho)$ increases.

The total cost per service is then given by:

$$\text{SERVICE COST} = fc(\mu) + \text{ship delay cost}$$

$$= fc(\mu) + SDC \cdot \frac{\lambda}{\mu} \cdot [\frac{1}{\mu-\lambda}]$$

where SDC is ship delay charge per hour assumed to be passed on by the shipping companies. $fc(\mu)$ is the cost of providing a certain unloading rate, including, power, repair and maintenance, cost of capital etc. By plotting this total cost per service a minimum is indicated. (Fig. V-2). This is plotted for an arrival rate of $\lambda = .04$ at an ore tonnage level of 12×10^6 MT/YR.

The optimum service rate $\mu_{opt.} = 0.21$, which is equivalent to an ore unloading rate of 11,000 tph, assuming a total of one hour

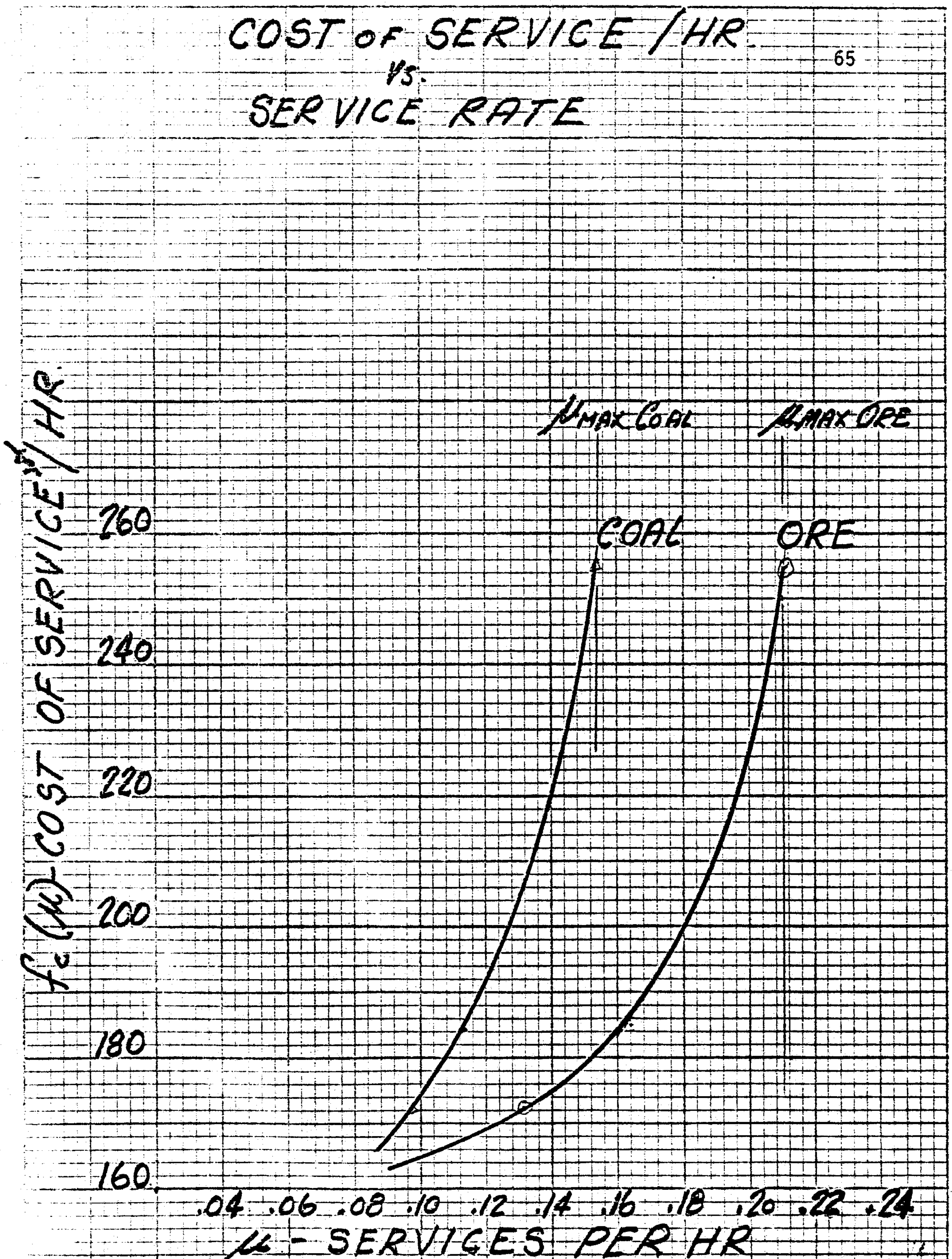

COST OF SERVICE / HR
VS.
SERVICE RATE
$f_c(\mu)$ COST OF SERVICE $/HR
μMAX COAL
μMAX ORE
COAL
ORE
260
240
220
200
180
160
.04 .06 .08 .10 .12 .14 .16 .18 .20 .22 .24
μ - SERVICES PER HR

FIG V-1

for approach, tie-up and departure.

A similar analysis can be applied to coal receiving, and results are plotted on Fig. V-3 which indicate $\mu_{opt.} = 0.14$ which is equivalent to a coal unloading rate of 6,700 tph.

The above results can be summarized in the following table.

Material	Tonnage Level	Optimum Unloading Rate Indicated
Steel in ladle	4.2×10^6	
Coal	2.75×10^6	6,100 tph
Ore	5×10^6	9,600 tph
Steel in ladle	10×10^6	
Coal	6.5×10^6	6,700 tph
Ore	12×10^6	11,000 tph

TABLE V-1

In this simplified analytical study each material has been analyzed separately in order to indicate the optimum.

However, in reality both coal and ore arrivals should be merged together to get a true measure of the interference, which results in ship delay time at the dock. Since the arrivals of each material were considered separately the ship delay times indicated by the above

COSTS vs SERVICE RATE

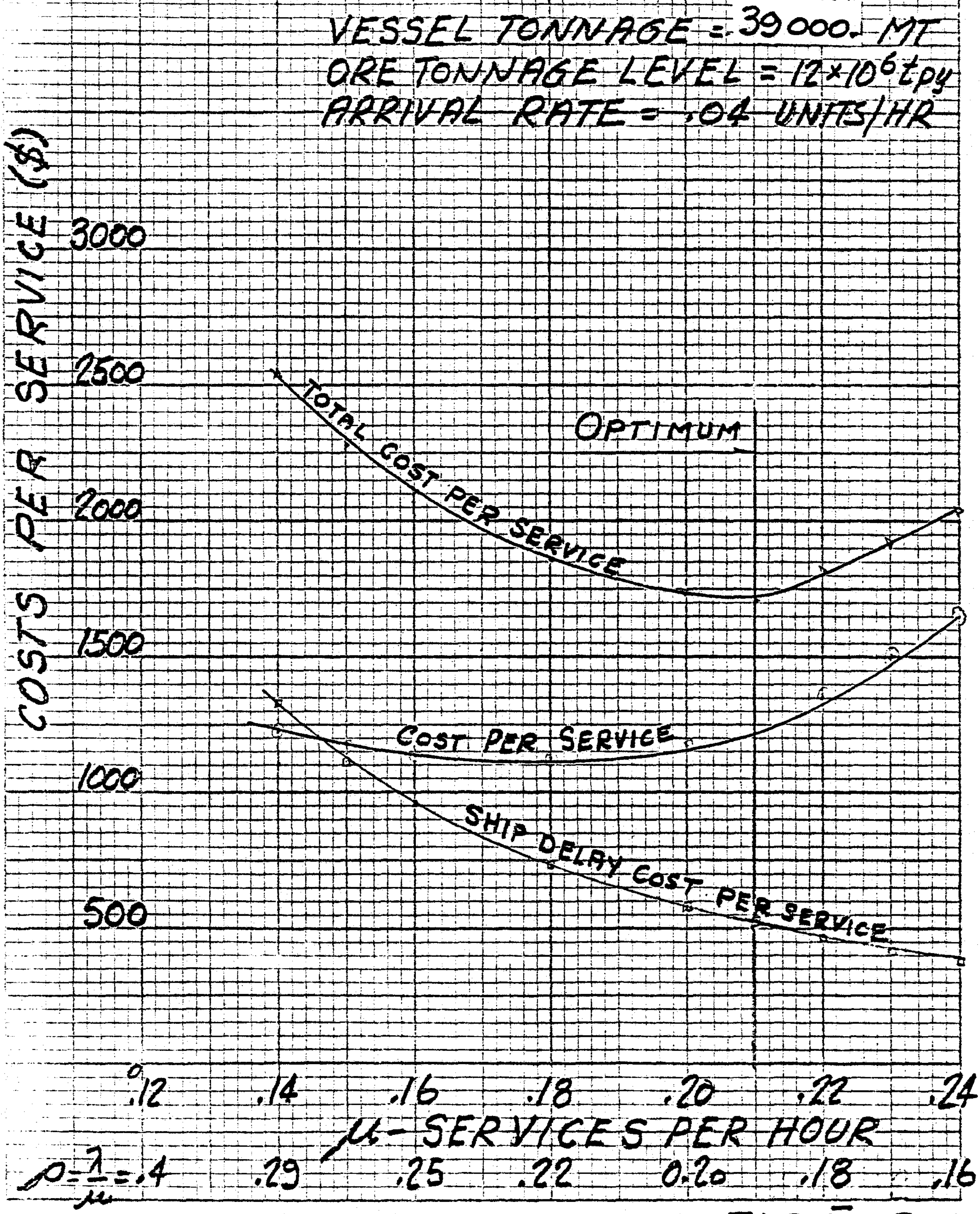


FIG V-2

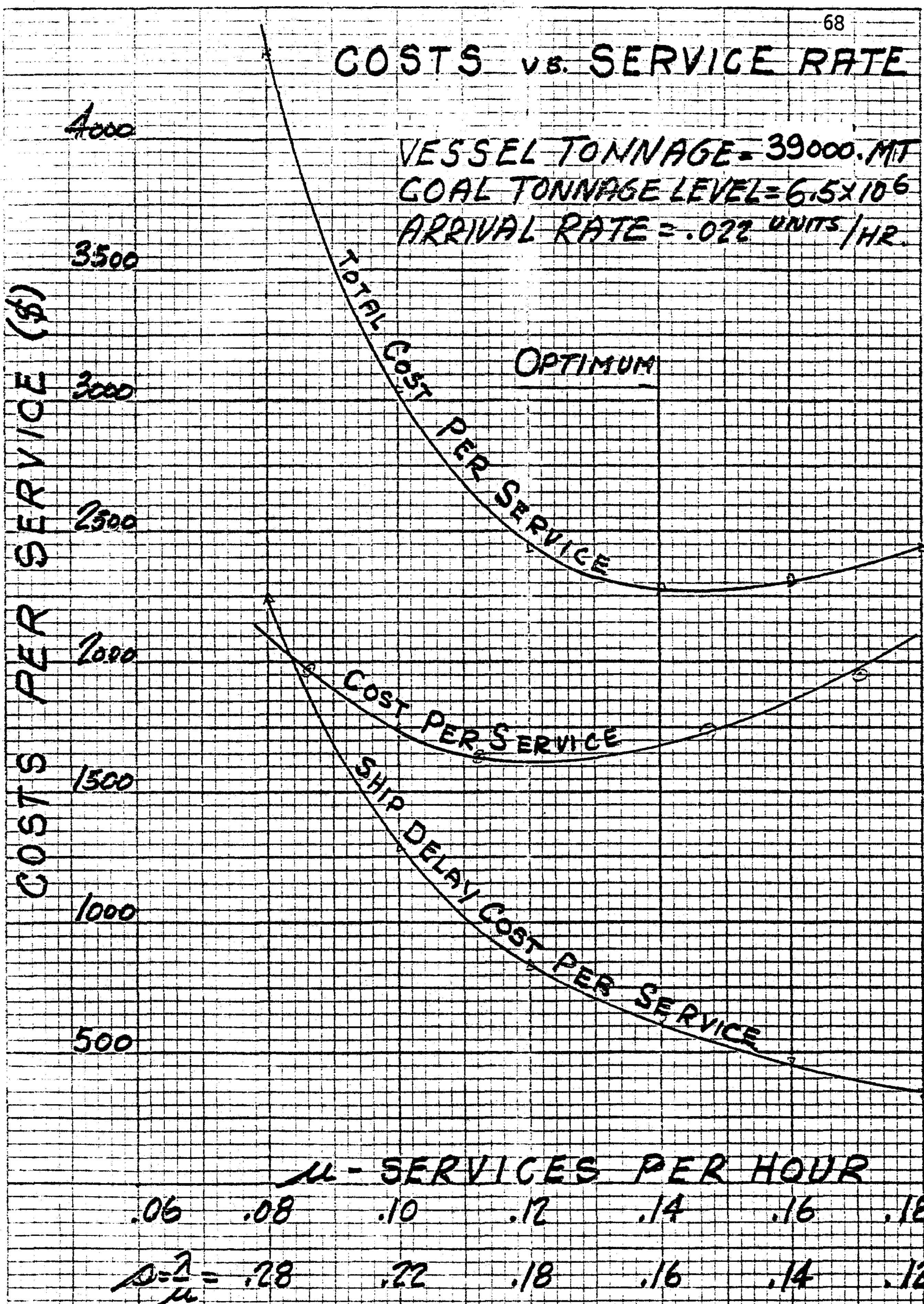


FIG V-3

RHF, SEC '75

study will tend to be too low. Both optimum rates indicated are near the maximum practical limits of receiving rates, therefore, in order to maintain these optimums as the tonnage levels and delay times increase, one must look at increasing the number of service channels or berths as well as maintaining optimum unloading rates (refer to Chapter II, Figs. II-1,2).

Predicting when the dock facility should be expanded to more than one berth and determination of optimum unloading rates is the subject of the following present value analysis using the model-generated delay times (Fig. III-10 and 11) and taking into account cost of capital and escalation.

Economic Analysis (Present Value)

The problem is to determine the point in time at which it is economically advantageous to expand the dock facility to a double berth. It is a question of weighing the capital cost necessary to construct a 2nd berth against the higher delay cost incurred by a single berth. To accomplish this a 'present value' analysis is employed.

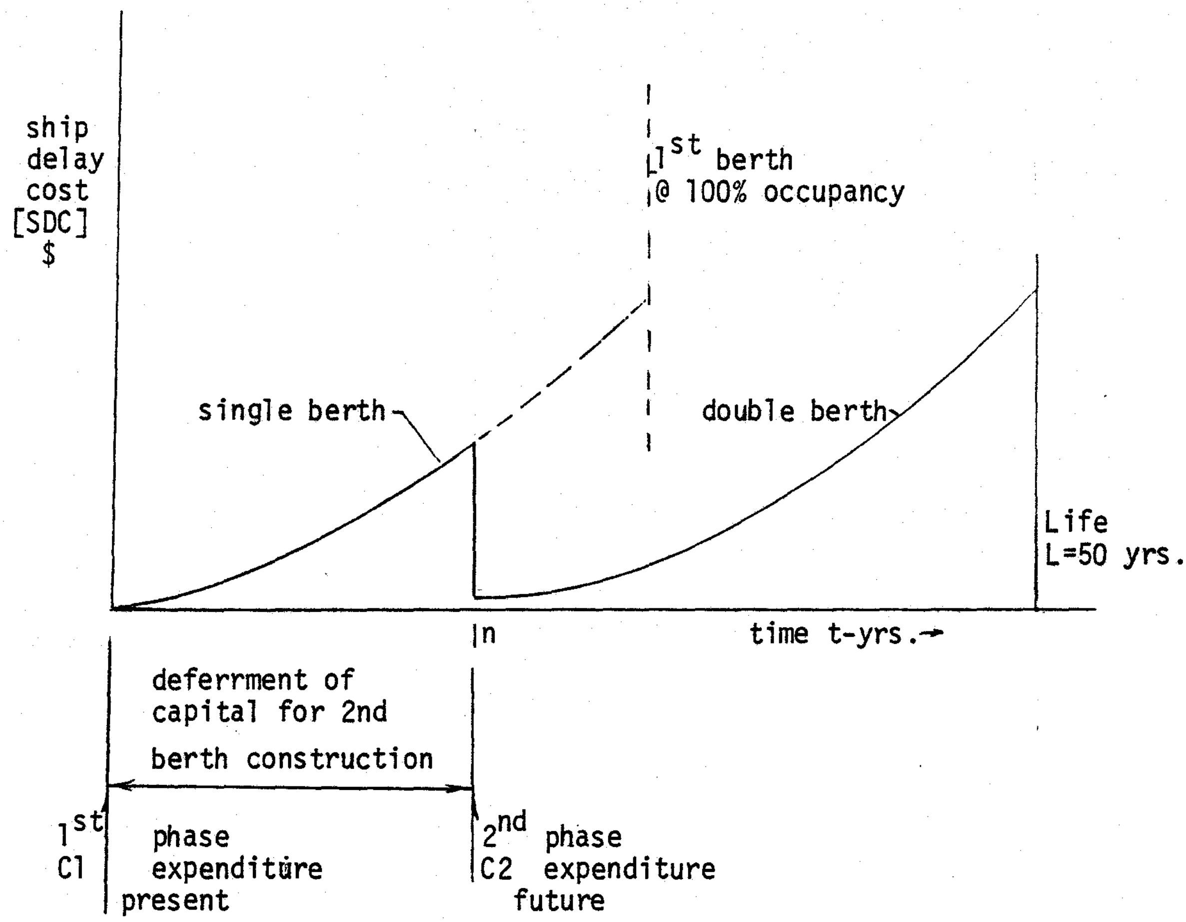


FIG. V-4

Using present value analysis all future capital and operating costs are discounted to the present so that a common base can be established to compare alternatives. A dollar invested at present is worth (1 + CC) dollars in one year and $(1 + CC)^n$ dollars in n years. Where CC is the compound interest rate or cost of capital over the period. Conversely, a payment of 1$ n years from now is equivalent to a payment now of $(1 + CC)^{-n}$. The term $(1 + CC)^{-n}$ is called the present worth factor or discounting factor.

Also to be considered is the fact that future capital expenditure will have escalated from present at a certain rate, say ER, so that a future expenditure of P present dollars will cost $P(1 + ER)^n$ future dollars.

Therefore, applying these two factors to the capital and operating costs simultaneously with the 2nd berth being constructed in n years at a capital cost of C2 the present value is in general:

$$PV = C1 + \sum_{t=1}^{L} [SDC(t) \cdot (1 + ER)^n \cdot (1 + CC)^{-n} + C2 (1 + ER)^n \cdot (1 + CC)^{-n}]^*$$

where;

C1 = initial capital cost of a single berth dock

C2 = capital cost of 2nd berth (present day dollars)

SDC(t) = ship delay cost for year t during the life L of the facility.

When $t > n$, SDC(t) for double berth dock is used.

The present value PV is calculated for the second berth constructed in every year from 1 to L or until the single berth dock reaches 100% occupancy at which time, of course, the building of a second berth is unavoidable if planned growth in production is to be achieved. This is shown diagramatically in Fig. V-4.

---

*The standard form often used for present worth discounting of operating costs can not be used here since the annual operating costs vary over the economic life. The summation of annual increments is a reasonable approximation in this case.

To determine how the present value and optimum time to construct the second berth vary with different vessel tonnages and unloading rates, the above present value procedure is repeated for different values of these parameters and the results plotted as shown in Fig. V-5. In this application it is assumed that the capital costs C1 and C2 and operating costs are equal for every alternative.

Fig. V-5 demonstrates how the optimum point -- defining the minimum present value and the most economical point in time for construction of the second berth -- moves downward to the right as material handling capability is increased.

The best alternative appears to be the one with the maximum receiving capability having a present value of $\$26 \times 10^6$. However, in order to increase capability from the first alternative of 25000, 3000, 5000 to 39000, 8000, 10000 tph. the higher capital and power costs involved with the increased unloading capabilities must be taken into account. It is assumed here that the cost of increasing vessel tonnage from 25,000 tonnes to 39,000 tonnes is accounted for by the shipping companies due to increased efficiency, thus lower overhead and operating cost per tonne shipped. It is assumed that none of this benefit is passed on to the user in the form of reduced rates.

Fig. V-5 simply demonstrated the general trend and interaction of the main variables. In order to achieve a more exact analysis, taking into account capital and power costs as a function of unloading rates, three basic unloading alternatives are studied as outlined on

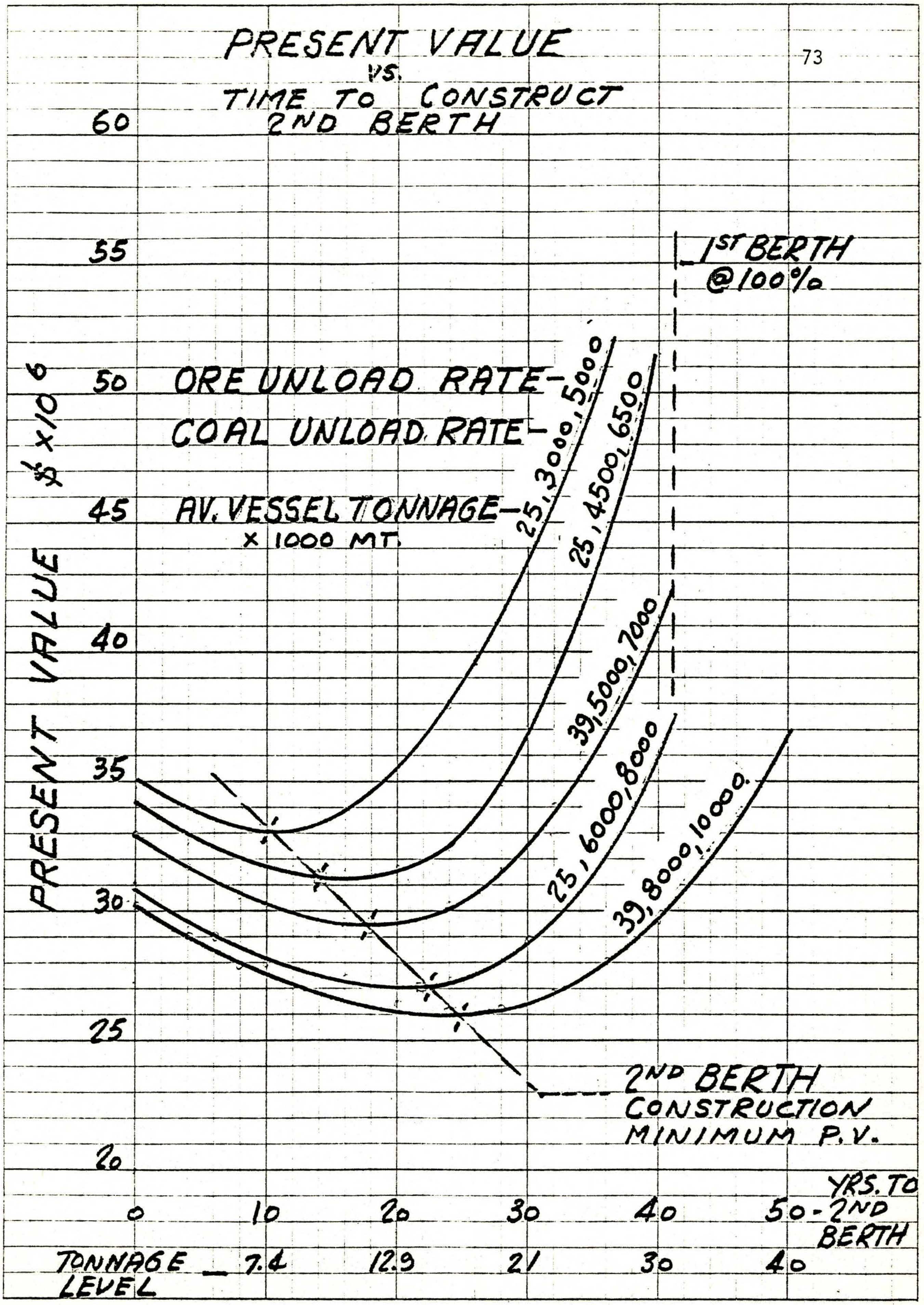

PRESENT VALUE
VS.
TIME TO CONSTRUCT
2ND BERTH
PRESENT VALUE $ x 10^6
60
55
50
45
40
35
30
25
20
1ST BERTH
@100%
ORE UNLOAD RATE-
COAL UNLOAD RATE-
AV. VESSEL TONNAGE-
x 1000 MT.
25,3000,5000
25,4500,6500
39,5000,7000
25,6000,8000
39,8000,10000.
2ND BERTH
CONSTRUCTION
MINIMUM P.V.
0
10
20
30
40
50
YRS. TO 2ND BERTH
TONNAGE LEVEL
7.4
12.9
21
30
40

FIG V-5

Table V-1. These three alternatives were simulated and the resulting present values for each alternative plotted in Fig. V-6. The ratio $\frac{1 + ER}{1 + CC}$ was set at 0.964. The affect of different Er and CC values on the present value will be discussed later.

Fig. V-6 shows that even with the higher costs associated with alternate II the present value is still minimum for this alternative $\$35.8 \times 10^6$ compared to $\$42.6 \times 10^6$ for III. The optimum time to construct the second berth for II is 26 years at approximately 17×10^6 tonnage level compared to I at 19 years and a tonnage level of approximately 13×10^6.

Conveyor Combinations

In the present value analysis plotted in Fig. V-6 an attempt was made to simplify the analysis by applying the same unloading rates for both stages. In reality the conveyor rates can be staged within each phase by adding drive units. In other words the facility could be started in the first stage with unloading rates of 5000/7000 tph and increased to 8000/10000 tph before it became necessary to expand the facility to two berths if provision for expansion was made in the initial installation. (This affect was demonstrated analytically in Fig. II-1). Also, the 2nd phase could be staged in the same way.

Present Value Study

ALTERNATE	MATERIAL	UNLOADING RATE tph		CAPITAL COST C1	C2	POWER COST ($/HR) PER CNVR
				x $10^6$$	x $10^6$$	
I	Coal Ore	5000 7000	1st & 2nd Cnvrs.	24.2	10	50
II	Coal Ore	8000 10000	1st & 2nd Cnvrs.	25.6	11	77
		1st Cnvr.	2nd Cnvr.			
III	Coal Ore	5000 7000	5000 -	24.2	9	59

TABLE V-2

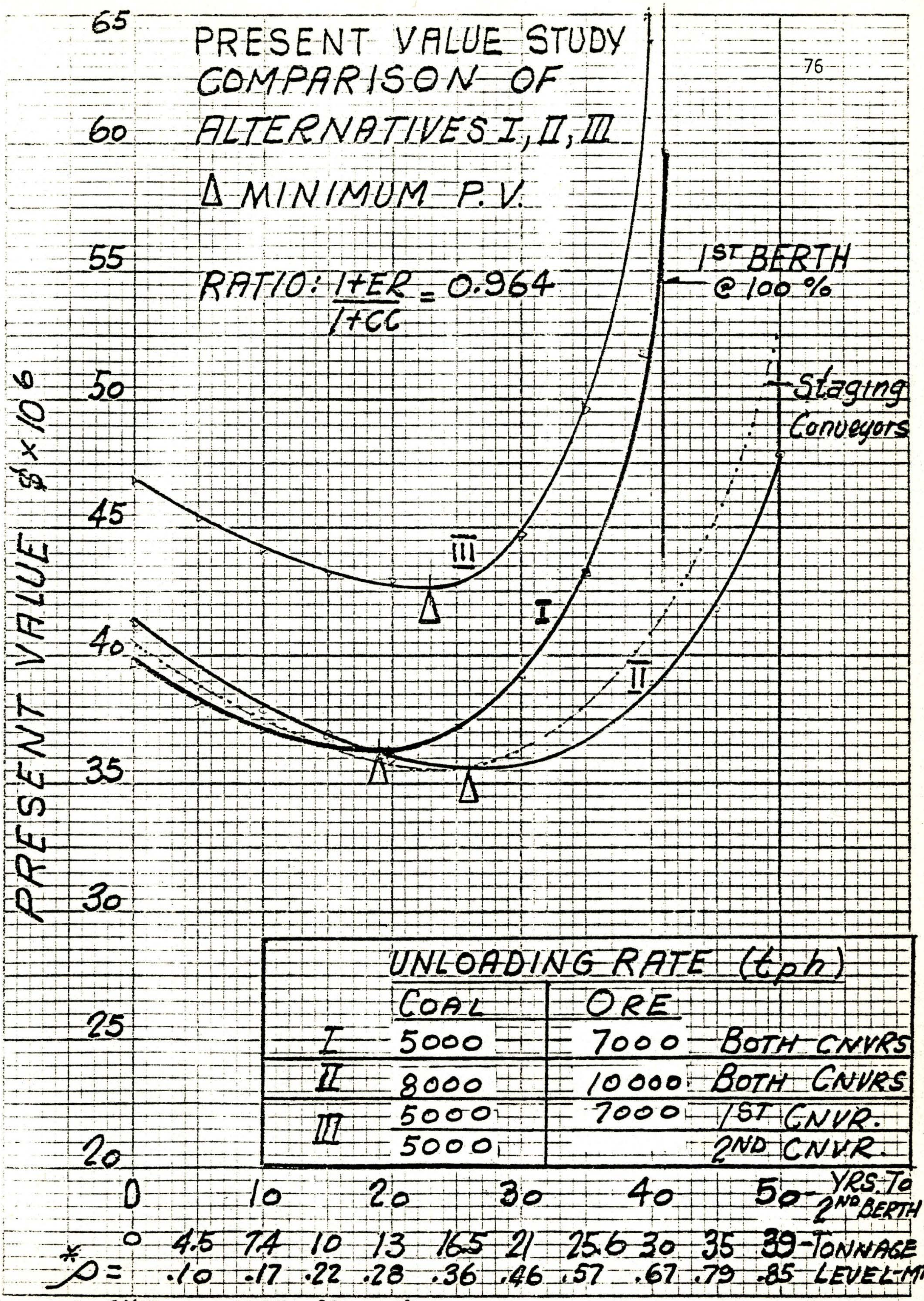
Note:

1. Capital Costs include wharf and basic conveyor costs, i.e. (belts, drives) - except for Alternate III, it is assumed that stacker costs are equal.

2. For simplicity, since there are several conveyor combinations, and staging options, it is assumed that, except for III, conveyor capacities are the same for both stages. The affect of staging drives within the 1st Stage will be discussed later.

3. R.& M and depreciation assumed to be equal for every alternative, therefore, not considered.

4. For III it is assumed that only coal can be received at the 2nd berth. The cost has been reduced for having a coal stacker only.



* SHIP TONNAGE = 39000 t
CUR = 8000 t/HR

FIG V-6

The conveyor staging is summarized in Table V-3.

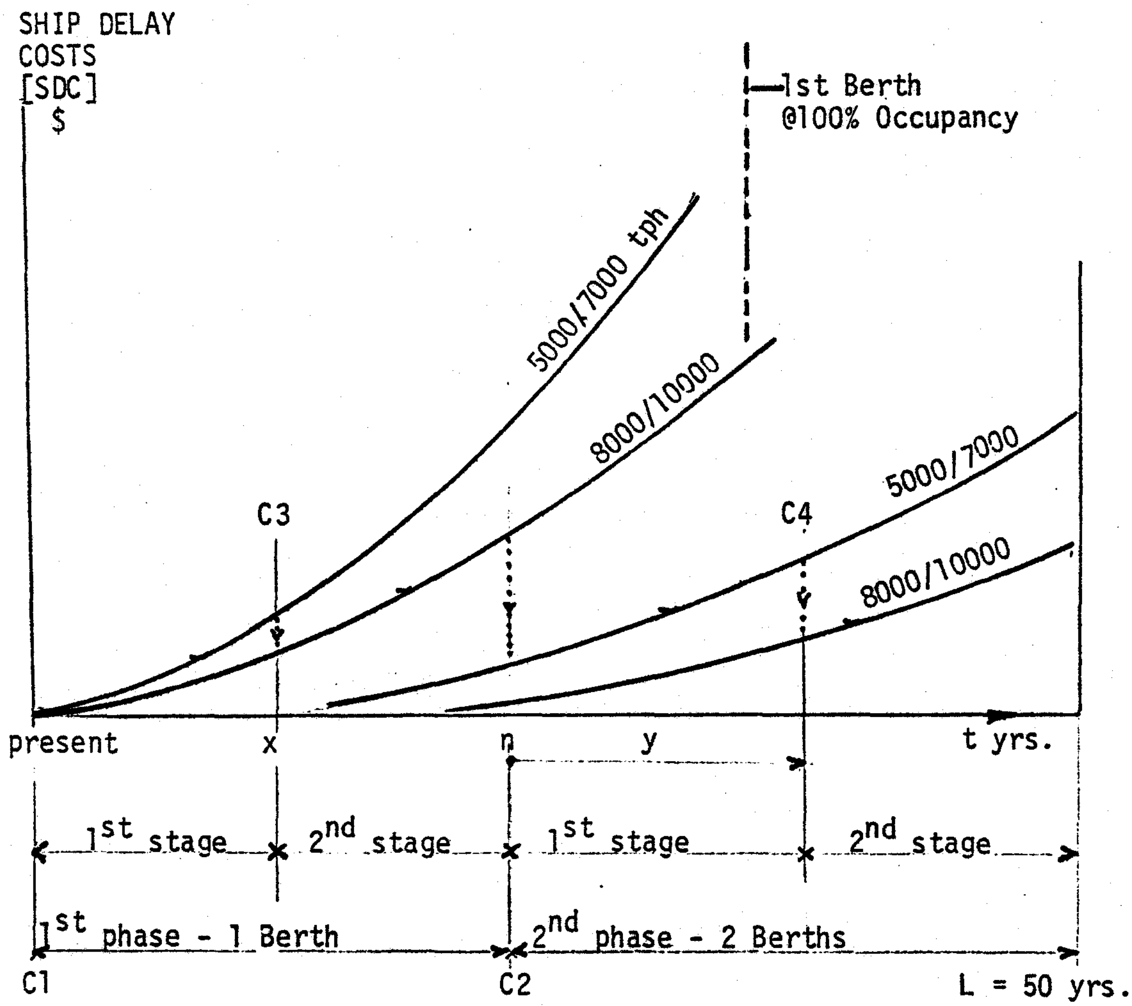
1st Phase - 1 Berth 1 Conveyor		2nd Phase - 2 Berths 2 Conveyors	
1st Stage	2nd Stage	1st Stage	2nd Stage
5000/7000	8000/10000	5000/7000	8000/10000

TABLE V-3

This staging would be done in an effort to reduce cost by deferring capital expenditure. The present value curves for the combinations shown in Table V-3 would show little deviation from alternates I & II when plotted on Fig. V-6. There are several complications to staging as shown in Table V-3 as follows:

If a smaller belt is installed in the 1st stage it may not be ready for replacement when it is economically feasible to expand to a larger belt due to higher delay costs. Therefore, it may be desirable to start with the larger belt with a good durability and simply add drive units to bring up the capacity. The cost of a drive unit (approx. $100,000) would not appreciably affect the present value considerations. The equipment (frames, idlers, etc.) would have to be sized for the larger belt initially to provide maximum flexibility, this involves a relatively small capital cost increase (approx. $50,000) and no operating cost increase.

The above staging may be shown graphically by redrawing Fig. V-4, as follows;



Capital costs C3 and C4 (Fig. V-7) are expended to increase the size of conveyor from 5000/7000 to 8000/10000 tph. C3 is deferred from the present x years and C4 is deferred from the present (n + y) years. There are now 3 variables to staging; n, x, y. Coupled with 2 conveyor alternatives. Only the most likely unloading rates have been studied for simplicity. In fact, there are several possible rates which would have further increased the number of combinations and complexity. As it is, Fig. V-7 contains 5 feasible combinations coupled with the variables n, x, y. Therefore, in theory, an infinite number of permutations are possible. However, the main variable n has the overriding effect on present value. Variables x and y involve relatively smaller capital cost expenditures C3 and C4, therefore, have little effect on the conclusions to be drawn from Fig. V-6. By staging within each phase the time to construct the 2nd berth (n) would extend on curve I toward the optimum on curve II. The effect on present value of the staging alternative outlined on Fig. V-7 is shown dotted on Fig. V-6. It should be stated again that, in order to stage the converyors effectively, flexibility must be designed into the system, i.e. the equipment (frames, idlers, etc.) must be designed to accept a larger future belt.

Based on the above it would seem prudent to stage the conveyors when they are worn out and must be replaced. The problem that arises in this case is that all belts (wharf and yard) will not wear out at the same time and the system would be still governed by the smallest conveyor belt. The durability or life of a belt is a function of cost and should be selected on the basis of staging and present value analysis. This subject is not within the scope of this study, however, some general conclusions may be made on expected belt life.

Belt suppliers estimate that the belts would wear at the rate of .003 in. to .005 in. per million tonnes transported. The belts have a top cover over the steel strands of 0.5 in., therefore, the life expected would be approximately 100 million tonnes. This would occur when the facility reached the 8 million tonne level.

The 8 million tonne level is approximately mid-way to the point at which the facility should be expanded to a second berth according to Fig. V-6, present value.

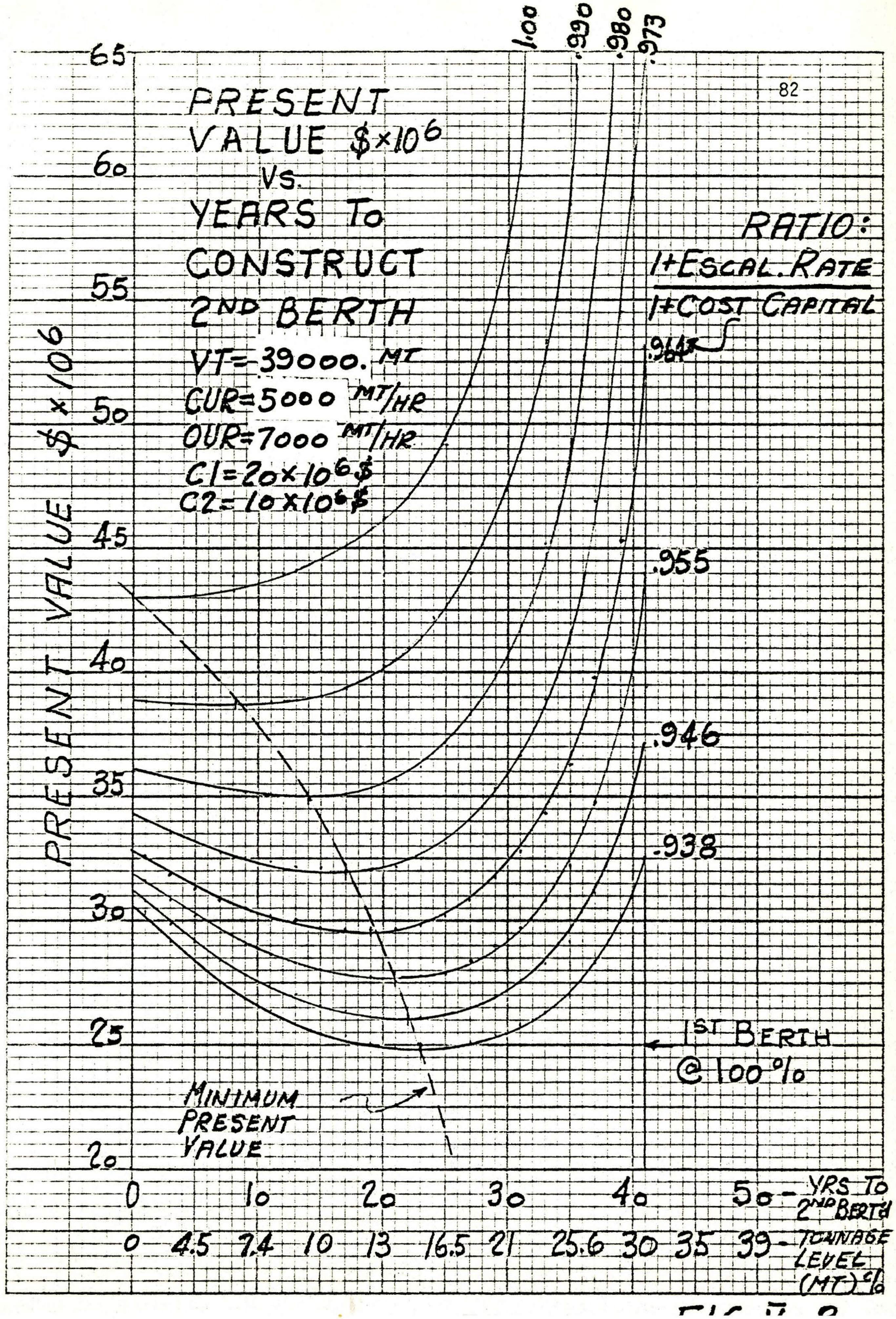
Referring to Fig. III-10, the ship delay cost at the 8 million tonne level would be approximately $150,000 per year. If the belt was replaced at this time with a 2,000 mm belt, the capacity would increase to 8,000 tph coal and 10,000 tph for ore and the delay cost would decrease to $70,000 per year. The investment for the wharf belt alone would be approximately $1,500,000.00. Therefore, the savings in delay cost of $80,000 per year would not offset this expenditure (5% return), however, when the facility is expanded the delay cost drops to approximately $3,000 per year. This again indicates that berth staging is the overriding factor in reducing operating costs.

Alternative III, (Fig. V-6) was proposed in an attempt to reduce capital expenditure in the 2nd phase by receiving only coal on the 2nd belt. Also, it would reduce the need to have a full size stacker to handle both coal and ore as in the 1st phase system. In effect only coal vessels could discharge into the 2nd belt, therefore, ore vessels would have to wait even if a berth was free. The effect of this on ship delay would be substantial and as a result the present value for that alternative would be much higher as shown by Fig. V-6. alternative III.

Excalation and Cost of Capital

Figs. V-8, 9, 10 demonstrate the effect on present value of varying the escalation rate (ER) and cost of capital (CC). These rates are expressed as a ratio: (1 + ER)/(1 + CC) so that the curves may apply to several different values of ER and CC. These curves only reflect the interaction between variables and do not take into account power costs. Also, it is assumed that C1 and C2 are the same for the various alternatives. To compare the present values with Fig. V-6 the present values of Fig. V-8, 9, 10 may be multipled by a factor of approximately 1.2.

Figs. V-8, 9, 10 demonstrate that as the escalation rate increases or as cost of capital decreases the minimum present value increases (dashed line) and the time to construct the 2nd berth moves nearer to the present. Obviously, if ER = CC both phases should be constructed at present as shown by the curve, RATIO: = 1.00.



PRESENT VALUE $×10^6 VS. YEARS TO CONSTRUCT 2ND BERTH
VT=39000. MT
CUR=5000 MT/HR
OUR=7000 MT/HR
C1=20×10^6 $
C2=10×10^6 $
PRESENT VALUE $×10^6
65
60
55
50
45
40
35
30
25
20
1.00
.990
.980
.973
.964
.955
.946
.938
RATIO: 1+ESCAL. RATE / 1+COST CAPITAL
1ST BERTH @100%
MINIMUM PRESENT VALUE
0
10
20
30
40
50
YRS TO 2ND BERTH
0
4.5
7.4
10
13
16.5
21
25.6
30
35
39
TONNAGE LEVEL (MT) %

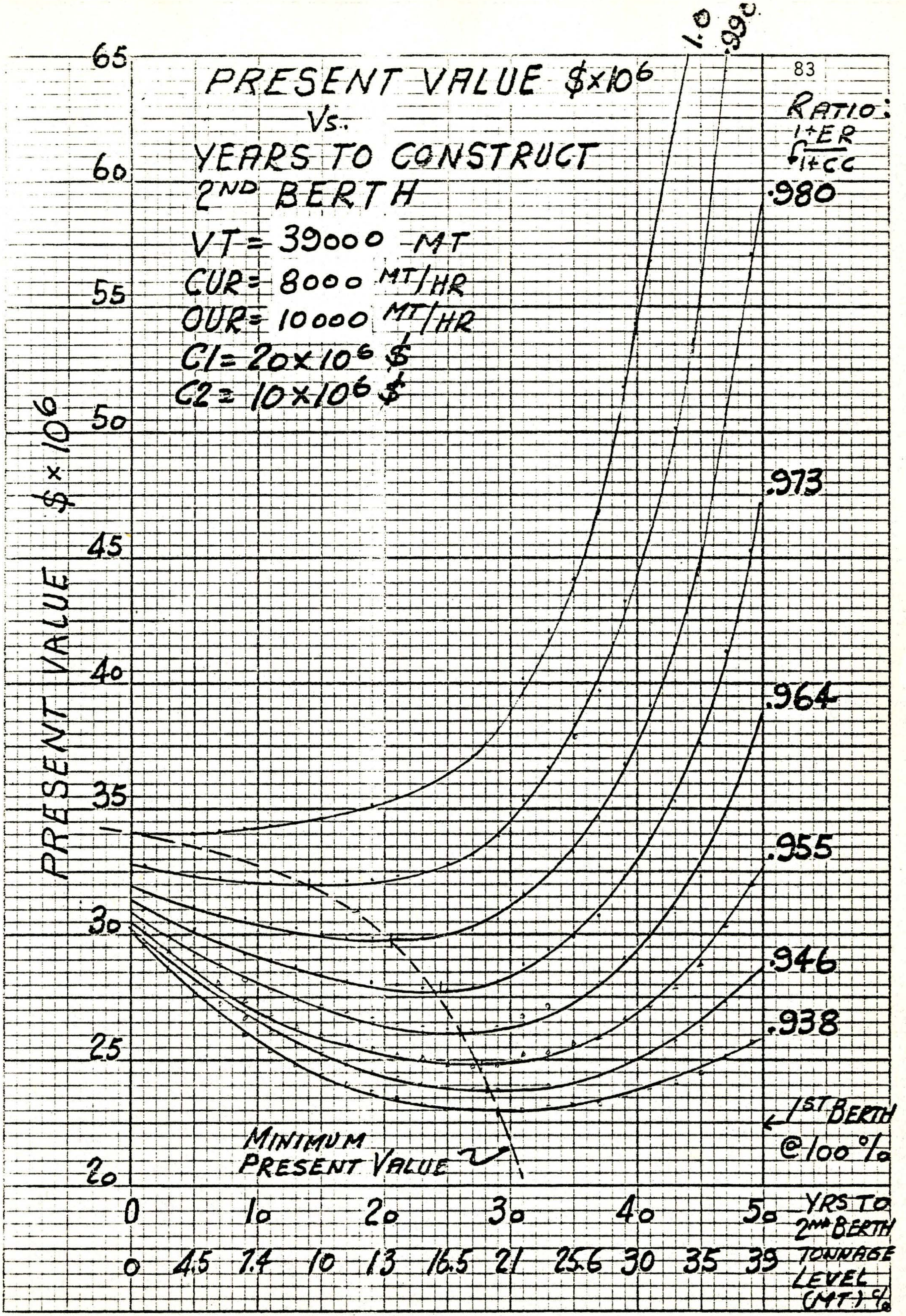
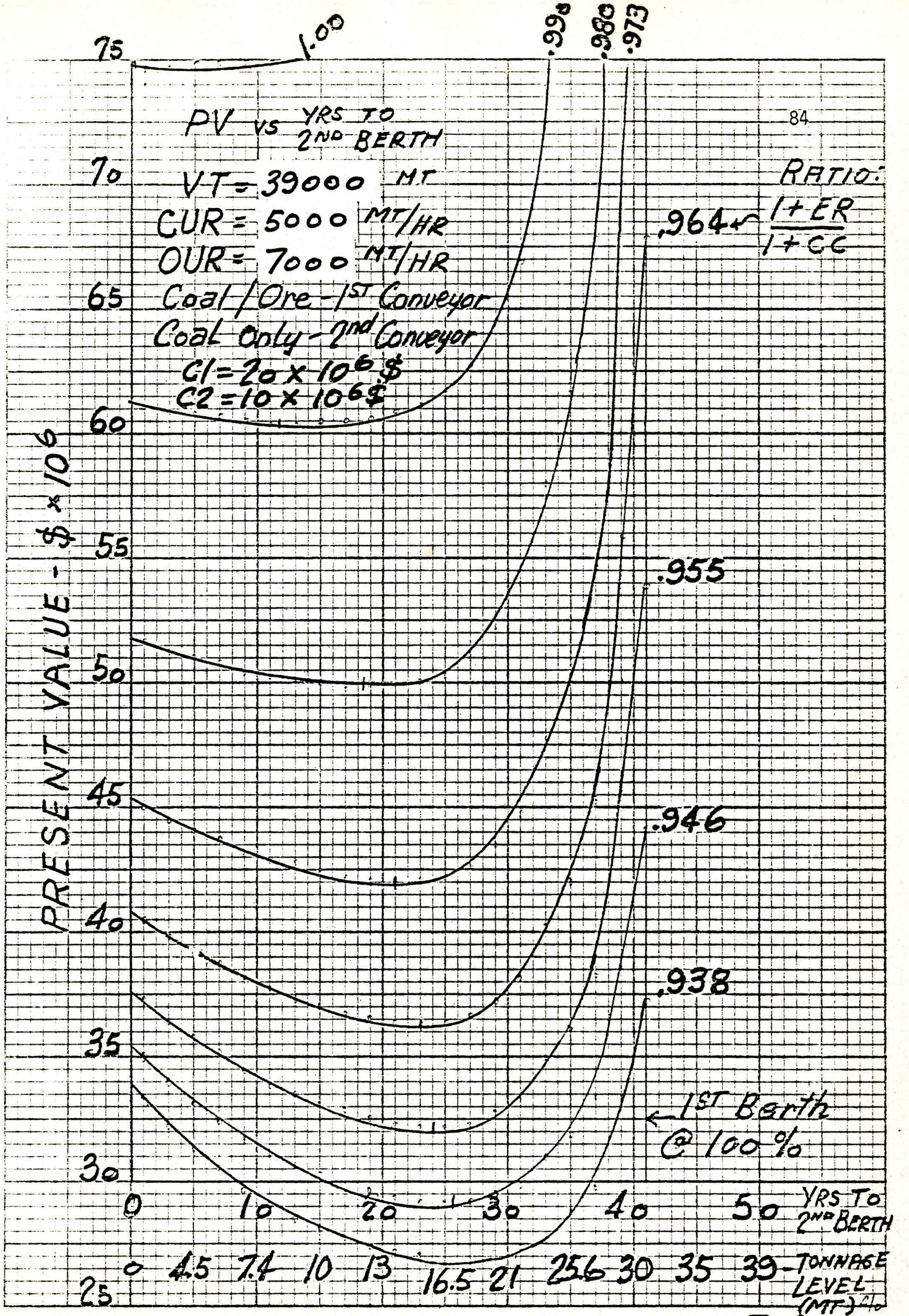

PRESENT VALUE $×10⁶
Vs.
YEARS TO CONSTRUCT
2ND BERTH
VT = 39000 MT
CUR = 8000 MT/HR
OUR = 10000 MT/HR
C1 = 20×10⁶ $
C2 = 10×10⁶ $
PRESENT VALUE $×10⁶
65
60
55
50
45
40
35
30
25
20
RATIO: (1+ER)/(1+CC)
1.0
.990
.980
.973
.964
.955
.946
.938
MINIMUM PRESENT VALUE
1ST BERTH @100%
0
10
20
30
40
50
YRS TO 2ND BERTH
0
4.5
7.4
10
13
16.5
21
25.6
30
35
39
TONNAGE LEVEL (MT) %

FIG V-9



PV vs YRS TO 2ND BERTH
VT = 39000 M.T
CUR = 5000 MT/HR
OUR = 7000 MT/HR
Coal / Ore - 1ST Conveyor
Coal Only - 2nd Conveyor
C1 = 20 x 10^6 $
C2 = 10 x 10^6 $
RATIO: (1+ER)/(1+CC)
1.00
.990
.980
.973
.964
.955
.946
.938
1ST Berth @ 100%
PRESENT VALUE - $ x 10^6
75
70
65
60
55
50
45
40
35
30
25
0 10 20 30 40 50 YRS TO 2ND BERTH
0 4.5 7.4 10 13 16.5 21 25.6 30 35 39 - TONNAGE LEVEL (MT) x10^6

FIG V-10

As the escalation rate decreases or cost of capital increases the expenditure for the 2nd phase construction is deferred more to the future.

Since the ER and CC are variables and future predictions cannot be made with accuracy a judgement must be made using existing values. Due to the fact that ER and CC vary with time it is very important to design the maximum amount of flexibility into the system so that it can be staged when future economics dictate.

A further complication in predicting the best course of action is the difficulty in predicting future production levels. Appendix 2 shows the production forecast upon which this study was based. If this forecast varies appreciably it may require a re-examination of the conclusions drawn from this study.

Because of the fact that production levels are difficult to predict (due to the fact they are a direct function of market demand) it reinforces the concept of staging capital expenditures in minimum feasible increments. This requires the system to be designed with as much flexibility as possible to try to cope with changing economic and market conditions.

CHAPTER VI

CONCLUSIONS AND DISCUSSION

In the preceeding chapters the development of the model has been described, results have been presented and tentative conclusions discussed. In this chapter the main conclusions are summarized together with a brief discussion of each.

Model Accuracy

In Chapter IV an indication of model accuracy was developed by testing the historical data, plotting the computer generated distribution, Fig. III - 1, 2, 4, 5, and by establishing bounds on the solution analytically, (Fig. III-8) by drawing on the queueing theory development of Chapter II.

Based on the above it may be stated with reasonable confidence that the model is able to simulate the actual process with enough accuracy to test and select an optimum course of action.

Present Value Analysis - Optimum Course of Action

In Chapter V a present value analysis was performed on the results of simulations of several feasible staging alternatives the results being presented in Fig. V-6. With the minimum present value as the criteria, alternate II would be selected as optimum, Fig. V-6. Alternate II has the lowest present value and longest time to Phase II. However, it provides staging only from one berth to two berths.

In adhering to the general concept put forward in Chapter V of staging expenditures in minimum feasible increments in order to cope with changing economic conditions one would have to choose an alternative that is close to optimum and adheres to this concept. On this basis one should choose the staging combination which calls for staging the conveyors in both phases. This alternative is a combination of alternatives I and II and is close to optimum based on the present value analysis. (See dotted curve Fig. V-6).

This alternative provides the greatest degree of flexibility and allows the owner to increase capacity as the production needs dictate by increasing conveyor belt size and adding drives prior to being forced by economics to expand the dock to 2 berths. The decision to increase belt capacity must be made when either the belt is worn out or ship delay cost become excessive, this decision being based on a present value analysis at that time. With this in mind some economic analysis should be applied to belt cost and durability.

Regardless of the staging within the 1st phase it can be predicted, based on present economics and production forecasts, that the 2nd phase should be constructed about the 15 million tonne level. Fig. V-6. Staging beyond the 2nd phase will be based on an economic analysis at some future time.

Escalation and Cost of Capital

The results of the present value analysis plotted on Fig. V-6 is based on a ratio: $\frac{1 + ER}{1 + CC} = .964$. This could result from an ER = 11% and a CC = 15% or ER = 8% and CC = 12%. In making use of the conclusions drawn from the present value analysis one should check the curves plotted on Fig. V-8, 9, 10 so that adjustments can be made to the present values depending on the current ER and CC values. For example, if the escalation rate increases or cost of capital decreases, the ratio: $\frac{1 + ER}{1 + CC}$ increases thus advancing the time to construct the 2nd phase. This will also affect the intermediate belt capacity staging making it more economical to increase the belt capacities and perhaps planning for shorter belt life on the initial installation.

Effects of Queue Size

The expected maximum queue size as a function of tonnage level is as follows:

	1st Berth				2nd Berth			
Tonnage level MT— (coal & ore)	0-5	5-8	8-12	12-16	12-16	16-20	20-30	30-40
Max. expected —— queue size:	1	2	3	4	2	3	4	5

Based on the above it is expected that queues of 1 or 2 will form several times a year at the lower tonnage levels. The maximum queue size will gradually increase as the number of arriving ships increase. Construction of the 2nd phase berth will reduce this problem until berth occupancy builds to its previous level. Provision should be made for a holding area in or near the approach channel. The problem of queue length becomes more critical as Texaco and Hydro shipping increases and as the Stelco production level increases.

Queues will form for a number of reasons;

a) Normal interference of arriving ships as simulated by the model as a result of the random nature of arrivals and berth times.

b) Mechanical breakdown of receiving system or ships unloading system. This is more critical if there is only one berth or if the system is not flexible enough to unload both materials at either berth or into either conveyor.

c) It is estimated that the weather will prevent ships from berthing about 6 or 8 days out of the season. Also, weather may affect the movement of ships en route in the seaway causing ships to group together. This in turn will create a queue at the dock. Even if the weather allows a ship to berth it may still be sufficiently rough to slow down the rate of unloading without excessive spillage, this in turn will have an effect on arriving ships.

The solutions proposed to reduce the affect of queues at higher tonnage levels are;

a) Try to schedule ships more closely especially if weather poses a temporary problem at the dock.

b) Re-route ships to Hilton Works, Hamilton.

c) Design a flexible receiving system so that ships carrying either material can unload at either berth or into either conveyor.

d) Carry out a scheduled maintenance program on receiving equipment to reduce breakdowns.

e) Dredging should be carefully scheduled to prevent interference at the dock.

f) A break water may have to be considered if delay times or spillage increase disproportionately due to weather. This may be an imminent problem due to the exposure of the wharf to waves, current and wind coupled with the problems of unloading into a relatively small hopper.

CHAPTER VII

RECOMMENDATIONS

Based on the conclusions drawn from this study and on the production levels used, the following recommendations are made;

Facility Staging

Due to uncertain economic conditions which affect production levels, cost of capital and escalation rates, it is recommended to adopt the concept of staging by minimum feasible increments as put forward in Chapter V. That is, expend initially as little capital as possible in line with the present economic conditions and still allow maximum flexibility in the system to expand as future economics dictate.

In line with the above concept it is recommended that the staging alternative of Fig. V-7 be adopted. This alternative is as follows;

Vessels

The fleet proposed for LED consists initially of 3 - 730' - 30,000 tonne vessels, to be increased by adding 850' - 39000 tonne vessels as the tonnage level increases. The average vessel tonnage of this fleet is approximately 39000 tonnes over the life of the facility. (See Appendix 2). This capability as recommended by the shipping companies seems adequate to meet the production needs with flexibility. The proposal to commission vessels of 1000' - 55000 tonne capacity seems to be contrary to the concept of flexibility and minimum increments since these large vessels would only transport ore from the upper lakes and would not be economical for coal from Lake Erie ports, also, they are prevented from entering the lower seaway because of draft. Further, the use of these large vessels would substantially increase the capital cost of the dock because of required berth size and draft. They would also be less manoeverable in the somewhat confined harbour at Lake Erie Development.

Conveyors

In accordance with the concept of minimum feasible increments, outlined in Chapter V, and to achieve close to the minimum present value (Fig. V-6) the following conveyor staging is recommended;

a) Design all conveyor equipment to accept a 2000 mm belt with provision to add drive units so that the capacity can be increased in future. If possible, design the belt life to approximately coincide with the forecasted time for expansion to a larger belt, at the 8 million tonne level. This may require a separate present value study on belt cost and durability. For the 2nd phase, economics at that time may dictate the installation of 2400 mm equipment to accept a larger belt in future if necessary.

b) As outlined on Fig. V-7 (dotted line) it is recommended that the optimum course of action for unloading rates, based on present economic conditions, is as follows;

1st phase/1st stage	-	5000 tph coal, 7000 tph ore
1st phase/2nd stage	-	8000 tph coal, 10000 tph ore
2nd phase/1st stage	-	5000 tph coal, 7000 tph ore
2nd phase/2nd stage	-	8000 tph coal, 10000 tph ore

Conveyor options beyond 1st phase/1st stage will be dictated by future economic conditions and tonnage levels, the above is a forecast based on present conditions. The important point is to design with the ability to expand in the future at minimum overall cost.

Berth Expansion

Based on the present value analysis of Chapter V as plotted in Fig. V-6 and on a ratio of $\frac{1 + ER}{1 + CC} = .964$ the 2nd phase expansion should take place at approximately the 15×10^6 tonne level. This of course may vary depending on future production levels and economic conditions.

Lake Level Fluctuations

The lake levels fluctuate seasonally and also on a 7 year cycle. When lake levels are high at the top of the 7 year cycle ship owners are able to carry a greater payload thus reducing their operating cost.

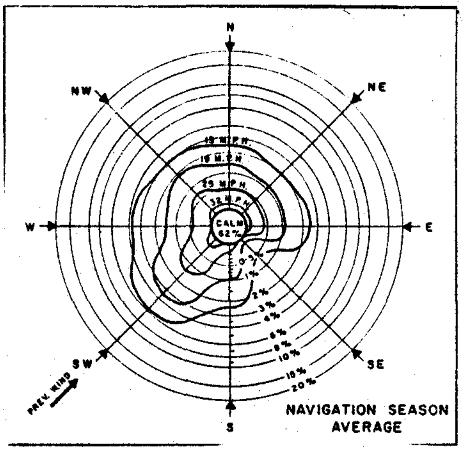
This should have an effect on the rates charged to the user. It is recommended that dredging be carefully scheduled as a function of this 7 year cycle in order to minimize dredging costs and maximize payloads. Lake levels are presently forecasted 6 months in advance. This allows enough time to plan the dredging program for the next season if necessary.

CHAPTER VIII

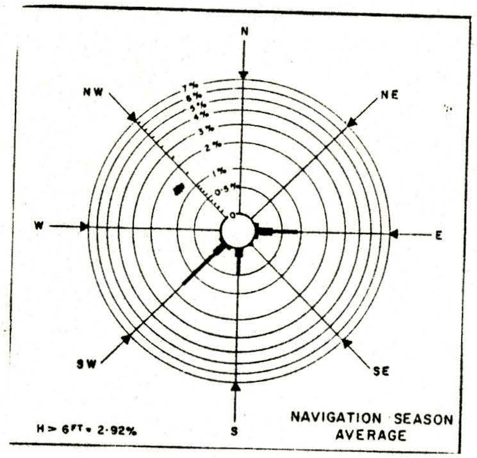
POSSIBLE FUTURE APPLICATIONS AND STUDIES

The following are areas recommended for further model application or study;

a) Program into the model the affects of weather on the berth time distributions with the use of wind and wave roses for the area which give the probability that the wind and waves will be from a certain direction with given magnitude. Typical roses are shown below;

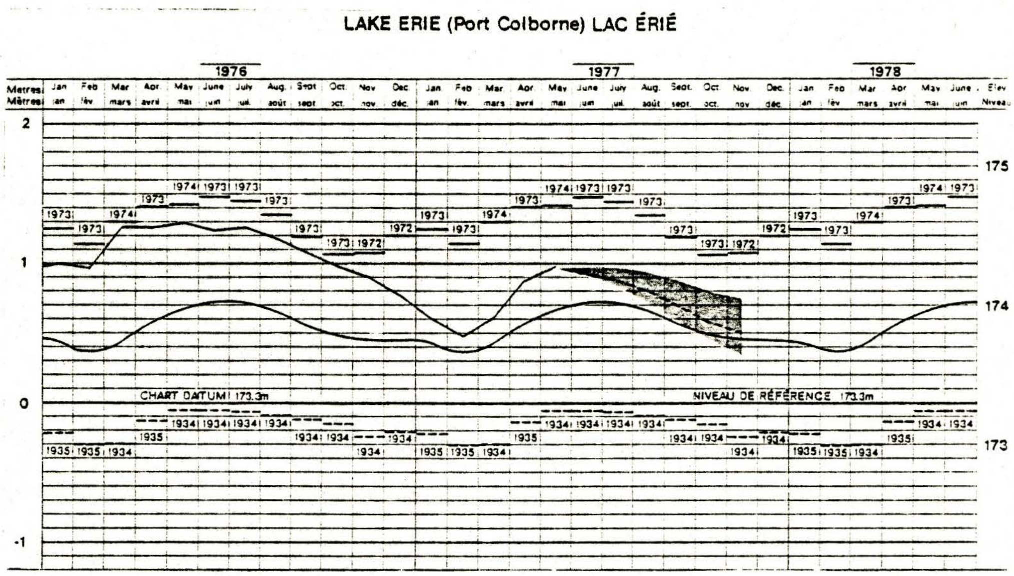


Wind Rose - Nanticoke



Wave Rose - Nanticoke

b) Study, in detail the economic effects of lake level fluctuations on dredging programs, and vessel payloads. This can be accomplished by incorporating the 'Inland Waters' lake level projections into the program, thus varying the draft and payload, and studying the resulting effects on waiting times. A typical lake level projection is shown below;



Typical Lake Level Projection

c) Simulate the effects on queue size and waiting time of mechanical breakdowns of shore receiving equipment. A prolonged service interruption will create an unsteady state of the system. The duration of this state and the resulting queue sizes and delay costs can be recorded for various length of interruption. From this information a preventitive maintenance program could be formulated.

d) Simulate the effects of large shipping of product from the dock and receiving of coal by barge from Lake Erie ports.

e) Study additional conveyor combinations to obtain refined staging predictions depending on the economy at the time. Possibly employ a computer optimization program as a subroutine.

f) Program into the model, Hydro and Texaco shipping frequencies to obtain a refined prediction of queue size and frequency, and a measure of possible congestion in the harbour area.

In general, the model should be used to aid future facility planning strategies consistent with future economic factors.

Data on ship arrivals and berth times should be collected at the new facility. The distribution curves used in the model can then be updated, re-applied to check previous conclusions. This will provide continuous monitoring of dock efficiency and aid in negotiations on rates with the shipping companies.

REFERENCES

1. Saaty, T.L. Elements of Queueing Theory, McGraw Hill, (1961).
2. Ruiz, E. et al Waiting Line Models, Reinhold, (1967), p. 43.
3. Morse, P.M. Queues, Inventories and Maintenance, McGraw Hill, (1961).
4. Hald, G. Statistical Theory with Engineering Applications, pg. 353.

APPENDICES

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C PROGRAM FOR SIMULATING THE RECEIVING OF VESSELS DELIVERING RAW
C MATERIALS AT A DOCK FACILITY,THE ALGORITHM GENERATES RANDOM ARRIVALS
C BERTH SERVICE TIMES ACCORDING TO POISSON AND ERLANG DISTRIBUTIONS
C RESP. ....IT MERGES COAL AND ORE ARRIVALS..INTERFERENCE WHICH
C CREATES QUEUES IS MONITORED AN WAITING TIMES AND COSTS ARE RECORDED
C THROUGH THE LIFE OF THE FACILITY
C
C VARIOUS UNLOADING RATES,VESSEL TONNAGES AND BERTH COMBINATIONS ARE SIM
C SIMULATED
C
C AN ECONOMIC ANALYSIS IS PERFORMED ON THE MODEL RESULTS USING PRESENT
C VALUE TECHNIQUES
C
C
C
      PROGRAM FULTON(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION OAT(1000),CAT(1000),BTO(1000),BTC(1000),A(1000)
      DIMENSION GT(12),BT(1000),NT(1000),SDC(2,50)
C
C READ DATA FROM TONNAGE FORECASTS CURVES--APPENDIX 2
      REAL SLOPE(5),CONST(5)
      DATA(SLOPE(KL),KL=1,5)/.56,.41,.29,.31,.5/
      DATA(CONST(KL),KL=1,5)/0.0,.385,1.1625,.87,-3.5/
C
C READ DATA ON UNLOADING RATES,DAYS IN SEASSON,DELAY COST,VESSEL TONNAGE
      WRITE(6,78)
   78 FORMAT(*INPUT 0 COAL UNLOADING RATE, ORE UNLD. RATE,DAYS IN SEASON
     +,SHIP DELAY($/HR.)*)
      CALL CONNEC(5LINPUT)
      CALL CONNEC(6LOUTPUT)
      CALL READX(OUR)
      CALL READX(CUR)
      CALL READX(DS)
      CALL READX(SC)
      NTRIES=3
      WRITE(6,206)
  206 FORMAT(1X,*COAL UNL.RATE*,2X,ORE UNL.RATE*,2X,DAYS IN SEASON
     +*,2X,*SHIP DELAY COST($/HR)*)
      WRITE(6,207)CUR,OUR,DS,CS
  207 FORMAT(1X,F10.1,5X,F10.1,5X,F10.1,6X,F10.1//)
      VT=39000.
      WRITE(6,1014)VT
 1014 FORMAT(1X,*AVERAGE VESSEL TONNAGE(MT)*F7.1)
      WRITE(6,204)
      WRITE(6,205)
C NB=NUMBER OF BERTHS
C NY=NUMBER OF YEARS
C NTRIES=NUMBER OF REPITITIONS OF SIMULATION
       IX=12345
      DO 6 I=1,12
 6    GT(I)=0.0
      DO 901 NB=1,2
      DO 900 NY=1,50
      TDLT=0.0
      DO 902 NTRY=1,NTRIES
      NQMAX=0
      XXX=NY
      KI=5
      IF(XXX.LT.23)KI=4
      IF(XXX.LT.13.75)KI=3
      IF(XXX.LT.6.5)KI=2
      IF(XXX.LT.2.5)KI=1
      ST=SLOPE(KI)*NY+CONST(KI)
```

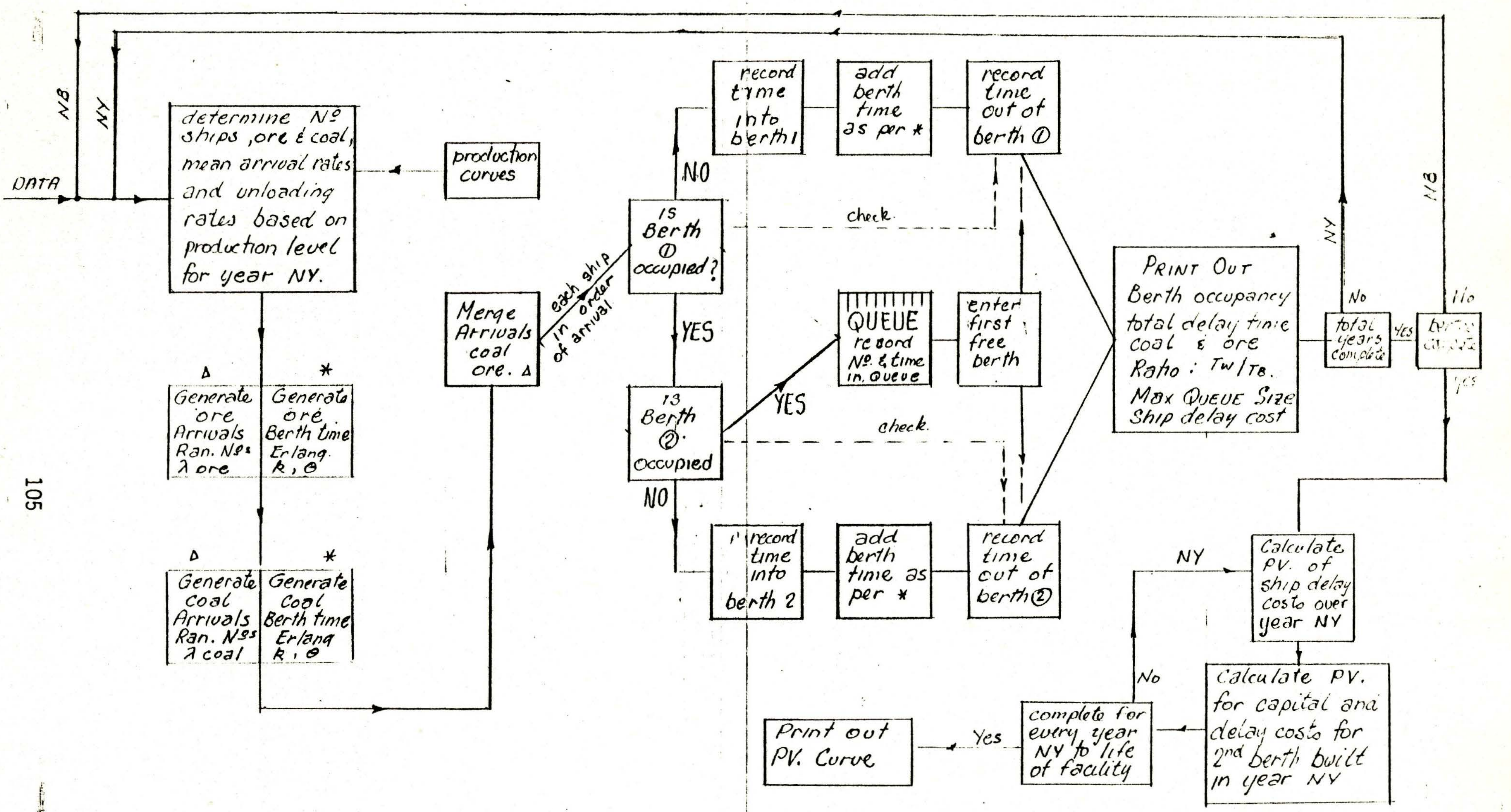
```
      OT=ST*1..?*10**6
      CT=ST*.64*10**6
      NOS=OT/VT
      NCS=CT/VT
      ATBO=(VT/OUR)+1.0
      ATBC=(VT/CUR)+1.0
      ALAMDAO=1./(NOS/(DS*24.))
      ALAMDAC=1./(NCS/(DS*24.))
      OAT(1)=0.0
      CAT(1)=0.0
C
=C GENERATE ORE RANDOM ARRIVAL TIMES
C NOS=NUMBER OF ORE SHIPS PER SEASON
C GENERATE ORE ARRIVALS
      DO 10 I=1,NOS
      CALL RANDU(IX,IX,P )
      K=I-1
      IF(I.EQ.1)K=1
      OAT(I)=OAT(K)-ALAMDAO*ALOG(P)
   10 CONTINUE
C
C GENERATE COAL RANDOM ARRIVAL TIMES
C NCS=NUMBER OF COAL SHIPS PER SEASON
C GENERATE COAL ARRIVALS
      DO 20 J=1,NCS
      CALL RANDU(IX,IX,P)
      KK=J-1
      IF(J.EQ.1)KK=1
      CAT(J)=CAT(KK)-ALAMDAC*ALOG(P)
   20 CONTINUE
C
C GENERATE + RANDOM BERTH SERVICE TIMES FOR ORE VESSELS,K=ERLANG
C PARAMETER
C ASSUME BERTHS ARE IDENTICAL FOR SERVICE
C GENERATE BERTH SERVICE TIMES FOR ORE
C ERLANG K=11
      K=11
      DO 30 I=1,NOS
  837 SUMT=0.0
      DO 40 J=1,K
      CALL RANDU(IX,IX,P)
      T= -(ATBO/K)*ALOG(P)
      SUMT=SUMT+T
   40 CONTINUE
      IF(SUMT.LT.5.)GO TO 837
      BTO(I)=SUMT
   30 CONTINUE
C
C GENERATE RANDOM BERTH SERVICE TIMES FOR COAL VESSELS
C
C
      K=6
      DO 50 I=1,NCS
  838 SUMT=0.0
      DO 60 J=1,K
      CALL RANDU(IX,IX,P)
      T=-(ATBC/K)*ALOG(P)
      SUMT=SUMT+T
   60 CONTINUE
      IF(SUMT.LT.6.)GO TO 838
      BTC(I)=SUMT
   50 CONTINUE
      NST=NCS+NOS
C
C  BEGIN SIMULATION PROCEDURE.ARRIVALS ARE SORTED AND QUEUED ON FIRST
C COME - FIRST SERVE BASIS
```

```
C TDLTO=TOTAL ORE VESSEL DELAY TIME
C TDLTC==TOTAL COAL VESSEL DELAY TIME
C
C
C SORT AND QUEUE ARRIVALS
C ORE(NT=1), COAL(NT=2)
      K=1
      N=1
      DO 65 I=1,NST
      IF(K.GT.NOS)GO TO 37
      A(I)=OAT(K)
      IF(N.GT.NCS)GO TO 38
      CATT=CAT(N)
      AA=A(I)
      IF(CATT.LT.AA)GO TO 37
   38 NT(I)=1
      BT(I)=BTO(K)
      K=K+1
      GO TO 65
   37 A(I)=CAT(N)
      NT(I)=2
      BT(I)=BTC(N)
      N=N+1
      GO TO 65
   65 CONTINUE
C
C ASSUME 2 BERTHS - EITHER ORE OR COAL FOR EACH BERTH
C FOR 1 BERTH OPERATION - BLOCK BERTH 2
      NNQ=0
      BTI1=0.0
      BTO1=0.0
      BTI2=0.0
      BTO2=0.0
C +WHEN ONE BERTH ONLY IS BEING ANALI+ZED  THE SECOND BERTH IS BLOCKED
C BY SETTING BTO2=100000.
C
      IF(NB.EQ.1)BTO2=100000.0
      TDLTO=0.0
      TDLTC=0.0
      TB=0.0
      DO 700 I=1,NST
C
      DIFF1=A(I)-BTO1
      DIFF2=A(I)-BTO2
C
      IF(DIFF1) 101,102,102
  101 IF(DIFF2)103,104,104
C
  103 CONTINUE
      DIFF1=ABS(DIFF1)
      DIFF2=ABS(DIFF2)
      IF(DIFF1.LE.DIFF2)GO TO 105
      BTI2=BTO2
      BTI=BTI2
      BTO2=BTI2+BT(I)+1.0
      NTTT=NT(I)
      GO TO (108,109),NTTT
  108 DLTO=BTI2-A(I)
      TDLTO=TDLTO+DLTO
      GO TO 701
  109 DLTC=BTI2-A(I)
      TDLTC=TDLTC+DLTC
      GO TO 701
  105 BTI1=BTO1
      BTI==BTI1
```

```
      BTO1=BTI1+BT(I)+1.0
      NTTT=NT(I)
      GO TO (106,107),NTTT
  106 DLTO=BTI1-A(I)
      TDLTO=TDLTO+DLTO
      GO TO 701
  107 DLTC=BTI1-A(I)
      TDLTC=TDLTC+DLTC
      GO TO 701
C
  102 BTI1=A(I)
      BTO1=BTI1+BT(I)+1.0
      NNQ=0
      GO TO 70
C
  104 BTI2=A(I)
      BTO2=BTI2+BT(I)+1.0
      NNQ=0
      GO TO 70
C CHECK QUEUE
  701 NQ=NNQ
      IF(NNQ.EQ.0)GO TO 810
      DO 790 JJ=1,NQ
      QTJJ=QT(JJ)
      AI=A(I)
      IF(AI.GT.QTJJ)GO TO 800
      GO TO 810
  800 NNQ=NNQ-1
  790 CONTINUE
  810 NNQ=NNQ+1
C
C CHECK MAX QUEUE SIZE=NQMAX
C
      IF(NNQ.GT.NQMAX)NQMAX=NNQ
      QT(NNQ)=BTI
C
C CALCULATE TOTAL TIME IN BERTH=TB AND TOTAL SHIP DELAY TIME=TDLT
C
   70 TB=TB+BT(I)+1.0
      SDLT=TDLTC+TDLTO
      DLTC=0.0
      DLTO=0.0
  700 CONTINUE
      TDLT=TDLT+SDLT
  902 CONTINUE
      SDLT=TDLT/NTRIES
C
C CALCULATE MAIN RESULTS
C WAITING TIME/BERTH TIME=SDLT/TB
C BO=BERTH OCCUPANCY
C SDC=SHIP DELAY COST
C
  204 FORMAT(1X,*NO.SHIPS*,3X,*RATIO*,2X,*BERTH*,4X,*TOTAL DELAY TIME*
     +,6X,*MAX,*+6X,*SDC*)
     +,6X,*SDC*)
  205 FORMAT(2X,*COAL*,2X,*ORE*,7X,*TW/TB*,2X,*OCCUP.(:)*,3X,*COAL*,
     +6X,*ORE*,5X,*QUEUE*)
      RATIO=SDLT/TB
      BO=(TB/(DS*24.))*100/NB
      IF(BO.GE.100.)GO TO 728
      SDC(NB,NY)=SDLT*SC/1000000.
      WRITE(6,203)NCS,NOS,RATIO,BO,TDLTC,TDLTO,NQMAX,SDC(NB,NY)
     +hx

  203 FORMAT(1X,I6,I9,2F9.2,2X,F9.2,F10.2,3X,I3,4X,F6.3)
      WRITE(6,404)
```

```
      GO TO 9Ø1
 728 IINY=NY
 9Ø1 CONTINUE
C
C
C
C  SIMULATION COMPLETE
C
C USING DELAY COSTS GENERATED ABOVE AND THE CAPITAL COSTS INPUT
C BELOW A PRESENT VALUE ANALYSIS IS PERFORMED
C
C PRESENT VALUE ANALYSIS
      WRITE(6,1Ø1Ø)
 1Ø1Ø FORMAT(*INPUTØ INIT. CAP. COST , CAP. COST - 2 BERTH ,
     + COST OF CAPIYAL , ESCALATION RATE*)
      CALL READX(C1)
      CALL READX(C2)
      CALL READX(CC)
      CALL READX(ER)
      WRITE(6,1ØØ6)
 1ØØ6 FORMAT(1X,*INIT.CAP.COST*2X,CAP.COST 2ND BERTH*,2X,*COST
     +,2X,*ESCAL.RATE*)
      WRITE(6,1ØØ7)C1,C2,CC,ER
 1ØØ7 FORMAT(1X,F1Ø.1,3X,F1Ø.1,5X,F4.2,1ØX,F4.2)
      WRITE(6,1ØØ3)
      DO 1ØØØ NY=1,5Ø
C
C 2ND BERTH CONSTRUCTED IN YEAR NY
C
      SUMPV=Ø.Ø
      NB=1
      DO 1ØØ1 I=1,5Ø
      IF(I.GT.NY)NB=2
      SUMPV=SUMPV+(SDC(NB,I)*(1+ER)**I)/((1+CC)**I)
 1ØØ1 CONTINUE
C
C PRESENT VALUE EXPRESSION
      PV=(C1+SUMPV+(C2*(1+ER)**NY)/((1+CC)**NY))/1ØØØØØØ.
C
      WRITE(6,1ØØ4) NY,PV
 1ØØ3 FORMAT(1X,*YEAR 2ND BERTH*,3X,*PRESENT VALUE -M$*)
 1ØØ4 FORMAT(7X,I3,14X,F5.1)
 1ØØØ CONTINUE
```



LOGIC FLOW SHEET
(Simplified)

RF 11/24/75

APPENDIX 2

TONNAGE FORECASTS

Stelco Tentitive Shipping Concepts

For L.E.D. - G. Oravec, May 30, 1975

Vessel Capabilities

		Vessel Class	
Carrying Capacity (metric tonnes)	Griffith	850 ft.	1000 ft.
Ore	29000	39000	55000
Coal	27210	39000	55000
Discharge Rate (metric tonnes/hr.)			
Ore	6100	7000-10000	6100-10000
Coal	4500	6300-8000	6300-8000

Present Fleet Composition

11 self-unlaoder made up of;

8 - 730' vessels

3 - 650' vessels to be retired

8 - 730' made up of;

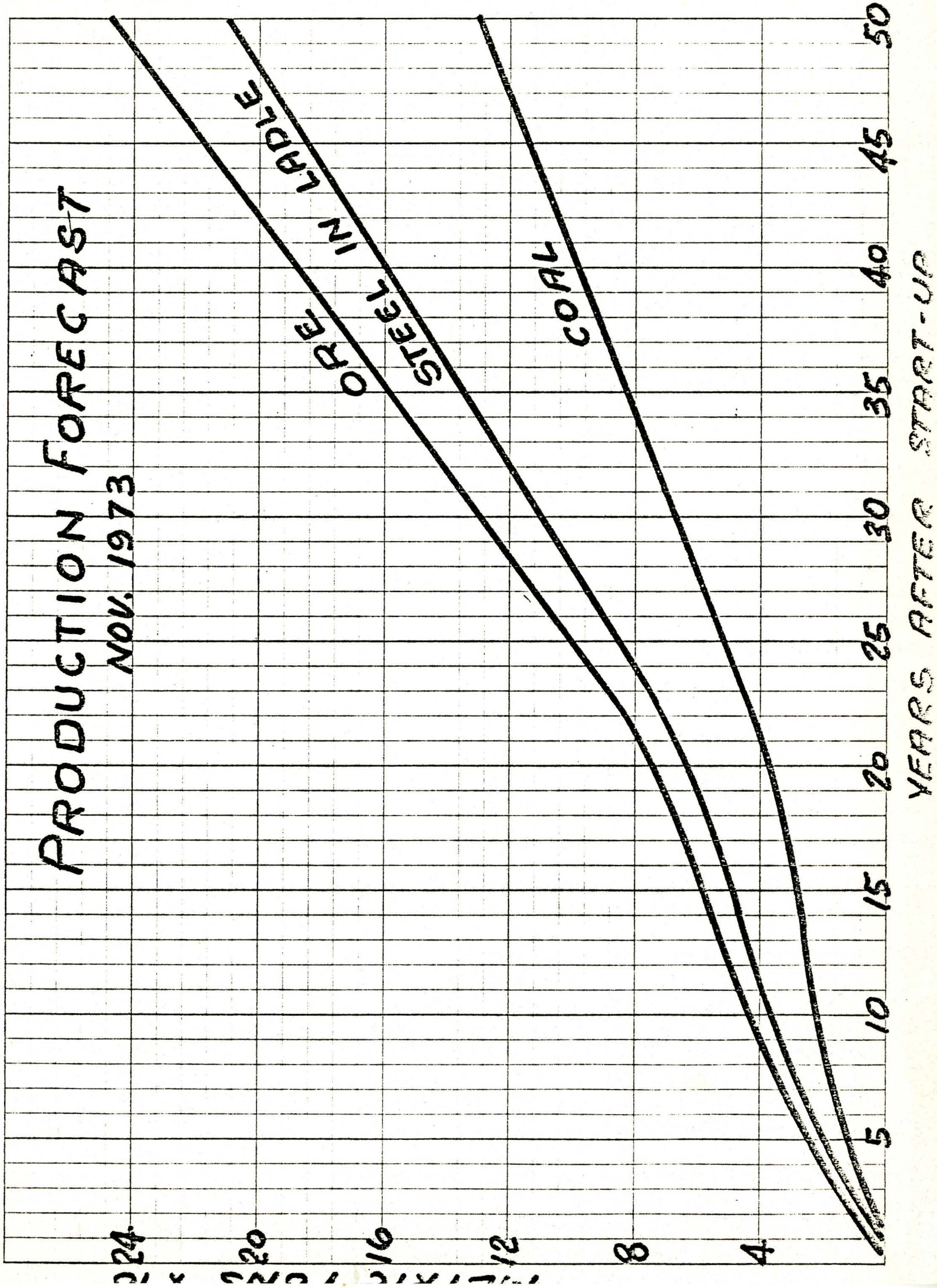
2 - 27000t vessels, coal

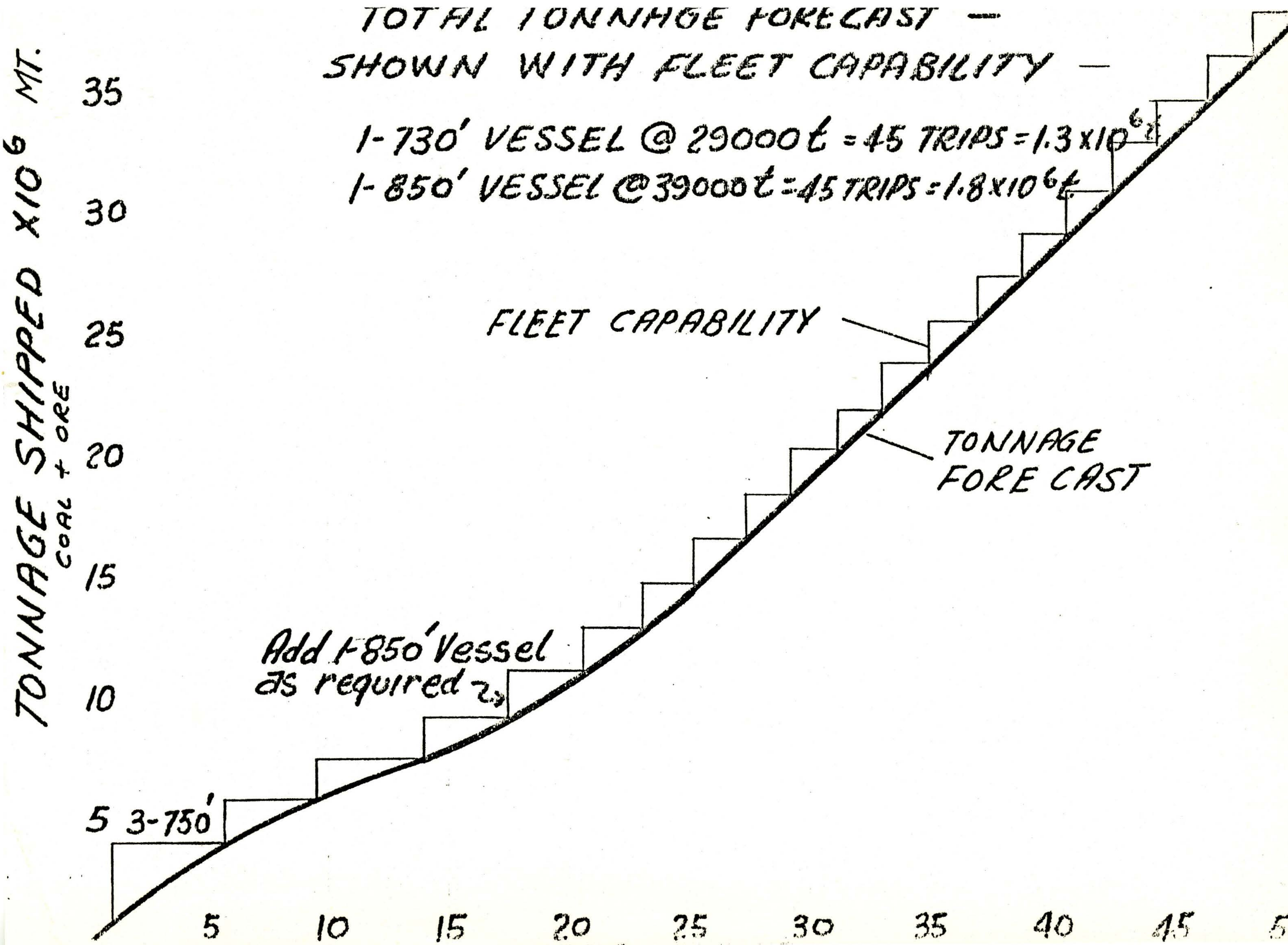
6 - 25000t vessels, coal

Future Fleet For L.E.D.

3 - 730' vessels to start

\+ 1 - 850' vessel every 2 years as required.


PRODUCTION FORECAST
NOV. 1973
ORE
STEEL IN LADLE
COAL
YEARS AFTER START-UP
5
10
15
20
25
30
35
40
45
50
4
8
12
16
20
24


TOTAL TONNAGE FORECAST —
SHOWN WITH FLEET CAPABILITY —
1-730' VESSEL @ 29000 t = 45 TRIPS = 1.3 X 10^6 t
1-850' VESSEL @ 39000 t = 45 TRIPS = 1.8 X 10^6 t.
TONNAGE SHIPPED X10^6 MT.
COAL + ORE
35
30
25
20
15
10
5
3-750'
FLEET CAPABILITY
TONNAGE FORE CAST
Add 1-850' Vessel as required
5
10
15
20
25
30
35
40
45
50

APPENDIX 3

FUNCTIONS RELATED TO THE ERLANG DISTRIBUTION

FUNCTIONS Related to the Erlang distribution: P.M. Morse, Queues, Inventories, and Maintenance.

$$en(x) = \frac{x^n e^{-x}}{n!}$$

$$Em(x) = \sum_{n=0}^{m} en(x)$$

$$Dm(x) = \frac{1}{m+1} \sum_{n=0}^{m} En(x)$$

$$Em(x) = \int_x^{\infty} em(y)dy$$

$$Em + 1(x) = Em(x) + e_{m+1}(x)$$

$$\frac{d}{dx} Em(x) = E_{m-1}(x) - Em(x)$$

$$Dm(x) = \frac{1}{m+1} \int_x^{\infty} Em(y)dy = \sum_{n=0}^{m} (1 - \frac{n}{m+1})\ en(x)$$

$$(m+1)\ Dm(x) = mD_{m-1}(x) - (m+1)\ Em(x)$$

$$em(0) = Em(0) = Dm(0) = 1$$

$$e_0(x) = E_0(x) = D_0(x) = e^{-x}$$

APPENDIX 4

DERIVATION OF ERLANG PROBABILITY DENSITY FUNCTION FOR BERTH SERVICE TIMES

To find a pdf of T where $T = t_1 + t_2 + t_3 + \ldots t_k$ when tj independent random variables are exponentially distributed as follows;

$$g(tj) = k\theta\ e^{-k\theta t}$$

The moment Generating function of $g(tj) = M_{tj}(\theta)$ is used to derive the pdf of T, f(t), generally;

$$M_x(\phi) = E(e^{x\phi}) \quad \text{also} \quad E(x) = \int_{-\infty}^{\infty} x fx(x)dx$$

where x is a continuous random variable so $Mx(\phi) = E(e^{x\phi}) = \int_{-\infty}^{\infty} e^{x\phi}\ fx(d)dx$

also $\frac{d^k}{dt^k} M \times (\phi) \Big|_{\phi=0}^{@} = E[x^k]$

$$\therefore\ M_{tj}(\phi) = \int_0^{\infty} e^{x\phi} \cdot k\theta \cdot e^{-k\theta t} = \frac{k\theta}{k\theta-\phi} \quad \phi < k\theta.$$

Now the Moment generating function of T where $T = \sum_{j=1}^{k} tj$

is $M_T(\phi) = M_{t1}(\phi) \cdot M_{t2}(\phi) \ldots . M_{tk}(\phi)$

$$\therefore\ M_T(\phi) = \left(\frac{k\theta}{k\theta-\phi}\right)^k \quad \text{theorem } M_T(\phi) = (M_{tj}(\phi)]^k$$

Now the one-sided Laplace Transform of a function f is defined by $L[f(x)] = \int_0^{\infty} e^{-sx}\ f(x)\ dx$

Now if $fx(t) = 0$ when $t < 0$, $L[fx(x)] = M_x(t)$ where $t = -s$, thus

$$fx(x) = L^{-1}\ Mx(-s) \qquad (1)$$

Equation 1.0 says that if we know that Moment generating function Mx(t) then by letting t = -s, Mx is a function of s and fx(x) is the Leplace transform of Mx

$$\therefore \; f_t(t) = L^{-1} \{(\frac{k\,\theta}{s+k\theta})^k\} \quad \ldots. \quad (t = -s)$$

using Laplace Transform tables,

$$ft(t) = \frac{k\theta^k}{\Gamma(k)} \; t^{k-1} \; e^{-k\theta t} \qquad t, k, > 0$$

regrouping yields; $ft(t) = \frac{k\theta}{(k-1)!} (k\theta t)^{k-1} \cdot e^{-k\theta t}$ 'Erlang density'

where $\Gamma(k) = (k-1)!$

Letting $\alpha = k\theta$, $M - (\phi) = \int_0^\infty e^{\phi t} \alpha e^{-\alpha t} = \frac{\alpha}{\alpha \cdot \phi}$, $\phi < \alpha$

$E[T] = \frac{d}{dt} (\frac{\alpha}{\alpha-\phi}) \;|^{@}_{\phi=0} = \frac{1}{\alpha}$ = expected service time

The parameters α and k are related to the mean and variance, thus;

$$\mu_x = \frac{d}{d\phi} (\frac{\alpha}{\alpha-\phi})^k \;|^{@}_{\phi=0} = \frac{k}{\alpha}$$

2nd $$\sigma_x{}^2 = \frac{d^2}{d\phi^2} (\frac{\alpha}{\alpha-\phi})_{\phi=0} = - \frac{k^2}{\sigma^2} = \frac{k}{\alpha^2}$$

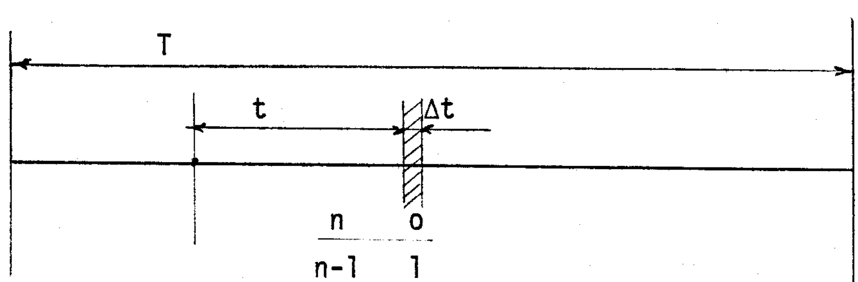
APPENDIX 5

DERIVATION OF POISSON FREQUENCY DISTRIBUTION FOR ARRIVAL TIMES

Inter Arrival Times - Derivation

Let T be a fixed time period and assume an arrival E in any time interval $S_1 < T$ is independent of the arrival in any other non-overlapping time interval $S_2 < T$ and suppose the probability of this arrival occurring in time interval of length Δt is proportional to Δt and that Δt is sufficiently small that the probability that more than one arrival occurs is negligible, then P[E occurs within Δt] $= \lambda\Delta t$ for some λ.

Now considering the probability $Pn(t)$ that an arrival will occur exactly n times within t and noting that $Po(\Delta t) = 1 - P_1(\Delta t)$ for small t and $= 1 - \lambda(\Delta t)$ for small Δt and $(t + \Delta t) < T$ it follows that $Pn(t + \Delta t)$ = P[E occurs n times in t and o times in Δt] + P[E occurs n-1 times in t and 1 time in Δt]



consequently

$$Pn(t+\Delta t) = P[E\cdot n \text{ times}|t] * P[E\cdot 0 \text{ times}|\Delta t] + P[E\cdot(n-1)|t]$$
$$+ P[E\cdot 1 \text{ time}|\Delta t]$$

from the probability law; $P[E_1E_2] = P[E_1] \cdot P[E_2]$

It can be shown that;

$$Pn(t+\Delta t) = Pn(t) * Po(\Delta t) + Pn\text{-}1(t) * P_1(\Delta t)$$
$$= Pn(t) * (1-\lambda\Delta t) + Pn\text{-}1(t) * \lambda\Delta t$$

or

$$\frac{Pn(t+\Delta t) - Pn(t)}{\Delta t} = \lambda[Pn\text{-}1(t) - Pn(t)]$$

since

$$\lim_{\Delta t \to 0} \frac{Pn(t+\Delta t) - Pn(t)}{\Delta t} = P'n(t)$$

$$P'n(t) = \lambda[Pn\text{-}1(t) - Pn(t)] \qquad (1)$$

Consequently

$$Po'(t) = -\lambda\, Po(t) \text{ since } P_{-1}(t) = o$$

hence

$$Po(t) = e^{-\lambda t}$$

substitute n = 1 in equation (1)

then $P_1'(t) = \lambda[e^{-\lambda t} - P_1(t)]$

Solve different equation to find $P_1(t)$

reform: $\frac{dy}{dt} + \lambda y = \lambda e^{-\lambda t}$ (2)

General: $F(t)\frac{dy}{dt} + G(t)\, y = H(t)$

with $\frac{dy}{dt}$ and y on left side suggests derivative of product say $\phi(t) \cdot y$

$$\phi(t)\,\frac{dy}{dt} + \frac{d\phi(t)}{dt} \qquad (3)$$

multiple (2) by $\phi(t)$

$$\phi(t)\,\frac{dy}{dt} + \lambda\phi(t) \cdot y = \phi(t)\,\lambda e^{-\lambda t} \qquad (4)$$

Equate 2nd terms in Equations (3) and (4) by choosing $\phi(t)$ such that

$$\frac{d\phi(t)}{dt} = \phi(t) \cdot \lambda$$

$$\frac{d\phi(t)}{\phi(t)} = \lambda dt$$

$$\int \lambda dt = \ln[\phi(t)]$$

$$\phi(t) = \exp[\int \lambda dt]$$

$$\exp[\int \lambda dt]\,\frac{dy}{dt} + \exp[\int \lambda dt]\,\lambda y = e^{-\lambda t}\,\exp[\int \lambda dt]$$

$$y\,e^{\lambda t} = \lambda \int e^{-\lambda t} \cdot e^{\lambda t}\,dt + c$$

$$y\,e^{\lambda t} = \lambda t + c$$

$$y = \lambda t e^{-\lambda t} + c\,e^{-\lambda t}$$

$$y = 0 \text{ @ } t = 0 \quad \therefore P_1(t) = \lambda t e^{-\lambda t}$$

continuing for n = 2 $P_2'(t) = \lambda[P_1(t) - P_2(t)]$

$$P_2'(t) = \lambda[\lambda t e^{-\lambda t} - P_2(t)]$$

repeating the same solution for $P_2(t)$

$$P_2(t) = \frac{\lambda^2 t^2}{2}\,e^{-\lambda t}$$

repeating the same solution for $P_3(t)$;

$$P_3(t) = \frac{\lambda^3 t^3 e^{-\lambda t}}{6}$$

the general form for n is, therefore;

$$Pn(t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

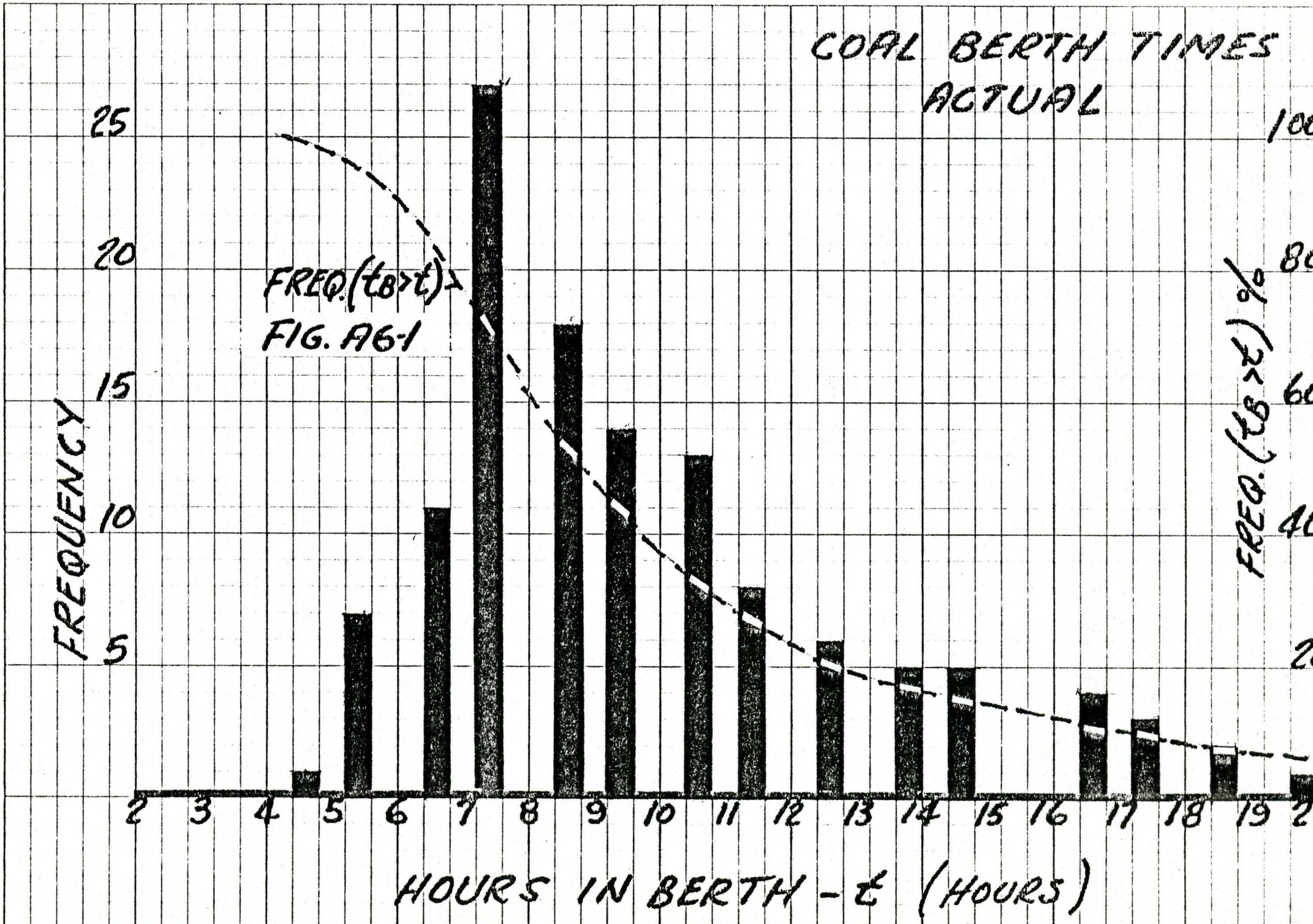
which is the Poisson frequency distribution.

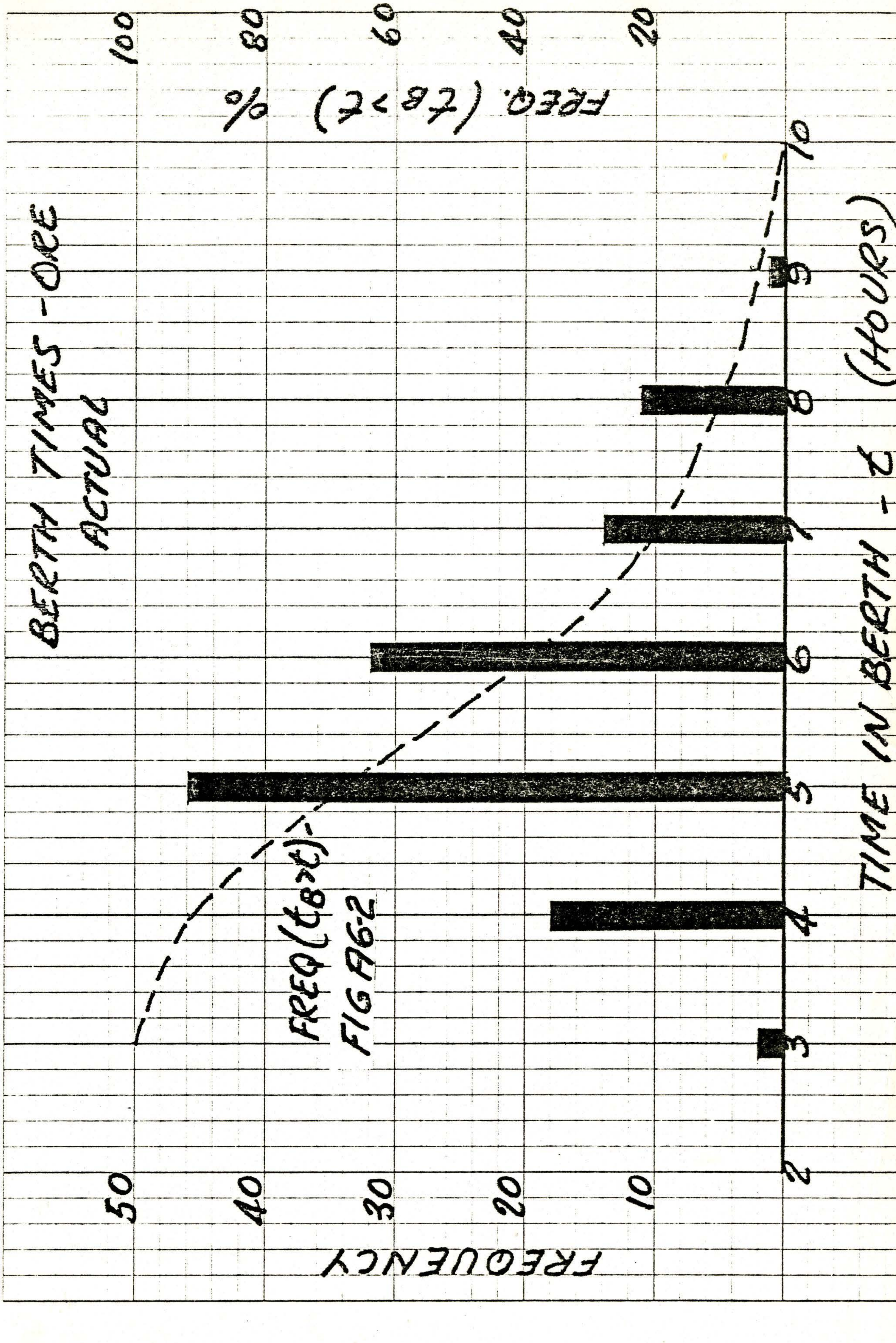
APPENDIX 6

HISTORICAL DATA BERTH SERVICE TIMES

AND

ARRIVAL TIME DISTRIBUTIONS FOR ORE AND COAL


COAL BERTH TIMES
ACTUAL
FREQ.(tB>t)
FIG. A6-1
FREQUENCY
FREQ. (tB>t) %
25
20
15
10
5
100
80
60
40
20
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
HOURS IN BERTH - t (HOURS)


BERTH TIMES - ORE
ACTUAL
TIME IN BERTH - t (HOURS)
FREQUENCY
FREQ. (tB<t) %
FREQ(tB>t)
FIG A6-2
100 80 60 40 20
50 40 30 20 10
2 3 4 5 6 7 8 9 10

Interarrival Times Independence Test Calculations

$r_1 = 11$

$r_2 = 7$

$r_3 = 1$

$$R_k = \sum_{i=k}^{n-1} r_i = R_1 = 19$$

$$R_2 = 8$$

$$R_3 = 1$$

$$R = \sum_{i=1}^{n-1} r_i = 19$$

$$E(r_1) = \frac{2}{4!}[29(5) - (-1)] = 12$$

$$E(r_2) = \frac{2}{5!}(29[11] - [14]) = 5$$

$$E(r_3) = \frac{2}{6!}(29[9+9+1] - [27+27-3-4]) = 1.4$$

$$E(R_1) = \frac{2}{3!}[29(2) - (1)] = 19$$

$$E(R_2) = \frac{2}{4!}[29(3) - 5] = 7$$

$$E(R_3) = \frac{2}{5!}[29(4) - 11] = 1.75$$

$$E(R) = \frac{1}{3}(2[29] - 1) = 19$$

Berth Times Independence Test Calculations

Runs			
1	2	3	4
12	6	2	1

$R_1 = 21$

$R_2 = 9$

$R_3 = 3$

$R_4 = 1$

$R = 21$

$$E(r_1) = \frac{2}{4!}[35(5) - (-1)] = 14.6$$

$$E(r_2) = \frac{2}{5!}[35(11) - 14] = 6.2$$

$$E(r_3) = \frac{2}{6!}[35(19) - 47] = 1.7$$

$$E(r_4) = \frac{2}{7!}[35(29) - 104] = .4$$

$$E(R_1) = \frac{2}{3!}[35(2) - 1] = 23$$

$$E(R_2) = \frac{2}{4!}[35(3) - 5] = 8.3$$

$$E(R_3) = \frac{2}{5!}[35(4) - 11] = 2.2$$

$$E(R_4) = \frac{2}{6!}[35(5) - 19] = .43$$

$$E(R) = \frac{1}{3}(2(35) - 1) = 23$$

Chi-square Test for Ore Arrival

From Fig. III-4

$$\chi^2 = \sum_{i=1}^{6} \frac{(21-26)^2}{26} + \frac{(40-37)^2}{37} + \frac{(25-27)^2}{27} + \frac{(10.1-11)^2}{11} + \frac{(5.1-5)^2}{5} + \frac{(.9-.5)^2}{.5}$$

$\chi^2 = 1.75$, $k - 1 = 5$ degrees of freedom.

Using Chi-square distribution to test significance of 0.01

$$P(\chi^2 > 15.09) = 0.01 \qquad \text{(Tables)}$$

Therefore, since 1.75 << 15.09 there is no significant difference between the observed and theoretical distribution (Poisson).

<u>Chi-square Test for Coal Berth Time</u>

From Fig. III-2

$\frac{1}{\theta} = 8.63$

$\theta = .116$

$k = 6$

$k\theta = .695$

Erlang Distribution: $f(t) = \frac{k\theta}{(k-1)!} \cdot (k\theta t)^{k-1} \cdot e^{-k\theta t}$

Berth Service Time t-Hrs.	Observed Frequencies	Erlang Theoretical Frequency	$\chi^2 = \frac{(f_i-e_i)^2}{e_i}$
4.5	1	1	0
5.5	7	8	.125
6.5	11	11	0
7.5	27	12.6	16
8.5	18	13	1.9
9.5	14	11.5	.54
10.5	13	10.3	.708
11.5	8	8.5	.029
12.5	6	6.7	.07
	105		19.4

Using the Chi-square distribution to test significance of 0.01.

$P(\chi^2 > 20.1 = 0.01$ (Tables) Therefore, since $19.4 < 20.1$, the observed distribution is accepted as being Erlang.

Vessel Arrival Distributions Fig. III-4,5

The number of vessels arriving during 3 day intervals were recorded throughout the shipping season from the historical data (example included in this appendix).

SUMMARY OF ORE ARRIVALS:

n	0	1	2	3	4	5
freq.	19	37	22	10	5	0
% prob. of n arriving in 3 day interval	20.4	40	23.7	10.7	5.4	0

Similarly with Coal Vessels;

n	0	1	2	3	4	5
freq.	19	35	26	9	4	0
% prob.	20	38	28	10	4	0

COAL 1971

VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Tarantau	Sandusky	1/8/72	900A	1/8	730P	1/8	830P	10:30	replace hitches
Quetico	✓	1/3	630A	1/3	430P	1/3	450P	10:00	
Tadoussac	✓	12/23	610P	12/24	300A	12/24	320A	8:50	
Manitoulin	✓	12/14	950A	12/14	620P	12/14	640P	8:30	
Tadoussac	✓	12/13	440A	12/13	240P	12/13	300P	10:00	
Quetico	✓	12/9	810P	12/10	430A	12/10	450A	8:20	
Hochelaga	✓	12/1	210P	12/2	630A	12/2	650A	16:20	8 hr delay - belt motor
Hochelaga	✓	10/26	230A	10/26	1000A	10/26	1020A	7:30	
Hochelaga	✓	10/21	830A	10/21	330P	10/21	350P	7:00	
Hochelaga	✓	10/17	140A	10/17	850A	10/17	910A	7:10	
Manitoulin	✓	10/15	750A	10/15	400P	10/15	420P	8:10	
Gleneagles	✓	10/3	530A	10/3	420P	10/3	440P	10:50	
Hochelaga	✓	9/29	450A	9/29	1140A	9/29	1200P	6:50	
Hochelaga	✓	9/26	500A	9/26	1200P	9/26	1220P	7:00	
Hochelaga	✓	9/18	110A	9/18	900A	9/18	920A	7:50	
Hochelaga	✓	9/14	420P	9/14	1130P	9/14	1150P	7:10	
Gleneagles	✓	9/12	150P	9/12	920P	9/12	940P	7:30	
Gleneagles	✓	9/7	320P	9/7	1140P	9/8	1200A	8:20	
Gleneagles	✓	8/30	1230P	8/30	1050P	8/30	1110P	10:20	
Hochelaga	✓	8/17	1100A	8/17	610P	8/17	630P	7:10	
Hochelaga	✓	8/14	350A	8/14	1130A	8/14	1150A	7:40	
Hochelaga	✓	8/11	1240A	8/11	840A	8/11	900A	8:00	
Hochelaga	✓	8/7	1110A	8/7	630P	8/7	650P	7:20	
Gleneagles	✓	8/1	710P	8/2	820A	8/2	840A	13:10	
Manitoulin	✓	7/25	1240A	7/25	840A	7/25	900A	8:00	
Hochelaga	✓	7/18	100P	7/18	900P	7/18	920P	8:00	
Hochelaga	✓	7/15	310A	7/15	150P	7/15	210P	10:40	
Hochelaga	✓	7/9	940A	7/9	1040P	7/9	1100P	13:00	
Manitoulin	✓	7/6	400A	7/6	1210P	7/6	1230P	8:10	
Manitoulin	✓	7/3	520A	7/3	110P	7/3	130P	7:50	
Gleneagles	✓	6/29	210P	6/30	200A	6/30	220A	11:50	
Manitoulin	✓	6/25	1120P	6/26	710A	6/26	730A	7:50	
Manitoulin	✓	6/23	720A	6/23	350P	6/23	410P	8:30	
Manitoulin	✓	6/16	740A	6/16	900P	6/16	920P	13:20	belt broke - 2 hrs
Manitoulin	✓	6/13	420A	6/13	1150A	6/13	1210P	7:30	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Kinnitoulin	Sandusky Toledo	5/11	1050A	5/11	540P	5/11	600P	6:50	
Toulin	✓	4/29	600P	4/30	200A	4/30	200A	8:00	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Quetico	Ashtabula	1/5/72	900P	1/6	630P	1/6	650P	21:30	
Quetico	✓	12/17	1010A	12/18	940A	12/18	1000A	22:20	
Quetico	✓	12/13	200P	12/14	210A	12/14	230A	12:10	
Hochelaga	✓	10/31	900A	10/31	840P	10/31	900P	11:40	
Hochelaga	✓	10/28	320P	10/29	510A	10/29	530A	13:50	
Hochelaga	✓	10/12	510P	10/13	700A	10/13	720A	13:50	
Manitoulin	✓	9/27	1010A	9/28	1230A	9/28	1250A	14:20	
Manitoulin	✓	9/24	620P	9/25	810A	9/25	830A	13:50	
Manitoulin	✓	9/13	1120P	9/14	150P	9/14	210P	14:30	
Hochelaga	✓	8/30	1250P	8/31	340A	8/31	400A	14:50	
Hochelaga	✓	8/20	430A	8/20	440P	8/20	500P	12:10	
Manitoulin	✓	7/9	510A	7/9	440P	7/9	500P	11:30	
Manitoulin	✓	5/14	800P	5/15	800A	5/15	820A	12:00	
Hochelaga	✓	5/4	630P	5/5	430P	5/5	450P	10:00	
Hochelaga	✓	4/24	1200P	4/25	420P	4/25	440P	27:20	
Sadowski	✓	4/14	840P	4/15	930A	4/15	950A	12:50	
Hochelaga	✓	7/3	100P	7/4	300A	7/4	320A	14:00	
Hochelaga	✓	6/14	930A	6/15	100A	6/15	120A	15:30	
Hochelaga	✓	5/31	130P	6/1	230A	6/1	250A	13:00	
Hochelaga	✓	5/24	150P	5/25	120A	5/25	140A	12:30	
Hochelaga	✓	5/21	1050A	5/22	340A	5/22	400A	16:50	
Hochelaga	✓	5/17	1240P	5/17	1120P	5/17	1140P	10:40	
Tarantau	Ashtabula Conneaut	1/1/72	1:20A	1/1	840P	1/1	900P	18:30	
Tarantau	✓	12/20	920A	12/21	1250A	12/21	110A	15:30	
Hochelaga	Ashtabula Toledo	7/29	430P	7/30	1240A	7/30	100A	8:10	

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VESSEL	ORIGIN	ARRIVED	FINISHED	CLEARED	TIME AT DOCK	REMARKS
Frontenac	Conneaut	12/27 450P	12/28 210A	12/28 230A	9:20	
Manitoulin	✓	12/16 830P	12/17 540A	12/17 600A	9:10	
Gleneagles	✓	12/4 130P	12/4 800P	12/4 820P	6:30	
Hochelaga	✓	11/16 540A	11/16 430P	11/16 450P	10:50	
Gleneagles	✓	11/6 400P	11/7 230P	11/7 930P	22:30	conveyor trouble; [illegible]
Manitoulin	✓	11/2 210A	11/2 950A	11/2 1010A	7:40	
Hochelaga	✓	10/8 920A	10/8 500P	10/8 520P	7:40	
Hochelaga	✓	10/1 610P	10/2 210A	10/2 230A	8:00	
Gleneagles	✓	9/15 1220P	9/15 700P	9/15 720P	6:40	
Hochelaga	✓	9/7 530A	9/7 520P	9/7 540P	11:50	
Gleneagles	✓	9/4 420A	9/4 1150A	9/4 1210P	7:30	
Hochelaga	✓	8/27 700A	8/27 440P	8/27 500P	9:40	
Manitoulin	✓	8/17 400A	8/17 1150A	8/17 1210P	7:50	
Hochelaga	✓	7/26 610A	7/26 140P	7/26 200P	7:30	
Hochelaga	✓	7/23 1230P	7/23 650P	7/23 700P	6:20	
Hochelaga	✓	7/21 130A	7/21 810A	7/21 830A	6:40	
Manitoulin	✓	6/30 310A	6/30 1210P	6/30 1230P	9:00	
Hochelaga	✓	6/17 1020P	6/18 140P	6/18 200P	15:20	
Hochelaga	✓	4/21 320A	4/21 620P	4/21 640P	15:00	
Frontenac	Conneaut Ashtabula	12/20 920A	12/21 1250A	12/21 110A	15:30	
Frontenac	✓	1/1/72 120A	1/1/72 840P	1/1 900P	18:30	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Manitoulin	Toledo	12/21	1020A	12/21	510P	12/21	530P	6:50	
Hochelaga	Toledo / Ashtabula	7/29	430P	7/30	1240A	7/30	100A	8:10	
Farrantau	Toledo / Sandusky	1/5/72	730A	1/5/72	550P	1/5	610P	10:20	
Quetico	✓	12/29	540P	12/30	400A	12/30	420P	9:10	
Farrantau	✓	12/24	140P	12/24	900P	12/25	430A	7:20	high winds
Farrantau	✓	12/17	400P	12/18	340A	12/18	400A	11:40	
Hochelaga	✓	12/11	350A	12/11	100P	12/11	400P	9:10	cleaning cargo holds
Hochelaga	✓	12/6	1030P	12/7	530A	12/7	550A	7:00	
Hochelaga	✓	10/5	800P	10/6	140A	10/6	200A	5:40	
Gleneagles	✓	9/29	450P	9/29	1130P	9/29	1150P	6:40	
Hochelaga	✓	9/22	700A	9/22	200P	9/22	220P	7:00	
Hochelaga	✓	9/11	350A	9/11	1120A	9/11	1140A	7:30	
Hochelaga	✓	9/3	600P	9/4	1240A	9/4	100A	6:40	
Gleneagles	✓	8/26	340P	8/27	120A	8/27	140A	9:40	
Hochelaga	✓	8/24	220P	8/24	930P	8/24	950P	7:10	
Manitoulin	✓	8/20	900P	8/21	450A	8/21	730A	7:50	test boat draft
Gleneagles	✓	8/6	220A	8/6	1150A	8/6	1210P	9:30	
Manitoulin	✓	6/20	630A	6/20	230P	6/20	250P	8:00	
Manitoulin	✓	6/10	110A	6/10	830A	6/10	850A	7:20	
Manitoulin	✓	5/27	1100P	5/28	700A	5/28	720A	8:00	
Hochelaga	✓	5/24	150P	5/25	720A	5/25	740A	17:30	
Manitoulin	✓	5/18	100P	5/18	850P	5/18	910P	7:50	
Manitoulin	✓	5/11	1050P	5/11	540P	5/11	600P	6:50	
Manitoulin	✓	4/29	600P	4/30	200A	4/30	220A	8:00	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Manitoulin	Sandusky	6/6	750A	6/6	330P	6/6	350P	7:40	
Oelaga	✓	6/3	920P	6/4	900A	6/4	920A	11:40	
Hochelaga	✓	5/28	820P	5/29	820A	5/29	840A	12:00	
Manitoulin	✓	5/24	740A	5/24	330P	5/24	350P	7:50	
Manitoulin	✓	5/21	130P	5/21	950P	5/21	1010P	8:20	
Hochelaga	✓	5/13	130P	5/14	240A	5/14	300P	13:10	
Hochelaga	✓	5/9	1140A	5/10	1210A	5/10	1230A	12:30	
Manitoulin	✓	5/7	710P	5/8	340A	5/8	400A	8:30	
Manitoulin	✓	5/4	700A	5/4	240P	5/4	300P	7:40	
Hochelaga	✓	4/30	740A	4/30	740P	4/30	800P	12:00	
Manitoulin	✓	4/25	800A	4/25	400P	4/25	420P	8:00	
Gleneagles	✓	4/21	1030P	4/22	1050A	4/22	1110A	12:20	
Manitoulin	✓	4/21	800P	4/22	400A	4/22	420A	8:00	
Potomac	✓	4/18	240P	4/18	950P	4/18	1010P	7:10	
Boston	Sandusky Toledo	1/5/72	730A	1/5	550P	1/5	610P	10:20	
Juetica	✓	12/29	540P	12/29	400A	12/29	420P	9:10	
Trenton	✓	12/24	140P	12/24	900P	12/25	430A	7:20	high winds
Trenton	✓	12/17	400P	12/18	340A	12/18	400A	11:40	
Hochelaga	✓	12/11	350A	12/11	100P	12/11	400P	9:10	high winds
Hochelaga	✓	12/6	1030P	12/7	530A	12/7	550A	7:00	
Hochelaga	✓	10/5	800P	10/6	140A	10/6	200A	5:40	
Gleneagles	✓	9/29	450P	9/29	1130P	9/29	1150P	6:40	
Hochelaga	✓	9/22	700A	9/22	200P	9/22	220P	7:00	
Hochelaga	✓	9/11	350A	9/11	1120A	9/11	1140A	7:30	
Hochelaga	✓	9/3	600P	9/4	1240A	9/4	100A	6:40	
Gleneagles	✓	8/26	340P	8/27	120A	8/27	140A	9:40	
Hochelaga	✓	8/24	220P	8/24	930P	8/24	950P	7:10	
Manitoulin	✓	8/20	900P	8/21	450A	8/21	730A	7:50	test boat draft
Gleneagles	✓	8/6	220A	8/6	1150A	8/6	1210P	9:30	
Manitoulin	✓	6/20	630A	6/20	230P	6/20	250P	8:00	
Manitoulin	✓	6/10	110A	6/10	830A	6/10	850A	7:20	
Manitoulin	✓	5/27	1100P	5/28	700A	5/28	720A	8:00	
Manitoulin	✓	5/18	100P	5/18	850P	5/18	910P	7:50	

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VESSEL	ORIGIN	ARRIVED	FINISHED	CLEARED	TIME AT DOCK	REMARKS
Tadoussac	Pointe Noire	11/23 1030A	11/23 540P	11/23 610P	7:10	
[illegible] Toulon	✓	11/18 200A	11/18 920A	11/18 930A	7:20	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Tadoussac	Taconite	12/11	500P	12/11	1120P	12/11	1140P	6:20	
Saguenay	✓	12/9	1110P	12/10	420A	12/10	440A	5:10	
Tarantau	✓	12/9	900A	12/9	330P	12/9	350P	6:30	
Manitoulin	✓	12/4	500A	12/4	1050A	12/4	1110A	5:50	
Saguenay	✓	11/30	630P	11/30	1200A	11/30	1240A	5:30	
McGiffin	✓	11/22	230P	11/23	120A	11/23	140A	11:00	
Manitoulin	✓	11/21	1020A	11/21	400P	11/21	420P	5:40	
Manitoulin	✓	11/8	750P	11/9	200A	11/9	220A	6:10	
Manitoulin	✓	10/31	1140A	10/31	510P	10/31	530P	5:30	
Saguenay	✓	10/30	630P	10/30	1130P	10/30	1150P	5:00	
Tadoussac	✓	10/23	310P	10/23	800P	10/23	830P	4:50	
Quetico	✓	10/20	250P	10/20	1120P	10/20	1140P	8:30	
Quetico	✓	10/12	130A	10/12	800A	10/12	820A	6:30	
Manitoulin	✓	10/9	840P	10/10	410A	10/10	430A	7:30	
McGiffin	✓	10/5	310A	10/5	850A	10/5	910A	5:40	
Manitoulin	✓	9/30	120P	9/30	730P	9/30	750P	6:10	
McGiffin	✓	9/24	1250P	9/25	100A	9/25	120A	12:10	waiting for Tadoussac
Tadoussac	✓	9/24	800A	9/24	610P	9/24	630P	10:10	waiting for Stadacona
Stadacona	✓	9/24	700A	9/24	1200P	9/24	1220P	5:00	
Manitoulin	✓	9/23	610A	9/23	1050A	9/23	1110A	4:40	
Saguenay	✓	9/20	300A	9/20	820A	9/20	840A	5:20	
McGiffin	✓	9/13	940A	9/13	400P	9/13	420P	6:20	
Manitoulin	✓	9/11	910P	9/12	350A	9/12	410A	6:40	
Quetico	✓	9/10	1100P	9/11	1000A	9/11	1120A	11:00	changed bearing
Tadoussac	✓	9/5	1120P	9/6	440A	9/6	510A	5:20	
Manitoulin	✓	9/4	630A	9/4	110P	9/4	130P	6:40	
Quetico	✓	8/30	340A	8/30	1050A	8/30	1110A	7:10	
Tadoussac	✓	8/22	1100A	8/22	420P	8/22	440P	5:20	
McGiffin	✓	8/21	1210A	8/21	710A	8/21	730A	7:00	
McGiffin	✓	8/13	730A	8/13	110P	8/13	130P	5:40	
Manitoulin	✓	8/12	1110A	8/12	600P	8/12	620P	6:50	
Quetico	✓	8/8	700P	8/9	340A	8/9	400A	8:40	
McGiffin	✓	8/5	140P	8/5	710P	8/5	730P	5:30	
Tadoussac	✓	8/4	1020P	8/5	410A	8/5	420A	5:40	
Tarantau	✓	7/30	400A	7/30	1020A	7/30	1040A	6:20	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Manitoulin	Taconite	7/28	220P	7/28	800P	7/28	820P	5:40	
Tadoussac	✓	7/26	900A	7/26	300P	7/26	320P	6:00	
Manitoulin	✓	7/17	740A	7/17	1240P	7/17	100P	5:00	
Frontenac	✓	7/15	450P	7/15	1000P	7/15	1020P	5:10	
Tadoussac	✓	7/10	710P	7/11	1200A	7/11	1220A	4:50	
Frontenac	✓	7/8	940A	7/8	240P	7/8	300P	5:00	
Tadoussac	✓	7/3	120P	7/3	600P	7/3	620P	4:40	
Frontenac	✓	7/1	1040A	7/1	400P	7/1	420P	5:20	
Tadoussac	✓	6/26	540A	6/26	1020A	6/26	1040A	4:40	
Tadoussac	✓	6/19	1210A	6/19	520A	6/19	540A	5:10	
[illegible]	✓	6/18	930P	6/19	330A	6/19	510A	6:00	repairs and ballast
Tadoussac	✓	6/11	920P	6/12	220A	6/12	240A	5:00	
Hochelaga	✓	6/1	550P	6/1	1120P	6/2	530A	5:30	repairs to propeller
Hochelaga	✓	5/20	330P	5/20	830P	5/20	850P	5:00	
Tadoussac	Taconite Thunder Bay	8/29	1150P	8/30	640A	8/30	700P	6:50	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Manitoulin	Thunder Bay	12/14	620P	12/15	1230A	12/15	1250A	6:10	
Quetico	✓	12/8	900P	12/9	450A	12/9	510A	7:50	
Quetico	✓	12/1	410P	12/1	1110P	12/1	1130P	7:00	
Stadacona	✓	11/29	1230P	11/29	440P	11/29	500P	4:10	
Quetico	✓	11/22	330P	11/22	1140P	11/23	1200A	8:10	
Quetico	✓	11/15	610A	11/15	200P	11/15	220P	7:50	
Quetico	✓	11/7	600A	11/7	1220P	11/7	1250P	6:20	
Tadoussac	✓	11/5	500A	11/5	1010A	11/5	1030A	5:10	
Quetico	✓	10/31	1210A	10/31	800A	10/31	830A	7:50	
McGiffin	✓	10/22	340A	10/22	910A	10/22	930A	5:30	
McGiffin	✓	10/14	940A	10/14	410P	10/14	430P	6:30	
Tadoussac	✓	10/14	1210A	10/14	530A	10/14	550A	5:20	
Quetico	✓	10/4	810A	10/4	320P	10/4	340P	7:10	
Quetico	✓	9/26	1040P	9/27	540A	9/27	600A	7:00	
Quetico	✓	9/18	1050P	9/19	600A	9/19	620A	7:10	
Tadoussac	✓	9/13	140A	9/13	650A	9/13	710A	5:10	
McGiffin	✓	9/5	120P	9/5	830P	9/5	850P	7:10	
Manitoulin	✓	8/27	1150A	8/27	620P	8/27	640P	6:30	
Quetico	✓	8/22	1110P	8/23	540A	8/23	600A	6:30	
Quetico	✓	8/16	330A	8/16	1040A	8/16	1100A	7:10	
Saguenay	✓	8/13	530A	8/13	340P	8/13	400P	10:10	belt trouble
Tadoussac	✓	8/11	630P	8/11	1120P	8/11	1140P	4:50	
Hochelaga	✓	8/7	810A	8/7	330P	8/7	350P	7:20	
Quetico	✓	8/1	540A	8/1	110P	8/1	130P	7:30	
McGiffin	✓	7/28	950A	7/28	440P	7/28	500P	6:50	
Tarantau	✓	7/23	230A	7/23	840A	7/23	900A	6:10	
McGiffin	✓	7/21	810A	7/21	130P	7/21	150P	5:20	
McGiffin	✓	7/14	450A	7/14	1000A	7/14	1020A	5:10	
McGiffin	✓	7/7	410A	7/7	910A	7/7	930A	5:00	
McGiffin	✓	6/29	710A	6/29	1210P	6/29	1230P	5:00	
Manitoulin	✓	6/24	1200P	6/24	600P	6/24	620P	6:00	
McGiffin	✓	6/10	610A	6/10	1050A	6/10	1110A	4:40	
McGiffin	✓	6/7	220P	6/7	850P	6/7	910P	6:30	
Tadoussac 32	✓	6/4	1230P	6/4	510P	6/4	530P	4:40	
Manitoulin	✓	5/31	1000A	5/31	320P	5/31	340P	5:20	

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VESSEL	ORIGIN	ARRIVED		FINISHED		CLEARED		TIME AT DOCK	REMARKS
Tadoussac	Thunder Bay	5/28	840P	5/29	210A	5/29	230A	5:30	
Fifflin	✓	5/24	120P	5/24	600P	5/24	630P	4:40	
Tadoussac	✓	5/22	530A	5/22	1030A	5/22	1050A	5:00	
Montrealer	✓	5/18	600A	5/18	1050A	5/18	1130A	4:50	
Tadoussac	✓	5/14	740A	5/14	1250P	5/14	110P	5:10	
Fifflin	✓	5/13	740P	5/14	140A	5/14	200A	6:00	
Tadoussac	✓	5/7	210P	5/7	640P	5/7	700P	4:30	
Montrealer	✓	5/4	720P	5/5	210A	5/5	240A	6:50	
Tadoussac	✓	4/30	550A	4/30	1110A	4/30	1130A	5:20	
Montrealer	✓	4/28	230A	4/28	730A	4/28	750A	5:00	
[illegible]	✓	4/23	740A	4/23	200P	4/23	230P	6:20	
Tadoussac	✓	4/22	1100P	4/23	620A	4/23	650A	7:20	
Montrealer	✓	4/19	1140P	4/20	500A	4/20	820A	5:20	engine trouble
Montrealer	✓	5/11	100P	5/11	600P	5/11	650P	5:00	
Tadoussac 39	Thunder Bay Taconite	8/29	1150P	8/30	640A	8/30	700A	6:50	

APPENDIX 7

ECONOMICS OF DOCK ALTERNATIVES

DESCRIPTION	PROGRESS	ORIGINAL ENG. ALLOCATION			PROJECTED FINAL COST		
		BASE	CONTINGENCY	ESCALATION	BASE	CONTINGENCY	ESCALATION
PERMANENT CAUSEWAY	88% COMP	1,703,000	172,500	452,700	1,517,833	172,500	452,700
TEMPORARY CAUSEWAY CONST.	68% COMP	352,000	61,400	101,900	351,052	61,400	101,900
CAUSEWAY BRIDGE WITH PIERS ON SPREAD FOOTINGS	18% COMP	3,643,000	368,400	1,063,600	2,735,320	368,400	1,063,600
DREDGING	23.3% COMP	2,351,000	332,700	747,300	1,964,600	332,700	747,300
WHARF	10% COMP	8,904,000	845,400	2,566,400	7,481,181	845,400	2,566,400
RELOCATE AND REARRANGE	9.1% COMP	248,000	23,600	67,600	271,600	23,600	67,600
ENGINEERING	95% COMP	995,700	99,300	100,500	995,700	99,300	100,500
TOTAL		18,196,700	1,909,300	5,100,000	15,317,286	1,909,300	5,100,000
		25,200,000			22,326,586		

C

B

A

APPENDIX 8

BACK-UP CALCULATIONS FOR PRESENT VALUE

ANALYSIS OF CONVEYOR ALTERNATIVES

Econometrics - Chapter V (Fig. V-2, V-3)

The following calculation are back-up for manual derivation of Figs. V-2 and V-3.

Service Costs - Wharf System

From Power | cnvr loading rate
curves 'Stephens - Adams';

		$/Hr.
8000 tph. ore		
St. 2500, 1800mm, 3 × 900 HP	3,029,990.	
extra for 2000mm m/c	29,390.	
Capital Cost	$3059380	
.1597 crf. for (i=15, n=20)	= 488,767.$/yr.	
	= 56 $/hr.	56.00
R&M assume replace belt every 5 yrs.		
1,020,000 × sfdf (i=25, n=5) = .148	--------	17.00
Power 1.3¢/KWH × 2000 = 26 $/hr.		26.00
		99.00
	Mis. 10%	9.90
		108.00

11000 tph. ore

ST 3150 × 2000 × 4 × 900 HP

Capital Cost 3,313,570.		
crf i=15, n=20 = 529376 $/yr. =		60.00
R&M 1,300,000 × .148 (Belt)		20.00
Power Cost 1.3¢ KWH × 2700 =		35.10
		115.1
Hrs./Service - 3900t ships	Misc. %	11.5
		126.6

	8000 tph.	10000 tph.
ORE	5.125 + (1 hr.)	3.7 + (1 hr.)*
	5000 tph.	8000 tph.
COAL	7.9 + (1 hr.)	5.78 + (1 hr.)

*Assume a total of 1 hour for approach and departure

S ice Costs - Yard System

8 tph.			$/Hr.
S 500 11800mm M/c			
2 900 Hp drives	1,077,880.		
e a 2000mm M/c	11,130.		
1 tra drive	155,750.		
e a belts 100m.	12,190.		
	1,256,950.		
c (i=15, n=20) 200,810 $/yr. =			23.00
R 1,256,950 × .148 = 186,028 $/yr. =			21.23
P r 1.3 × 2000			26.00
			70.23
		10%	7.0
			77.23

1) tph.

tephens-Adams alternate Y3. 2,281,840

rf (i=15, n=20) = 364,409 $/yr. =			42.00
&M 2,281,840 × .148 = 337,712 $/yr.			39.00
›wer 1.3. × 2700			35.10
			116.10
		10%	11.6
›tal Cost Wharf + Yard Cnvrs.			127.7
t Power Costs. $/hr.	8000 tph.		185.23
8 52.			
1) 70.20			254.3

S ice Costs

7 tph Ore, 5000 tph Coal

a rnative	W2	cc =	3,092,560.
	Y1	cc =	1,077,880.
			$4,170,440.

C		76.00
R 2,200,000 × .148		37.00
P r 4500 HP × .746 × 1.3		43.64
		156.6
	10% Misc.	15.7
		172.3

	7000 tph.		Cost/Service
re	6.5 + 1	μ = .133.	1292
	5000 tph.		
oal	9.1 + 1	μ = .099	1740

	tph.	$^{1}/_{\mu}$	μ	cost/Hr.	Cost/Service
ι	7000	7.5	.133	172.3	1292
	8000	6.125	.163	185.23	1135
	10000	4.7	.212	254.3	1195
Co	4500	10.1	.099	172.3	1740
	5200	8.9	.112	185.23	1648
	7100	6.78	.147	254.3	1724

ORE: Dock actor: $\dfrac{1195 - 1135}{.212 - .163} = \dfrac{60}{.049} = 1224.5$

COAL: $\dfrac{1724 - 1648}{.147 - .112} = \dfrac{76}{.035} = 2171$

DCF = Cost per Ser... per service rate $\left[\dfrac{\text{Cost/Service}}{\text{Service/Hr.}}\right]$

for a given value of λ find the optimum cost per ship unloaded.

Total Cost = $fc(\mu) + SDC \,.\, W$

where; $fc(\mu)$ = cost per service taken on plot Fig. V-2.

SDC = ship delay charge per hour

W = mean wait for service

$$\text{Total Cost} = fc(\mu) + SDC \cdot \frac{1}{\mu-\lambda}$$

λ ore = .04 for 12×10^6 tonnes

μ	$fc(\mu)$	$\frac{SDC}{\mu-\lambda}$	Total Cost Per Service $\lambda = .04$
.14	1220	4600	5820
.15	1170	4182	5351
.16	1145	3833	4978
.18	1135	3285	4420
.20	1170	2875	4045
.21	1195	2705	3900
.22	1350	2556	3906
.23	1500	2350	3850
.24	1650	2300	3950

Calculated With Waiting Time Only In Berth

$\lambda = 0.04 \quad 12 \times 10^6$ tonnes/yr.

$\lambda = .017 \quad 5 \times 10^6$

μ	$fc(\mu)$	$SDC(\frac{\lambda}{\mu} \cdot \frac{1}{\mu-\lambda})$		Total Costs	
ORE		λ=.04	λ=.017	λ=.04	λ=.017
.14	1220	1314	454	2534	1674
.15	1170	1115	392	2285	1562
.16	1145	958	342	2103	1487
.18 .19	1135 1112	730	267	1865	1401

.20	1170	575	214	1745	1384*
.21	1195	515	193	1110*	1388
.22	1350	464		1814	
.23	1500	409		1903	
.24	1650	383		2033	

COAL λ = .022 6.5 × 10^6 tonnes/year

λ = .009 2.75 × 10^6 tonnes/year

		λ=.022	λ=.009	λ=.022	λ=.009
.08	2100	2220		4321	
.10	1750	1297	455	3047	2205
.12	1600	845	311	2445	1911
.13	1630		263		1893*
.14	1670	624	226	2294*	1896
.16	1850	467	171	2316	2021
.18	2100	349			2449

* optimum

APPENDIX 9

ECONOMICS OF CONVEYOR DESIGN

EXCERPTS

FROM REPORT BY 'STEPHENS-ADAMSON'

SELF-UNLOADING RATES OF

CANADIAN-FLAG LAKE CARRIERS

1.1 Present Fleet

The "standard rates" for the existing fleet are, rounded to preferred numbers:

- Volume 4 500 t/h of coal
- Power 6 300 t/h of pellets

These vessels have a payload of about 30 000 tonnes and their size is limited to allow them to sail through the Welland Canal.

1.2 Future Fleet

With the Lake Erie Development by Stelco and the expansion to full capacity of the Nanticoke power plant by Ontario Hydro, Canadian ship owners are planning to build so-called "thousand footers", taking full advantage of the new locks at Sault-Ste.-Marie.

The unloading rate of such vessels with pellets is 10 000 t/h. The increase in rate (60%) is therefore equal to the increase in vessel payload.

While the rate of handling pellets is generally agreed upon, such is not the case with coal, particularly western coal. The latest figures which we have just obtained for requirements on the U.S. side of the Lakes call for 10 000 m^3/h or 8 000 t/h of coal.

On the Canadian side, the rates have not been decided yet between the users and the shipowners.

1.3 Timetable

It is impossible at this time to put dates on the commissioning of the larger carriers. This will depend on:

- Stelco's own requirements in time;
- Ontario Hydro's schedule of development at Nanticoke;
- the use of Western Canada coal in Ontario, either by Stelco for iron making or by Ontario Hydro for power generation.

BELT WIDTH AND SPEED COMBINATIONS

2.1 Belt Trough

In line with present practice at several large installations, we suggest a belt troughing angle of 40 degrees.

2.2 Material Characteristics

The basic materials are metallurgical coal and pellets:

Material	Unit mass t/m^3	Surcharge angle, degrees
Coal	0.8	20
Pellets	2.0	5

2.3 Belt Speeds

While coal can be handled at 5.6 or 6 m/s without much difficulty, such is not the case with pellets. A suitable compromise is 4.0 m/s, for belt conveyors handling either only pellets, or both pellets and coal. For belts handling metallurgical coal only - except when handling pellets on an emergency basis - a belt speed of 5.0 m/s (i.e. 1.25 times 4.0 m/s) is perfectly acceptable.

2.4 Volumetric Capacities

The attached table gives the volumetric capacites of the various belt widths at two speeds (4.0 & 5.0 m/s) for coal and one speed (4.0 m/s) for pellets.

TABLE 2.1 VOLUMETRIC CAPACITIES

COAL	TROUGH 40^o	SURCHARGE 20^o	ρ = 0.8 t/m^3	
B, mm	1 800	2 000	2 200	2 400
A, m^2	0.40	0.50	0.61	0.72
Q, t/h				
v = 4.0 m/s	4 500	5 600	7 100	8 000
v = 5.0 m/s	5 600	7 100	9 000	10 000

PELLETS	TROUGH 40^o	SURCHARGE 5^o	ρ = 2.0 t/m^3	
B, mm	1 800	2 000	2 200	2 400
A, m^2	0.32	0.39	0.49	0.58
Q, t/h				
v = 4.0 m/s	9 000	11 200	14 000	16 000

COMMENTS ON VOLUMETRIC CAPACITIES

The figures shown in the Capacity Table allow the formulation of some preliminary conclusions:

3.1 The unloading rates of the present fleet can be taken care of by a 1 800 mm wide belt.

3.2 To unload 8 000 t/h of coal on a multi purpose belt, i.e. at 4.0 m/s, requires a 2 400 mm wide belt. When carrying pellets, this belt would be loaded at only 60%.

3.3 When two parallel conveyor systems are required to unload both coal and pellets simultaneously, we believe that sufficient time will have elapsed so that the problem will be better known as to the origin of the coal, the amounts to be carried and the savings, if any, which might be derived from faster unloading rates.

Therefore, we suggest that reasonable forecasts are in the order of:

- 6 300 to 7 100 t/h(8000 to 9 000 m^3/h) of COAL;
- 10 000 to 11 200 t/h of PELLETS

A word of caution is however required here. Being a large user, STELCO has considerable influence on the Canadian bulk carrier trade on the Great Lakes. Thus there is the danger in any of the possible solutions that, by advising the shipowners of its unloading capacity plans, STELCO would in effect influence the shipowners as to what the self-unloding rates should be for new buildings. This in time may not lead to the optimum in overall long term costs.

4. The standard approach in conveyor design is to calculate the tensions and power to suit the required flow rates.

   As we have seen, the belt loading rates here are at best uncertain. We suggest, therefore, a different approach. From the approximate rates, preliminary calculations give belt tensions. In turn, these belt tensions, lead to certain belt types. This calls then for two comments.

   First, to ensure availability from several sources at all times, internationally accepted ratings should be preferred. This is particularly important for the extension of the yard conveyor.

   Then, the cost of the belting goes up by jumps with each rating and is not a continuous, smooth, function of the belt tension. Since the terminals will play only a small part in the total cost, our approach is then to determine for each rating the maximum belt loading rates this rating allows.

   By doing so, Stelco maximizes the potential ship unloading rates at very little cost and keeps control of these rates, instead of letting only one aspect, that is, the problem as seen by the shipowners, determine these rates.

   The set of charts which will be presented now illustrates our point of view.

CONVEYOR LIMITATIONS

The following is a list for the limitations of belt selections, powers, capacities, and lengths.

BELT WIDTH	BELT TYPE	POWER	CAPACITY	LENGTH
A. Wharf Conveyor				
1 800 mm	ST2500	3 x 900 hp	8 000 t/h	1 790 m
1 800 mm	ST3150	4 x 900 hp	9 000 t/h	1 790 m
2 000 mm	ST3150	4 x 900 hp	11 200 t/h	1 790 m
B. Yard Conveyor				
1 800 mm	ST2500	2 x 900 hp	6 300 t/h	1 400 m
1 800 mm	ST2500	3 x 900 hp	6 300 t/h	2 400 m
1 800 mm	ST2500	2 x 900 hp	9 000 t/h	900 m
1 800 mm	ST2500	3 x 900 hp	9 000 t/h	1 700 m
1 800 mm	ST2500	4 x 900 hp	9 000 t/h	2 000 m
1 800 mm	ST3150	4 x 900 hp	9 000 t/h	2 400 m
2 000 mm	ST3150	3 x 900 hp	11 200 t/h	1 200 m
2 000 mm	ST3150	4 x 900 hp	11 200 t/h	1 900 m
2 000 mm	ST3150	5 x 900 hp	11 200 t/h	2 400 m

EXPLANATION OF CAPACITY CHARTS

5. The charts submitted here are intended to provide quantitative information on the various belt widths, belt ratings and motor continuations.

5.1 Wharf Conveyor

Two belt widths are contemplated. Several belt tension ratings and motor combinations are possible.

However, since the wharf conveyor length and lift are known, the figures are straight-forward.

5.2 Yard Conveyor

The analysis of the yard conveyor is complicated by these facts:

- the length increases in time;
- the stacker trailer may be designed in two different ways: as a straight tripper or as a tripper - elevating conveyor

5.3 Stacker Trailer Arrangement

The stacker may be equipped with either of these arrangements.

5.3.1 Straight Trailer

The straight trailer adds a lift of about 12.0 metres. While this increases the power required and the belt tension rating, the main problem is caused by the minimum radius of at least 800 metres.

This minimum radius increases vastly the length of the trailer. This, in turn, increases the minimum distance between the loading point and the closest position of the stacker.

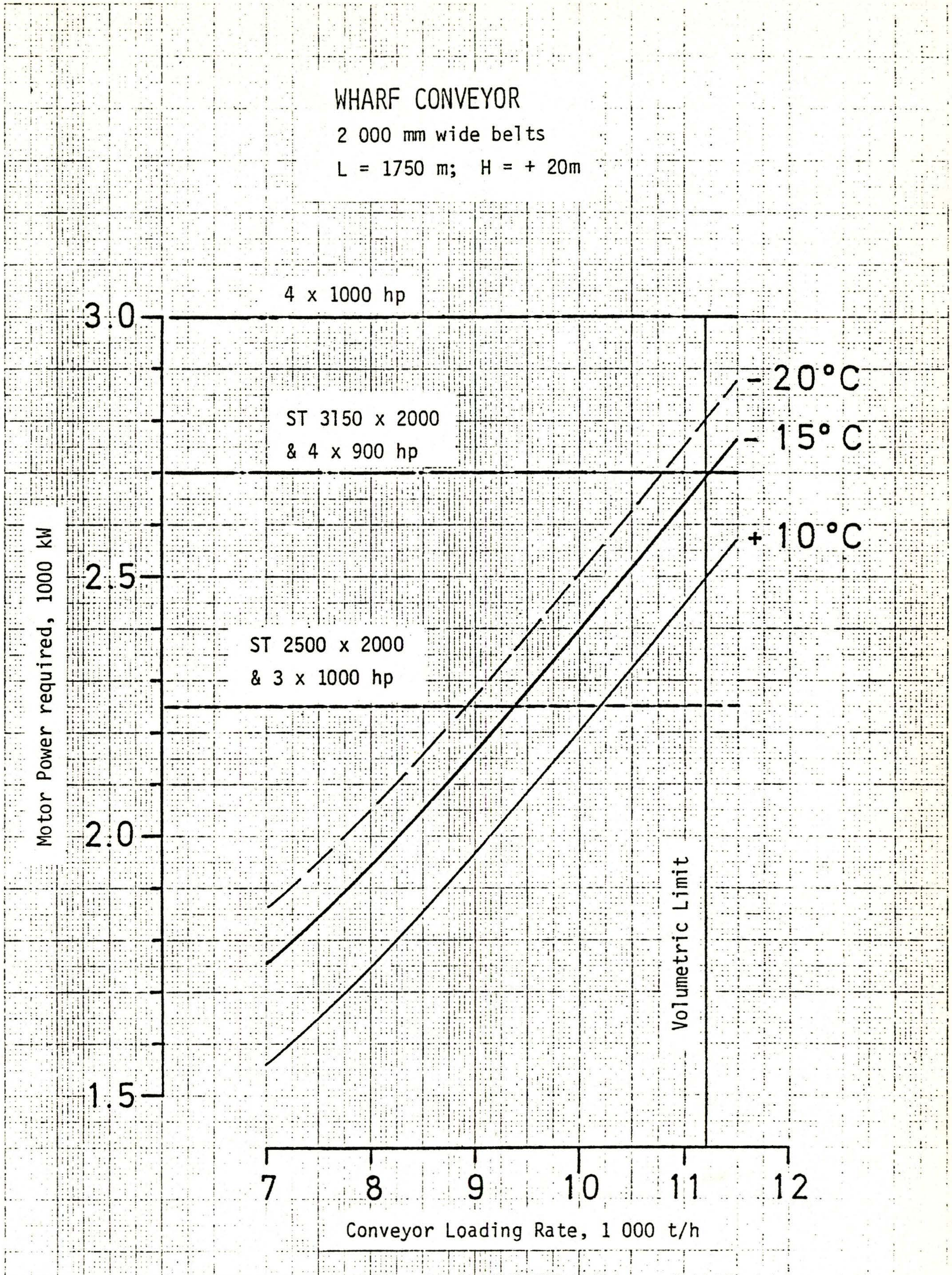
5.3.2 Tripper and Elevating Conveyor

The tripper and elevating conveyor system does add one transfer point. It must be observed, however, that it is an "in-line" transfer and thus not a difficult one to design properly.

5.3.2 Tripper and Elevating Conveyor - cont'd.

This solution has the first advantage of keeping the belt tensions at a level comparable to those of the wharf conveyor, thus permitting standardization.

The second advantage is that the problems due to the belt lifting off during starting are somewhat minimized.


WHARF CONVEYOR
2 000 mm wide belts
L = 1750 m; H = + 20m
4 x 1000 hp
ST 3150 x 2000
& 4 x 900 hp
ST 2500 x 2000
& 3 x 1000 hp
-20°C
-15°C
+10°C
Volumetric Limit
Motor Power required, 1000 kW
3.0
2.5
2.0
1.5
7
8
9
10
11
12
Conveyor Loading Rate, 1 000 t/h

SOLUTION A

This solution has been considered because the maximum steel cable belt width available from Canadian sources is 1 800 mm.

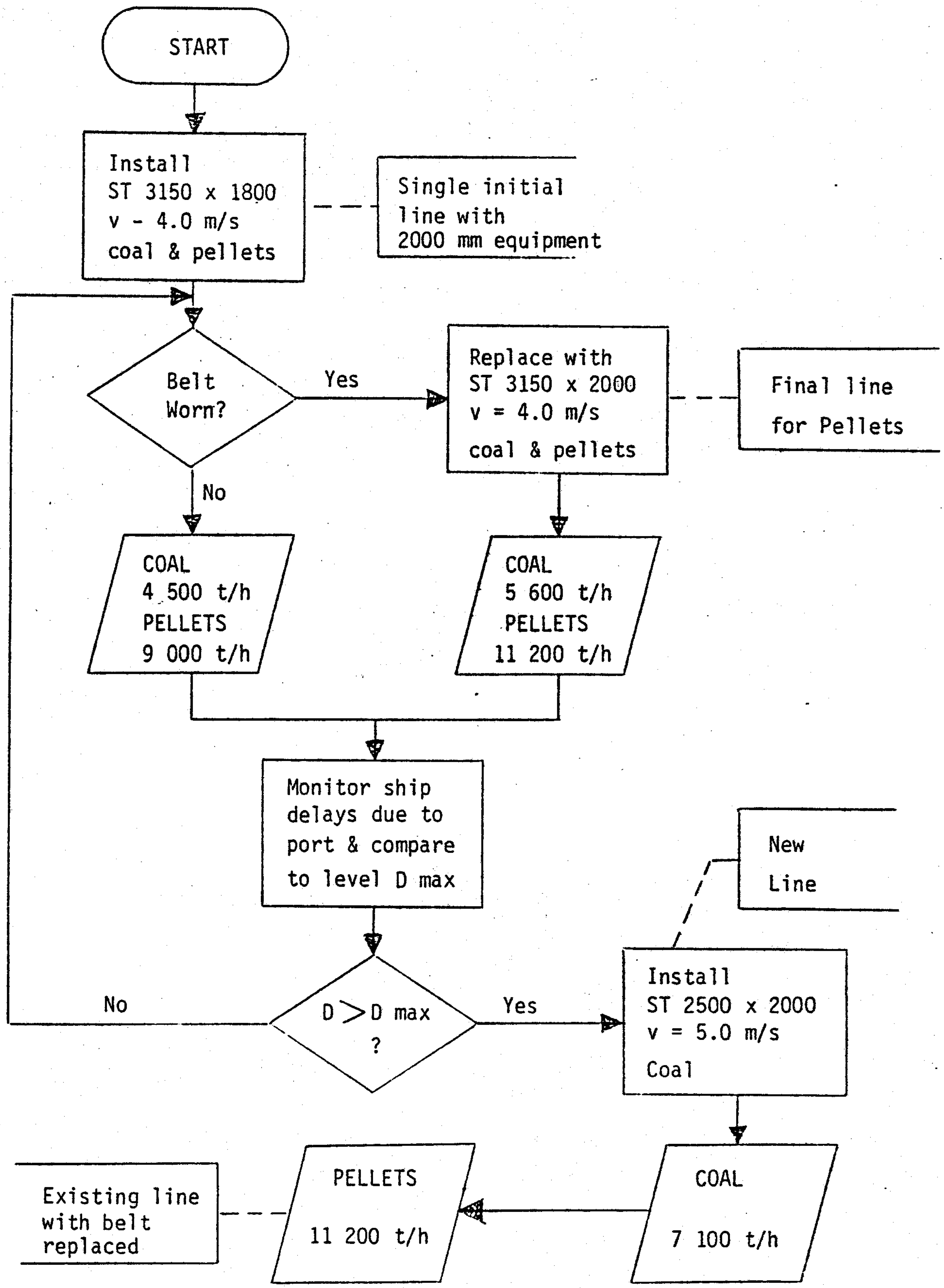
The conveyor equipment would be that for 2 000 mm wide belting, with short centre roll carriers, so that an 1 800 mm wide belt, may be easily installed initially.

FOR this solution, we have:

- a maximum possible Canadian content

AGAINST this solution, we find

- a strong risk of the belt width becoming soon inadequate, thus making it necessary to replace the belting before it is worn.


START
Install
ST 3150 x 1800
v - 4.0 m/s
coal & pellets
Single initial
line with
2000 mm equipment
Belt
Worn?
Yes
No
Replace with
ST 3150 x 2000
v = 4.0 m/s
coal & pellets
Final line
for Pellets
COAL
4 500 t/h
PELLETS
9 000 t/h
COAL
5 600 t/h
PELLETS
11 200 t/h
Monitor ship
delays due to
port & compare
to level D max
New
Line
D > D max
?
No
Yes
Install
ST 2500 x 2000
v = 5.0 m/s
Coal
COAL
7 100 t/h
PELLETS
11 200 t/h
Existing line
with belt
replaced

SOLUTION B

This solution consists essentially in installing the pellet line at its ultimate capacity, although not at its ultimate length.

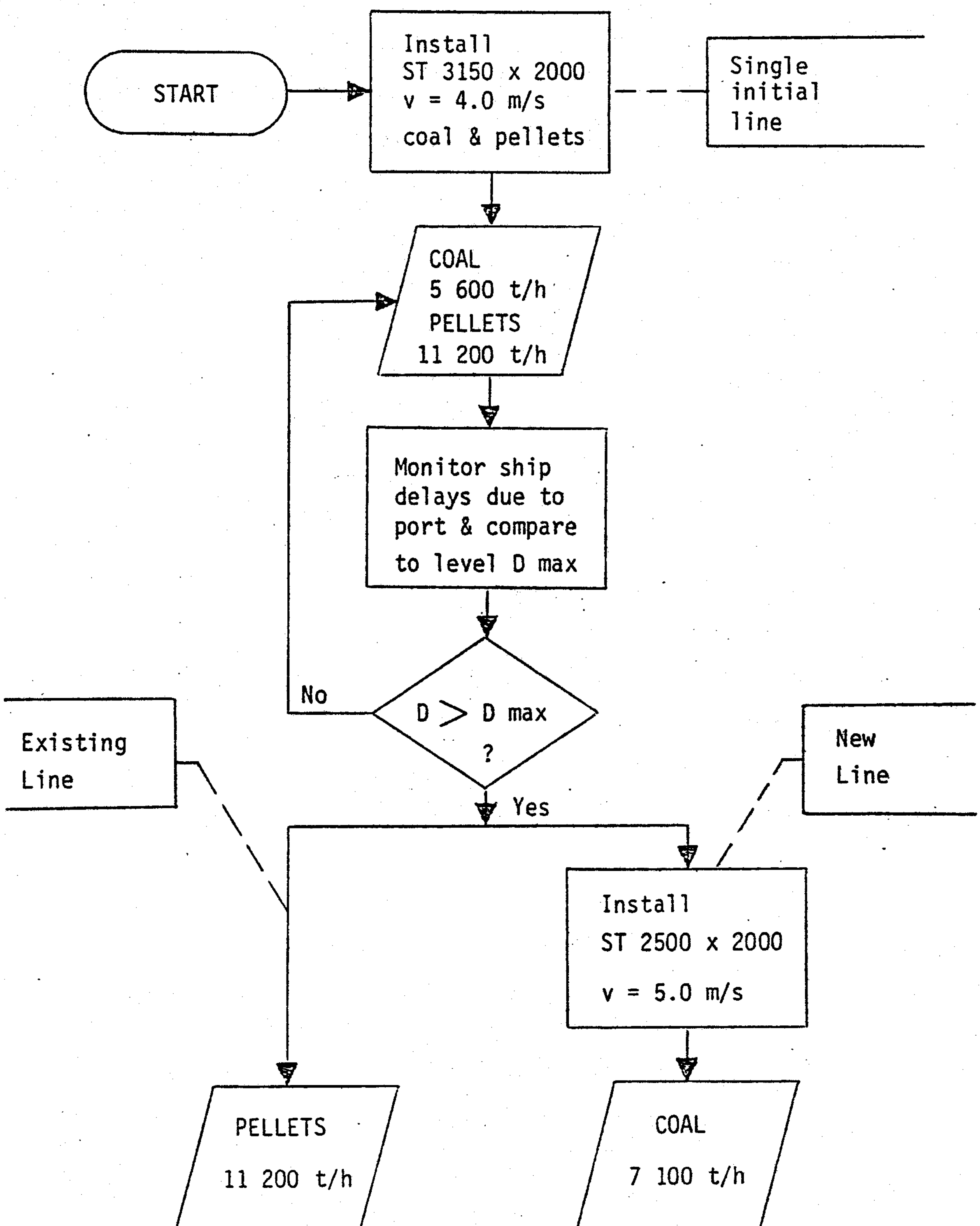
FOR this solution, we may note that:

- The pellet line will be capable of immediately handling the larger pellet carriers.

- Consequently, the time span before a separate coal line is required is the longest of all three solutions.

AGAINST this solution, we find that:

- The initial investment is the largest of the three solutions, since the most expensive belting is used in the first stage.


START
Install
ST 3150 x 2000
v = 4.0 m/s
coal & pellets
Single
initial
line
COAL
5 600 t/h
PELLETS
11 200 t/h
Monitor ship
delays due to
port & compare
to level D max
No
D > D max
?
Yes
Existing
Line
New
Line
Install
ST 2500 x 2000
v = 5.0 m/s
PELLETS
11 200 t/h
COAL
7 100 t/h

SOLUTION C

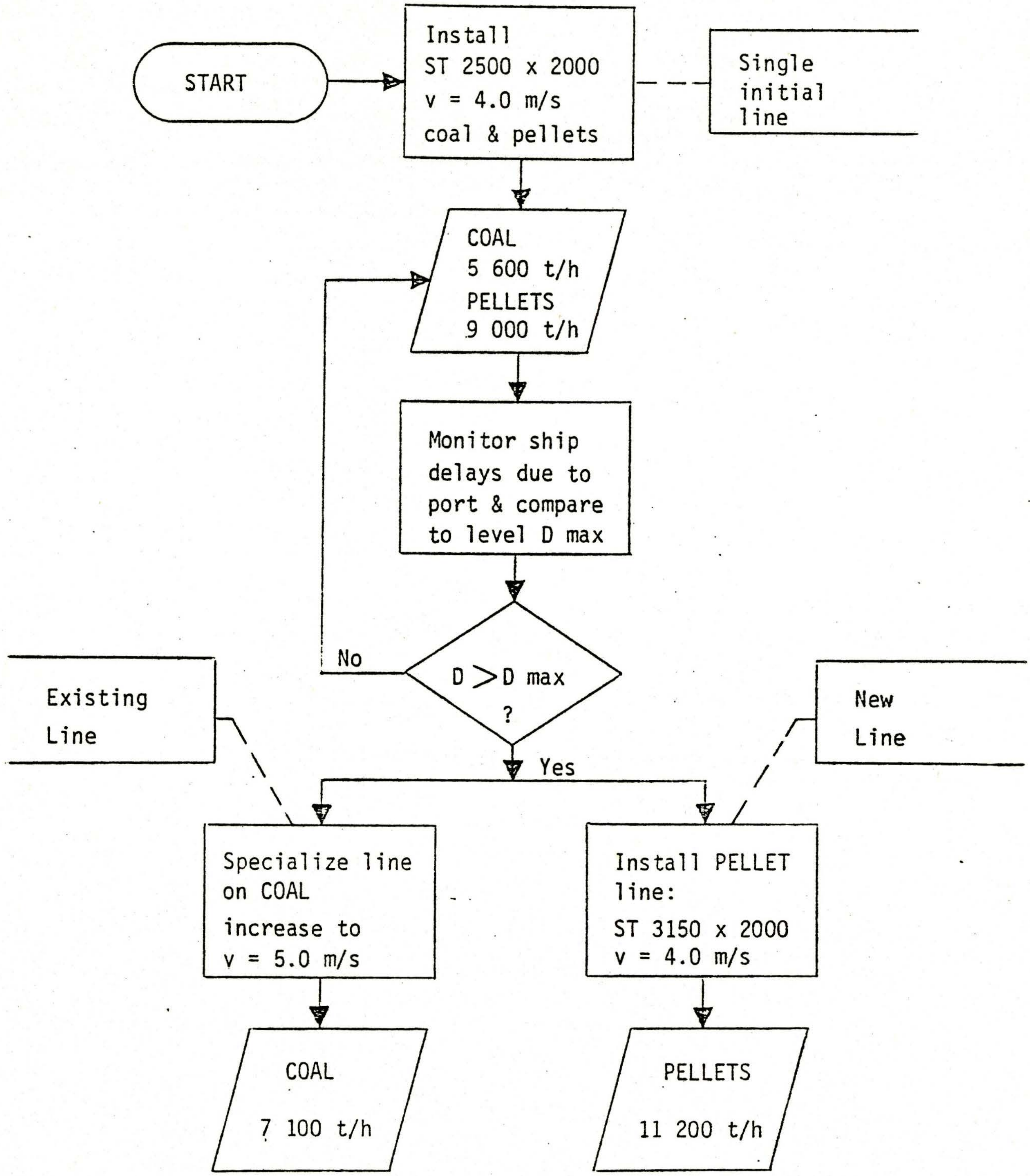
This solution consists in installing first the coal line which is initially used for both pellets and coal.

FOR this solution, we find that:

- The investment is less than in Solution B and of the same order as that of Solution A;
- At the time where a second line is required, the wear on the existing line should be moderate and the existing line would gain a new lease on life of belting and equipment by being specialized on coal
- The investment for the heavy pellet line is pushed further in time.

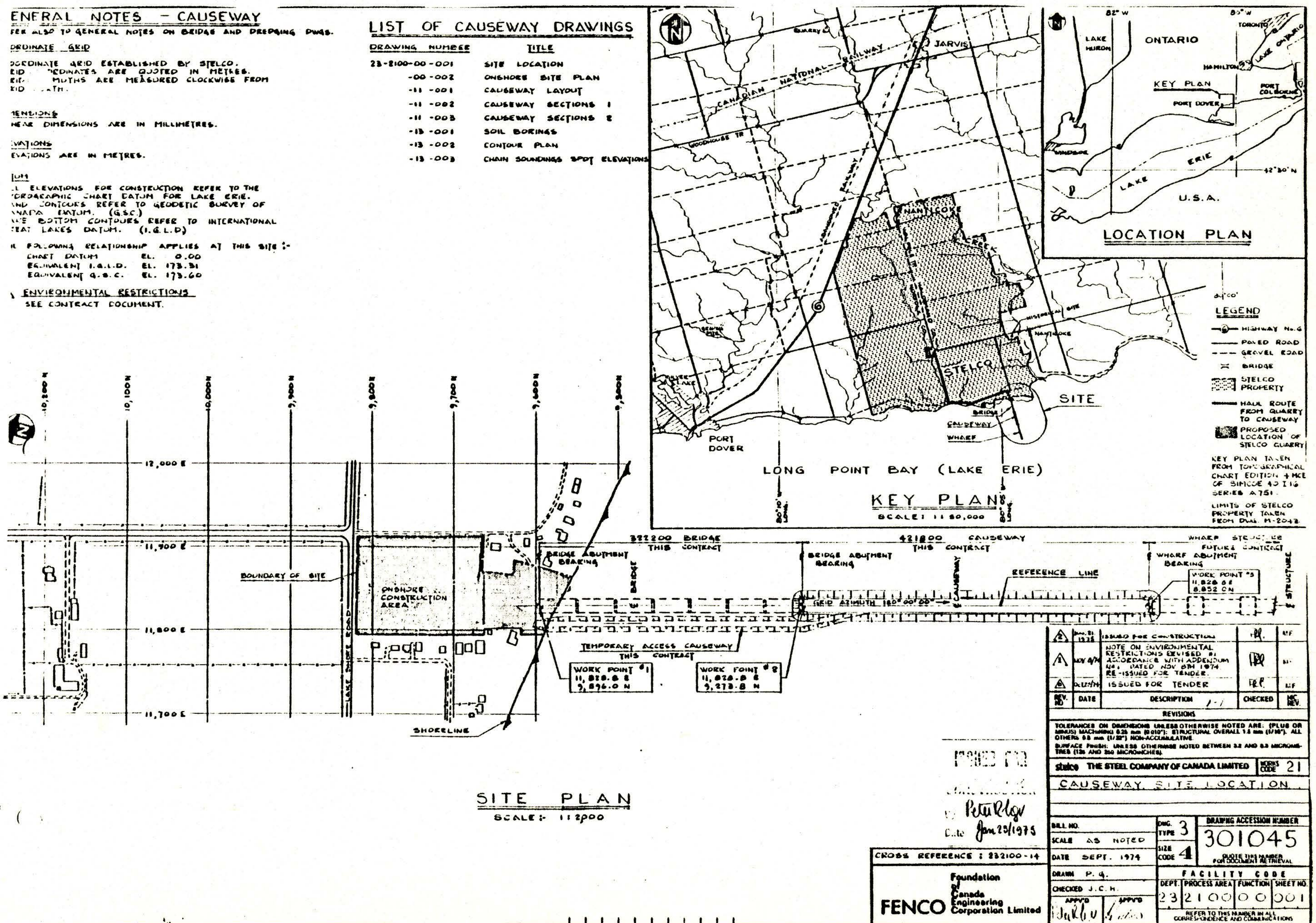
AGAINST this solution, we may note that:

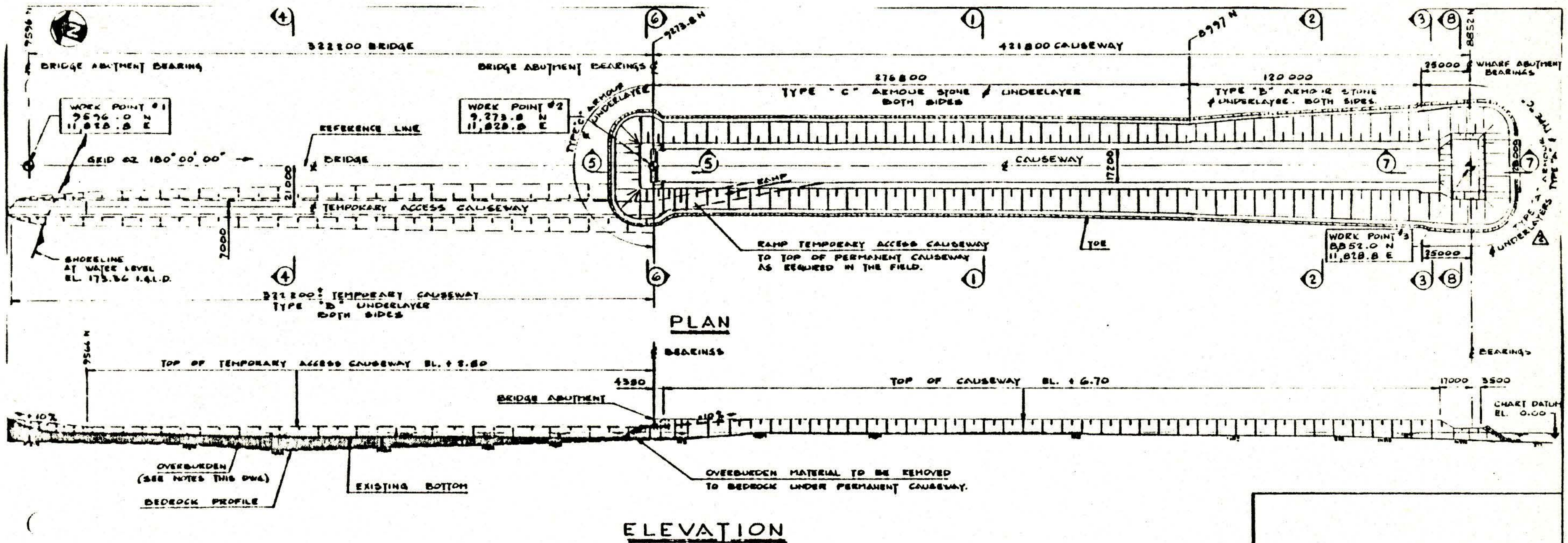
- The remark about Stelco's setting arbitrarily the unloading rates apply.


START
Install
ST 2500 x 2000
v = 4.0 m/s
coal & pellets
Single
initial
line
COAL
5 600 t/h
PELLETS
9 000 t/h
Monitor ship
delays due to
port & compare
to level D max
D > D max
?
No
Yes
Existing
Line
New
Line
Specialize line
on COAL
increase to
v = 5.0 m/s
Install PELLET
line:
ST 3150 x 2000
v = 4.0 m/s
COAL
7 100 t/h
PELLETS
11 200 t/h

APPENDIX 10

TYPICAL DOCK DRAWINGS


ENERAL NOTES - CAUSEWAY
FER ALSO TO GENERAL NOTES ON BRIDGE AND DREDGING DWGS.
ORDINATE GRID
OORDINATE GRID ESTABLISHED BY STELCO.
RID ORDINATES ARE QUOTED IN METRES.
RID MUTHS ARE MEASURED CLOCKWISE FROM
RID ATH.
MENSIONS
HEAR DIMENSIONS ARE IN MILLIMETRES.
VATIONS
EVATIONS ARE IN METRES.
TUM
L ELEVATIONS FOR CONSTRUCTION REFER TO THE
ROGRAPHIC CHART DATUM FOR LAKE ERIE.
AND CONTOURS REFER TO GEODETIC SURVEY OF
NADA DATUM. (G.S.C.)
KE BOTTOM CONTOURS REFER TO INTERNATIONAL
EAT LAKES DATUM. (I.G.L.D.)
E FOLLOWING RELATIONSHIP APPLIES AT THIS SITE :-
CHART DATUM EL. 0.00
EQUIVALENT I.G.L.D. EL. 173.31
EQUIVALENT G.S.C. EL. 173.60
ENVIRONMENTAL RESTRICTIONS
SEE CONTRACT DOCUMENT.
LIST OF CAUSEWAY DRAWINGS
DRAWING NUMBER TITLE
23-2100-00-001 SITE LOCATION
-00-002 ONSHORE SITE PLAN
-11-001 CAUSEWAY LAYOUT
-11-002 CAUSEWAY SECTIONS 1
-11-003 CAUSEWAY SECTIONS 2
-13-001 SOIL BORINGS
-13-002 CONTOUR PLAN
-13-003 CHAIN SOUNDINGS SPOT ELEVATIONS
JARVIS
CANADIAN NATIONAL RAILWAY
WOODHOUSE TP
NANTICOKE
CREEK
STELCO
SITE
BRIDGE
CAUSEWAY
WHARF
PORT DOVER
LONG POINT BAY (LAKE ERIE)
KEY PLAN
SCALE: 1:50,000
LAKE HURON
ONTARIO
TORONTO
LAKE ONTARIO
HAMILTON
KEY PLAN
PORT DOVER
PORT COLBORNE
LAKE ERIE
U.S.A.
82° W
80° W
42°30' N
LOCATION PLAN
LEGEND
HIGHWAY No. 6
PAVED ROAD
GRAVEL ROAD
BRIDGE
STELCO PROPERTY
HAUL ROUTE FROM QUARRY TO CAUSEWAY
PROPOSED LOCATION OF STELCO QUARRY
KEY PLAN TAKEN FROM TOPOGRAPHICAL CHART EDITION 4 MCE OF SIMCOE 40 I 16 SERIES A751.
LIMITS OF STELCO PROPERTY TAKEN FROM DWG. M-2043.
10,200 N
10,100 N
10,000 N
9,900 N
9,800 N
9,700 N
9,600 N
9,500 N
12,000 E
11,900 E
11,800 E
11,700 E
BOUNDARY OF SITE
LAKE SHORE ROAD
ONSHORE CONSTRUCTION AREA
SHORELINE
BRIDGE ABUTMENT BEARING
BRIDGE
322200 BRIDGE THIS CONTRACT
421800 CAUSEWAY THIS CONTRACT
CAUSEWAY
REFERENCE LINE
GRID AZIMUTH 180°00'00"
WHARF STRUCTURE FUTURE CONTRACT
WHARF ABUTMENT BEARING
WORK POINT #3 11,828.6 E 8,852.0 N
STRUCTURE
TEMPORARY ACCESS CAUSEWAY THIS CONTRACT
WORK POINT #1 11,828.6 E 9,596.0 N
WORK POINT #2 11,828.6 E 9,273.8 N
SITE PLAN
SCALE: 1:2000
ISSUED FOR CONSTRUCTION
NOTE ON ENVIRONMENTAL RESTRICTIONS REVISED IN ACCORDANCE WITH ADDENDUM No. 1 DATED NOV 8TH 1974
RE-ISSUED FOR TENDER.
ISSUED FOR TENDER
REV. NO.
DATE
DESCRIPTION
CHECKED
REVISIONS
TOLERANCES ON DIMENSIONS UNLESS OTHERWISE NOTED ARE: (PLUS OR MINUS) MACHINING 0.25 mm (0.010"); STRUCTURAL OVERALL 1.5 mm (1/16"). ALL OTHERS 0.8 mm (1/32") NON-ACCUMULATIVE.
SURFACE FINISH: UNLESS OTHERWISE NOTED BETWEEN 3.2 AND 6.3 MICROMETRES (125 AND 250 MICROINCHES).
stelco THE STEEL COMPANY OF CANADA LIMITED
WORKS CODE 21
CAUSEWAY SITE LOCATION
BILL NO.
SCALE AS NOTED
DATE SEPT. 1974
DRAWN P. G.
CHECKED J. C. H.
APPV'D
DWG. TYPE 3
SIZE CODE 4
DRAWING ACCESSION NUMBER
301045
QUOTE THIS NUMBER FOR DOCUMENT RETRIEVAL
FACILITY CODE
DEPT. PROCESS AREA FUNCTION SHEET NO.
23 2100 00 001
REFER TO THIS NUMBER IN ALL CORRESPONDENCE AND COMMUNICATIONS
CROSS REFERENCE : 232100-14
FENCO Foundation of Canada Engineering Corporation Limited
Date Jan 23/1975



NOTES

GENERAL NOTES

- REFER TO DWG. 23-2100-00-001

SECTIONS

- FOR SECTIONS (1) TO (3) INCLUSIVE REFER TO DWG. 23-2100-11-002
- FOR SECTIONS (4) TO (8) INCLUSIVE REFER TO DWG. 23-2100-11-003

CONSTRUCTION

- TEMPORARY CAUSEWAY MAY BE PLACED ON EXISTING OVERBURDEN.
- FILL FOR PERMANENT CAUSEWAY SHALL BE PLACED ON BEDROCK. ALL OVERBURDEN ENCOUNTERED IN THE AREA OF THE PERMANENT CAUSEWAY SHALL BE REMOVED BEFORE FILL MATERIAL IS PLACED.
- OVERBURDEN MATERIAL EXCAVATED FROM UNDER CAUSEWAY SHALL BE PLACED ADJACENT TO THE SIDES OF THE CAUSEWAY OUTSIDE THE TOE LIMITS AS DIRECTED BY THE ENGINEER.

MATERIALS

- FOR SIZE, GRADING AND DESCRIPTION OF MATERIALS REFER TO SPECIFICATIONS.
- ARMOUR AND UNDERLAYER STONE SIZES ARE QUOTED IN TONNES (METRIC TONS) AND KILOGRAMMES.
  1 TONNE = 1000 KG.

ISSUED FOR CONSTRUCTION
By Peter [signature]
Date January 27/1975

FENCO Foundation of Canada Engineering Corporation Limited

REV. NO.	DATE	DESCRIPTION	CHECKED	MC REV.
3	APRIL 2, 1975	ADDITION OF TYPE "C" UNDERLAYER AT OFFSHORE END OF CAUSEWAY		
2	Jan. 21 1975	ISSUED FOR CONSTRUCTION		
1		ISSUED FOR TENDER		

REVISIONS

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE NOTED ARE: (PLUS OR MINUS) MACHINING 0.25 mm (0.010"); STRUCTURAL OVERALL 1.6 mm (1/16"); ALL OTHERS 0.8 mm (1/32") NON-ACCUMULATIVE.
SURFACE FINISH: UNLESS OTHERWISE NOTED BETWEEN 32 AND 63 MICROINCHES (1.6 AND 0.8 MICRONS).

stelco THE STEEL COMPANY OF CANADA LIMITED — WORKS CODE 21

CAUSEWAY LAYOUT

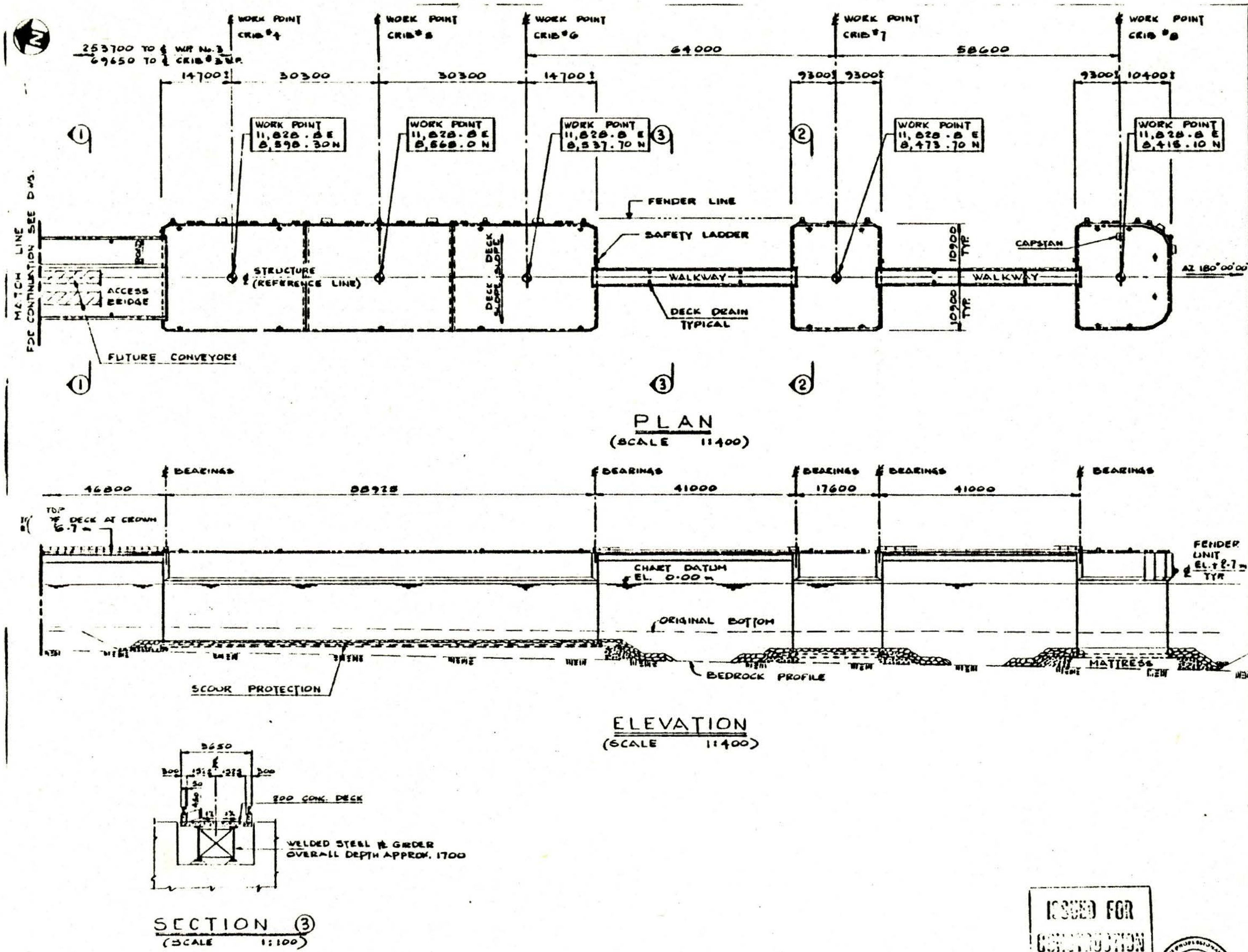
BILL NO.		DWG. TYPE	3
SCALE	1:1000	SIZE CODE	4
DATE	SEPT. 1974	DRAWING ACCESSION NUMBER	301047
DRAWN	P.G.		
CHECKED	J.C.H.		

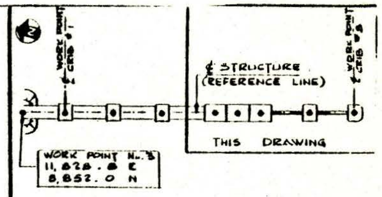
QUOTE THIS NUMBER FOR DOCUMENT RETRIEVAL

FACILITY CODE

DEPT	PROCESS AREA	FUNCTION	SHEET NO.
23	2100	11	001

REFER TO THIS NUMBER IN ALL CORRESPONDENCE





KEY PLAN
(WHARF STRUCTURE)

LEGEND

ON PLAN:
- SUPER ARCH FENDER UNIT
- USED RUBBER TIRE FENDER UNIT
- BOLLARD
- PIPE CURB
- GUIDE RAIL ON ACCESS BRIDGE / HANDRAIL ON WALKWAY

NOTES

FOR TYPICAL SECTIONS (1) AND (2) SEE DWG. 309288

LOADINGS & DESIGN SPECIFICATIONS

1. DESIGN LOADING ACCESS BRIDGES -
   ROADWAY - AASHO HS-20-44 PLUS IMPACT
   FUTURE CONVEYORS 0.89 METRIC TONS/METRE LIVELOAD EACH
   0.60 METRIC TONS/METRE DEADLOAD EACH
   0.73 METRIC TONS/SQ. METRE SUPERIMPOSED BESIDE CONVEYORS.
2. DESIGN LOADING WALKWAY BRIDGES -
   ROADWAY - AASHO H-10-44 OR UNIFORMLY DISTRIBUTED PEDESTRIAN LOAD OF 0.415 METRIC TONS/SQ. METRE.
3. DESIGN LOADING CRIB DECKS -
   CRIBS #1 to #6 HS-20-44 OR 2.44 METRIC TONS/SQ. METRE
   CRIBS #7 & #8 H10-44 OR 2.44 METRIC TONS/SQ. METRE
   DECK CRIBS #4 & #5
   AT FUTURE IRONORE HOPPERS 140 METRIC TONS CONCENTRATED LOAD AT EACH OF 4 COLUMNS.
   AT FUTURE COAL HOPPERS 110 METRIC TONS CONCENTRATED LOAD AT EACH OF 4 COLUMNS.
4. DESIGN SPECIFICATION BRIDGES -
   AASHO STANDARD SPECIFICATION FOR HIGHWAY BRIDGES 1973.

REV. NO.	DATE	DESCRIPTION	CHECKED	MC REV.
1	[illegible]	ISSUED FOR CONSTRUCTION.		
0	20 Dec. '74	ISSUED FOR TENDER		

REVISIONS

TOLERANCES ON DIMENSIONS UNLESS OTHERWISE NOTED ARE: (PLUS OR MINUS) MACHINING 0.25 mm (0.010"); STRUCTURAL OVERALL 1.6 mm (1/16"). ALL OTHERS 0.8 mm (1/32") NON-ACCUMULATIVE.
SURFACE FINISH: UNLESS OTHERWISE NOTED BETWEEN 3.2 AND 6.3 MICROMETRES (125 AND 250 MICROINCHES).

stelco THE STEEL COMPANY OF CANADA LIMITED — WORKS CODE 21

WHARF GEN. ARRANGEMENT II

ISSUED FOR CONSTRUCTION
By
Date APR 2 1975

CIVIL
A C HOUSTON

FENCO Foundation of Canada Engineering Corporation Limited

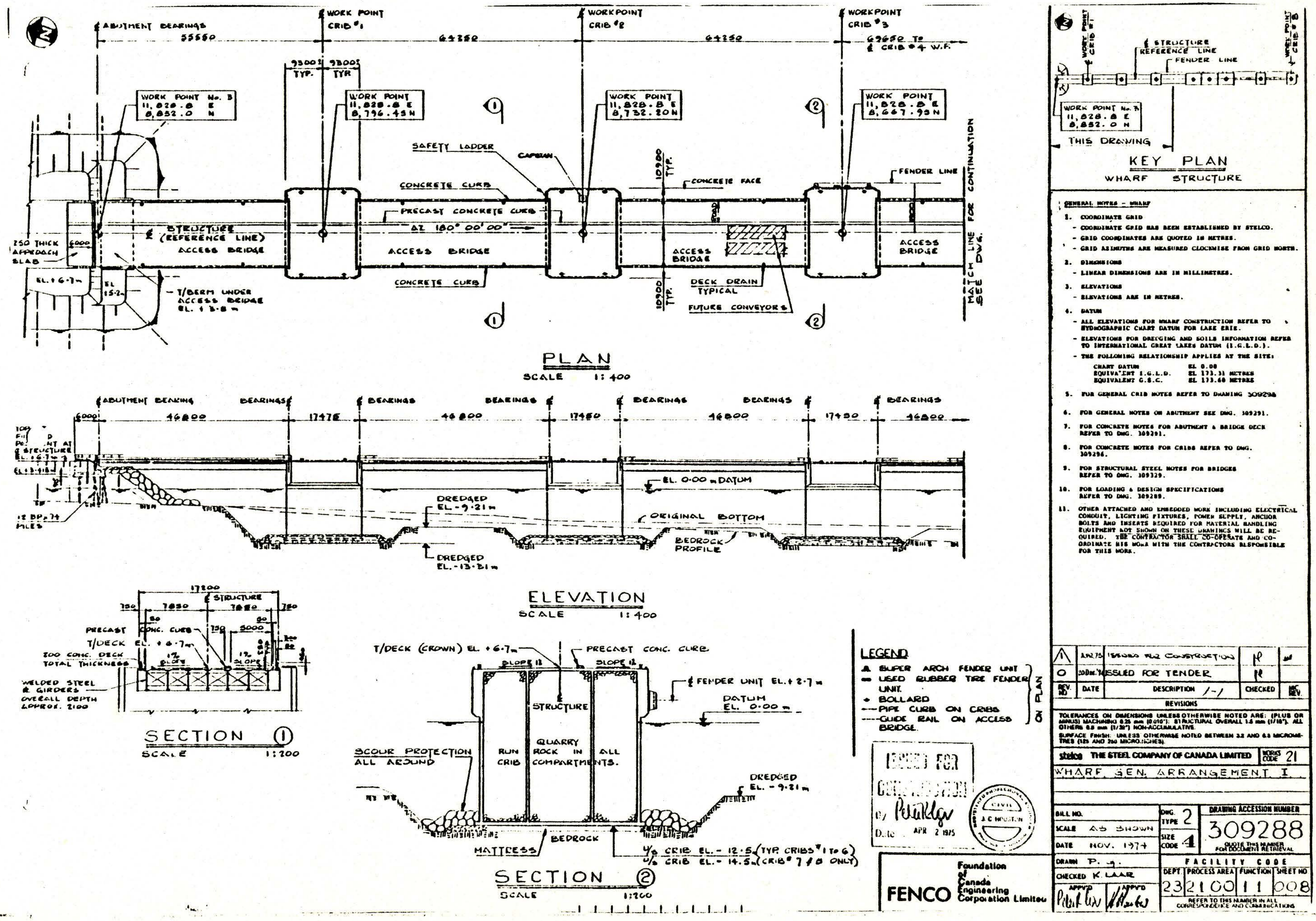
BILL NO.	
SCALE	AS SHOWN
DATE	NOV. 1974
DRAWN	P. G.
CHECKED	K. LAAR
APP'D	APP'D
DWG. TYPE	2
SIZE CODE	4

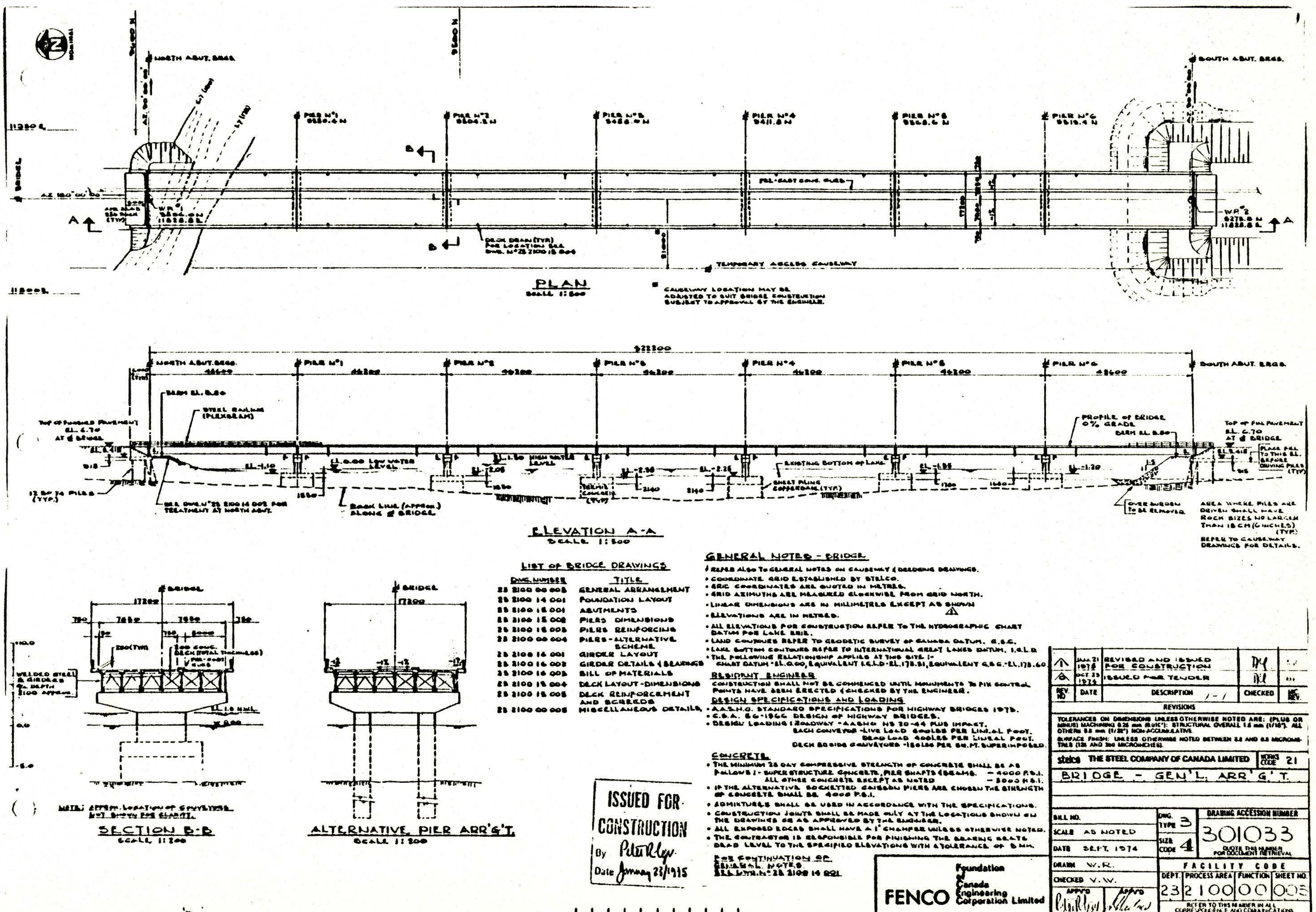
DRAWING ACCESSION NUMBER 309289
QUOTE THIS NUMBER FOR DOCUMENT RETRIEVAL

FACILITY CODE

DEPT.	PROCESS AREA	FUNCTION	SHEET NO.
23	2100	11	009

REFER TO THIS NUMBER IN ALL CORRESPONDENCE AND COMMUNICATIONS


PLAN
SCALE 1:400
ABUTMENT BEARINGS
WORK POINT CRIB #1
WORK POINT CRIB #2
WORK POINT CRIB #3
55550
64350
64350
69650 TO CRIB #4 W.F.
WORK POINT No. 3 11,828.8 E 8,852.0 N
WORK POINT 11,828.8 E 8,796.45 N
WORK POINT 11,828.8 E 8,732.20 N
WORK POINT 11,828.8 E 8,667.95 N
SAFETY LADDER
CONCRETE CURB
PRECAST CONCRETE CURB
AZ 180° 00' 00"
STRUCTURE (REFERENCE LINE)
ACCESS BRIDGE
CONCRETE FACE
FENDER LINE
DECK DRAIN TYPICAL
FUTURE CONVEYORS
MATCH LINE FOR CONTINUATION SEE DWG.
250 THICK APPROACH SLAB
T/BERM UNDER ACCESS BRIDGE EL. +3.8 m
ELEVATION
SCALE 1:400
ABUTMENT BEARING
BEARINGS
46800
17475
17450
EL. 0.00 m DATUM
DREDGED EL. -9.21 m
DREDGED EL. -13.21 m
ORIGINAL BOTTOM
BEDROCK PROFILE
12 BP, 74 PILES
SECTION 1
SCALE 1:200
17200
STRUCTURE
PRECAST CONC. CURB
T/DECK EL. +6.7 m
200 CONC. DECK TOTAL THICKNESS
WELDED STEEL & GIRDERS OVERALL DEPTH APPROX. 2100
SECTION 2
SCALE 1:200
T/DECK (CROWN) EL. +6.7 m
PRECAST CONC. CURB
FENDER UNIT EL. +2.7 m
DATUM EL. 0.00 m
SCOUR PROTECTION ALL AROUND
RUN CRIB
QUARRY ROCK IN ALL COMPARTMENTS.
DREDGED EL. -9.21 m
MATTRESS
BEDROCK
U/S CRIB EL. -12.5 m (TYP. CRIBS #1 TO 6)
U/S CRIB EL. -14.5 m (CRIB # 7 & 8 ONLY)
LEGEND
SUPER ARCH FENDER UNIT
USED RUBBER TIRE FENDER UNIT
BOLLARD
PIPE CURB ON CRIBS
GUIDE RAIL ON ACCESS BRIDGE
ON PLAN
KEY PLAN
WHARF STRUCTURE
THIS DRAWING
STRUCTURE REFERENCE LINE
FENDER LINE
GENERAL NOTES - WHARF
1. COORDINATE GRID
- COORDINATE GRID HAS BEEN ESTABLISHED BY STELCO.
- GRID COORDINATES ARE QUOTED IN METRES.
- GRID AZIMUTHS ARE MEASURED CLOCKWISE FROM GRID NORTH.
2. DIMENSIONS
- LINEAR DIMENSIONS ARE IN MILLIMETRES.
3. ELEVATIONS
- ELEVATIONS ARE IN METRES.
4. DATUM
- ALL ELEVATIONS FOR WHARF CONSTRUCTION REFER TO HYDROGRAPHIC CHART DATUM FOR LAKE ERIE.
- ELEVATIONS FOR DREDGING AND SOILS INFORMATION REFER TO INTERNATIONAL GREAT LAKES DATUM (I.G.L.D.).
- THE FOLLOWING RELATIONSHIP APPLIES AT THE SITE:
CHART DATUM EL 0.00
EQUIVALENT I.G.L.D. EL 173.31 METRES
EQUIVALENT G.S.C. EL 173.40 METRES
5. FOR GENERAL CRIB NOTES REFER TO DRAWING 309296
6. FOR GENERAL NOTES ON ABUTMENT SEE DWG. 309291.
7. FOR CONCRETE NOTES FOR ABUTMENT & BRIDGE DECK REFER TO DWG. 309291.
8. FOR CONCRETE NOTES FOR CRIBS REFER TO DWG. 309296.
9. FOR STRUCTURAL STEEL NOTES FOR BRIDGES REFER TO DWG. 309329.
10. FOR LOADING & DESIGN SPECIFICATIONS REFER TO DWG. 309289.
11. OTHER ATTACHED AND EMBEDDED WORK INCLUDING ELECTRICAL CONDUIT, LIGHTING FIXTURES, POWER SUPPLY, ANCHOR BOLTS AND INSERTS REQUIRED FOR MATERIAL HANDLING EQUIPMENT NOT SHOWN ON THESE DRAWINGS WILL BE REQUIRED. THE CONTRACTOR SHALL CO-OPERATE AND CO-ORDINATE HIS WORK WITH THE CONTRACTORS RESPONSIBLE FOR THIS WORK.
ISSUED FOR CONSTRUCTION
ISSUED FOR TENDER
REVISIONS
THE STEEL COMPANY OF CANADA LIMITED
WORKS CODE 21
WHARF GEN. ARRANGEMENT I
SCALE AS SHOWN
DATE NOV. 1974
DWG. TYPE 2
SIZE CODE 4
DRAWING ACCESSION NUMBER
309288
FACILITY CODE
23 2100 11 008
FENCO
Foundation of Canada Engineering Corporation Limited
APR 2 1975


PLAN
SCALE 1:500
ELEVATION A-A
SCALE 1:500
SECTION B-B
SCALE 1:200
ALTERNATIVE PIER ARR'G'T.
SCALE 1:200
LIST OF BRIDGE DRAWINGS
GENERAL NOTES - BRIDGE
CONCRETE
NORTH ABUT. BRGS.
SOUTH ABUT. BRGS.
TEMPORARY ACCESS CAUSEWAY
ISSUED FOR CONSTRUCTION
REVISED AND ISSUED FOR CONSTRUCTION
ISSUED FOR TENDER
THE STEEL COMPANY OF CANADA LIMITED
BRIDGE - GEN'L. ARR'G'T.
SCALE AS NOTED
DATE SEPT. 1974
DRAWN W.R.
CHECKED V.W.
301033
FENCO
Foundation of Canada Engineering Corporation Limited
23 2 100 00 005

APPENDIX 11

NOMENCLATURE & SYMBOLS

Ao(t)	Arrival time distribution = probability interarrival time greater than or equal to time t.
CC	Cost of Capital.
C1	Capital Cost for first stage development.
C2	Capital Cost for Second Stage development.
C.U.R.	Coal unloading rate.
ER	Escalation rate.
E(y)	Expected value of variable y.
F(t)	Probability distribution function.
f(t)	Probability density function (p.d.f.).
fc(μ)	Cost of Service function $/Hour.
Fc(t)	Complementary function of F(t).
K	Parameter of shape for Erlang distribution.
L	Mean number of ships (n) expected in the system (queue + berths).
Lg	Mean time expected in the system.
M	Number of berths.
MT or t	Metric TON or tonne = 2204.6 lb.
MT/HR t/HR.	Rate Metric Tons per Hour.
n	Number of vessels in the system = number in berths + number in queue.

O.U.R.	Ore unloading rate.
P	Probability.
Po	Probability system is idle after steady state is reached.
Pn	Probability system is in state n after steady state reached.
Pn(t)	Probability as a function of time.
P.V.	Present Value.
RN	Random Number.
SDC	Ship delay Cost, $/HR.
So(t)	Service time distribution = probability service time is greater than or equal to time t.
t	time.
TW	Waiting time queue.
TB	Time in berth.
Tm,n(Δt)	Probability of transition from state m to state n in time Δt.
Wq	Mean waiting time in the queue.
VT.	Vessel tonnage.
α	Erlang distribution scale factor = kθ.
θ	Service rate notation used with Erlang distribution.
$1/\theta$	Mean time to pass through a service channel.
λ	Average frequency of arrivals or arrival rate - ships/day.
$^1/_\lambda$	Average time between arrivals or interarrival time.
μ	Average frequency of services or service rate ships/Hour.

$^{1}/_{\mu}$	Average time to complete service.
ρ	Coefficient of utilization = $\frac{\lambda}{M\mu}$.
ϕ	Utilization factor = $M\rho = \lambda/\mu$ for single berth system.