ECONOMICS OF GREAT LAKES BULK CARRIERS IN WINTER OPERATIONS

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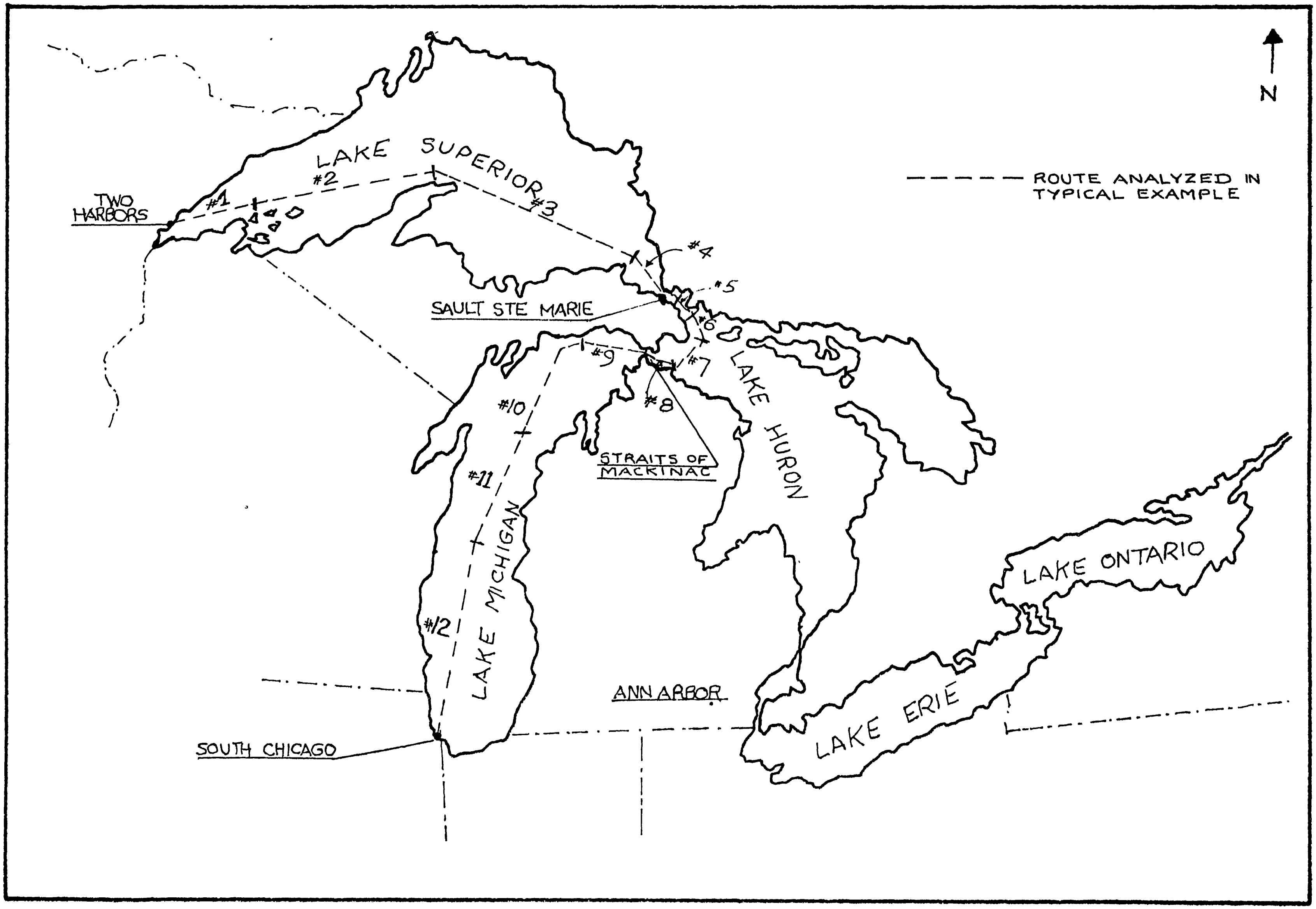
Report to Department of Commerce,
Maritime Administration
Contract No. 1-35487

November 1972

V-15.3



THE GREAT LAKES

FOREWORD

Since April 1971 we have been engaged in a study of the economics of winter navigation on the Great Lakes. This has been done under a continuing contract with the Maritime Administration's Office of Research and Development. We issued our first report in September of the same year under the title, "Cost-Benefit Analysis Model for Great Lakes Bulk Carriers Operating During an Extended Season." That was followed this past May by a 46-page set of additions and revisions. The intent of the present report is to combine the two foregoing publications into a comprehensive and convenient unit. We have changed the title in order to minimize the probability of confusing the old with the new.

Concurrent with this publication, we have submitted to the Maritime Administration a document: "Program and Usage for Cost-Benefit Analysis Model for Great Lakes Bulk Carriers Operating During an Extended Season." This document is a users' manual for the convenience of those who may need to have a thorough understanding of our computer program. Copies are available from the Maritime Administration's Office of Research and Development.

Work on the project continues. Ice conditions on Lake Huron, Lake Erie, and connecting waters are now being incorporated. We are looking at additional commodities. We are improving our analytical procedures for predicting speed through ice, and so forth. As work advances, we plan to publish additional reports that will in turn supersede this one.

FOREWORD

Winter navigation on the Great Lakes has been a reality since before the turn of the century when icebreaking carferries were placed into regular year-round service across Lake Michigan and in the Straits of Mackinac (1).* Nevertheless, the most important units of the Great Lakes fleet -- the bulk carriers -- were customarily laid up during November, and frequently confined their operating season to as little as seven months (1). Today, however, ships in one of the major iron ore fleets are operating on a ten-month basis (April through January) and there is widespread interest in further extension of the season, even perhaps to essentially the year around.

The trend that we see so strongly today had its beginnings with Admiral E. H. Thiele's proposal for season extensions dating back to 1959 (2). In 1962 the authors of reference 3 presented evidence that there were probably important economic benefits in Admiral Thiele's proposal. Other researchers, such as Prof. John Hazard, subsequently documented the resulting potential gains for commerce and industry in the entire Midwest (4).

In 1969 the U. S. Corps of Engineers completed an initial study for the Congress (5) and is now engaged in an ambitious multi-million dollar follow-up study of the costs and benefits of an extended season on the Lakes and through the Seaway. The

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*Numbers in parentheses indicate references in the Bibliography.

U. S. Coast Guard and the Maritime Administration, among other federal agencies, have also joined in a massive cooperative effort to assist private industry in this new development.

As an integral part of the overall program, the Maritime Administration last April placed the present study contract with The University of Michigan. The intent was to provide a method for predicting costs and benefits accruing to any Great Lakes shipowner who might engage in extended season operations. This was to be presented in the form of a computerized model of general applicability. The study was to complement others concurrently underway (sponsored by several federal agencies) encompassing costs to government and overall costs and benefits to private industry and the public. In addition, the model was to be constructed in a manner that would allow easy modification as new facts are gathered from continuing research and development.

The present report meets the foregoing specification, we believe, to the maximum extent possible under the existing constraints of time, budget, and available information. The value of the report lies in the analytical technique, or model, presented. The model clearly indicates the more critical areas for further research, and provides a sound framework for continuing investigation. As more experience is gained in actual winter operations and as more research reports become available the model can quickly be refined to a degree that will allow fast, reliable economic projections. These, in turn, can be used to optimize the design of ships -- or taken as inputs to broader analyses aimed at optimizing the entire transport system.

ACKNOWLEDGMENTS

This report is the product of many minds both internal and external to The University of Michigan.

Among the external sources, two design firms gave us every possible cooperation: R. A. Steran, Inc., of Sturgeon Bay, Wisconsin; and Marine Consultants and Designers of Cleveland, Ohio. Although both are occasionally quoted in the report, there are many other instances where their factual information was incorporated along with our own and no attribution given. Much of the data on ship weights, building costs, and operating costs benefited from their guidance. Mr. Ernest Marshall, glaciologist, contributed expert advice on ice conditions on the Great Lakes.

Several graduate students devoted much time and thought to the project. Among these was Mr. M. Walaa Anwar, who assisted with the structural analysis, and Mr. Peter Swift, who helped develop the cost and weight estimating methods, and Mr. Kwangse Kim, who wrote a large share of the computer program for our study.

Drawing on the experience of our friends in Northern Europe, we received much helpful advice from the following individuals:

Professor Jansson of the Technical University of Helsinki

Mr. Brenner of ABS (Helsinki)

ACKNOWLEDGMENTS

Captain Aalto of the Finnish Board of Navigation

Mr. Grunér of the Finnish Steamship Company

Mr. Sundström of Finnlines

Mr. Wihuri of Suomen Tankkilaiva Oy, Helsinki

Dr. Palosuo of the Finnish Institute of Marine Research

Mr. Pehrsson of Kamewa, Kristinehamn/Karlstadt

Dr. Waas of the Hamburg Ship Model Basin

Mr. Lauritzen of J. Lauritzen Lines, Copenhagen

Professor Prohaska of the Hydro and Aerodynamic Laboratories, Denmark

Dr. Røren of Det norske Veritas

Closer to home, we were fortunate enough to receive close cooperation from several ship operating companies, the U. S. Coast Guard. Individually, we want to offer particular thanks to:

Mr. C. F. Beukema of U. S. Steel Corporation Great Lakes Fleet

Mr. Richard Tesreau of U. S. Steel Corporation Great Lakes Fleet

Captain John Rankin of U. S. Steel Corporation Great Lakes Fleet

ACKNOWLEDGMENTS

Mr. W. R. Ransom of U. S. Steel Corporation Great Lakes Fleet

Mr. Clare Snider of Ford Motor Company Marine Division

Captain Dwight King of Cleveland Tankers

Mr. John Horton of Cleveland Cliffs Iron Co.

Mr. James Moon of Mobil Oil Company

Mr. M. E. Parr of the Maritime Administration supplied useful information on the new tax law as it affects Great Lakes Ships. Mr. Frank Kesterman and Mr. Paul Mentz of the Maritime Administration provided effective liaison between ourselves and the Office of Research and Develpment. Mr. John Couch of Litton Ship Systems Division assisted with advice on machinery capital costs.

While we are anxious to express our sincere thanks to all of the aforementioned individuals and organizations, we must also state that we bear full responsibility for any shortcomings contained herein. Researchers undertaking projects such as this under government sponsorship are encouraged to express their professional judgement. Therefore, points of view or opinions stated in this document do not necessarily represent the official position or policy of the Maritime Administration.

Charlene Mitchell merits special thanks for her exceptional patience and efficient operation in typing this report.

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CONTENTS

SYMBOLS & ABBREVIATIONS

A	uniform annual returns before tax
B	beam
BHP	brake horsepower
C	annual transport capacity
C_B	block coefficient
CN	cubic number $= \frac{LBD}{100}$
CP	controllable pitch
CR	capital recovery factor
Δ	displacement at summer loadline, long tons, fresh water
D	depth
DW	deadweight
K	number in crew
L	length between perpendiculars
LS	lightship weight
M	operating months per year
N	economic life of a ship, or years remaining in life of an existing ship

SYMBOLS AND ABBREVIATIONS

NPV	net present value
NPVI	net present value index
P	initial investment
r	freight rate, $ per long ton
RFR	required freight rate, $ per long ton
S	percentage ice cover
SHP	shaft horsepower
T	summer loadline draft
W_C	weight of conveyor system (exclusive of A-frame and hoppers)
W_M	weight of propulsion plant, wet
W_O	weight of outfitting and hull engineering
W_S	weight of structure
Y	uniform annual operating costs

Notes

1. Other symbols and abbreviations are explained wherever used.
2. All weights are in long tons and all dimensions in feet except as noted.
3. All costs are in 1971 dollars.

I. SUMMARY OF THE PROBLEM AND PROPOSED SOLUTION

The object of this study is to establish a widely-applicable procedure for estimating the economic benefits (to shipowners) from extensions of the Great Lakes operating season. An important secondary object is to help ship designers optimize the design of ships intended for ice operations.

The study attempts no firm conclusions or recommendations as to the best length of operating season or ship design. It weighs the economic costs and benefits to the shipowner and specifically ignores public costs for icebreaker assistance, etc. The study omits all reference to the benefits of lessened stockpiling requirements and miscellaneous problems relating to possible shore damage, etc.

In its present form, the proposed analytical procedure is, we believe, sound in principle. There are inevitably several gaps in quantitative factors -- both major and minor. Among the major gaps are the changing characteristics of the ice itself, average speeds obtainable through ice, and costs of hull reinforcement. Thus, while this report provides what we believe is a valid foundation, its usefulness will be limited until further knowledge is gained from ongoing research, including of course full scale experimental operations and methodical ice surveys.

The final outcome of our analysis is an economic measure of merit indicating the net benefit to the shipowner from various lengths of the operating season. As one may infer, of course, benefits to the shipowners should eventually become benefits to the public in the form of lower prices for consumer products.

Because of variations from year to year in the severity of weather and ice conditions, a ship with any given degree of ice strengthening would logically be operated for differing periods in the various winter seasons. Our analytical method recognizes this, treating weather and ice statistically. We use this term "ice strengthening" throughout this report in its broadest sense, including not only hull reinforcement but increased horsepower and other modifications intended to make the ship operable in ice. We do not, however, include any changes in hull form.

There are, of course, manifold variations in real-life scenarios in which different shipowners find themselves. Some are interested in extending the season with ships as yet unbuilt, others want to modify existing ships. The degree of federal assistance remains unknown. Each trade route has its own ice conditions and potential intensity of traffic. Each commodity has its own handling problems in cold weather. We have treated such factors parametrically, keeping to a minimum the arbitrary assumptions built into the analysis. The following outline summarizes the major factors and the variations considered in the present study:

A. Commodity and Trade Route

The study is presently applied to the pelletized ore trade from the Upper Lakes to Lake Michigan (specifically, Two Harbors to South Chicago). Other important trades, such as the ore movement between Lake Superior and Lake Erie ports, and the movement of grain, limestone, coal, and petroleum, merit further study. (We assume throughout this report that cargo will always be available at the loading port and receivable at the unloading port without undue delays.)

B. Ship Type

1. Bulkers (a term designating an ordinary bulk carrier without self-unloading gear)
2. Self-Unloaders
   a. With A-frame and boom
   b. Simple shuttle type (relying on matching shore based conveyors to carry the cargo away from the ship's side)

C. Degree of Ice Strengthening*

1. Class II (unmodified)**
2. Class IC
3. Class IB
4. Class IA
5. Class IA Super

See reference 6 for detailed requirements of the various ice classes.

D. Overall Weather and Ice Conditions

1. Mild
2. Normal
3. Severe

E. Ship Status

1. Existing ships
2. Ships in planning stage

F. Ship Characteristics

1. Length
2. Beam
3. Depth
4. Draft
5. Block coefficient
6. Shaft horsepower
7. Crew complement, etc.

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*Our assessment of the degree of ice strengthening is based on the Finnish rules, which simultaneously involve both structural reinforcement and minimum horsepower requirements. For our purposes, however, we are separating the hull and machinery requirements. Thus, when we refer to a ship as meeting a certain ice class, we are referring only to its structural characteristics.

**The Finnish ice rules have a category designated Ice Class II for ordinary merchant ships without any form of ice reinforcement. We are not using that category in the present study, however, because the hulls of the post-World War II Great Lakes bulk carriers are generally strong enough to qualify them under the lowest ice class: IC.

G. <u>Power Plant</u> (all single-screw)

1. Steam turbine
2. Twin intermediate-speed geared diesels

H. <u>Propeller</u>

1. Fixed blades
2. Controllable pitch

I. <u>Miscellaneous Factors</u>

1. With or without bow thruster
2. Cruiser or transom stern
3. Self-unloading rates
4. Dock loading and unloading rates

J. <u>Length of Operating Season</u>

1. Standard (8 months)
2. 9 months
3. 10 months
4. 11 months
5. 11.5 months
   (or any intermediate value)

Our analytical procedure and the computer program that is its offspring are presented in a way to allow them to be easily modified to accommodate other variations or assumed inputs.

Taking any desired combination of the above variables, the user can apply our methodical procedure to determine

I: SUMMARY OF THE PROBLEM

in sequence:

A. Design Characteristics

B. Weights

C. Investments

D. Operating Environment (ice conditions)

E. Speed and Power in Open Water and in Ice

F. Annual Transport Capability

G. Operating Costs

(Chapter II, DETAILED ANALYTICAL PROCEDURE, follows the format of the outline above and adds sections on measures of merit and final synthesis.)

In short, the user can start with any reasonable combination of design and voyage variables and follow our analytical procedure to predict the resulting economic benefit of various lengths of operating season. Repeated with varying design variables, the results can be used to find the optimal ship. One must keep in mind, of course, that the optimal ship does not necessarily result in the optimal transport system. This entire study should, indeed, be looked upon as only one component of a complete transport analysis now being undertaken by various federal agencies, ship owners, and other interested parties.

It should be noted here that the economic analysis is based on the costs and benefits of the entire operating season, not just the extension. The added computational work is necessary because ice strengthening involves changes in weight and transport capacity affecting summer as well as winter operations.

II. DETAILED ANALYTICAL METHODS

A. Design

There is no intent here to design a ship, but only to analyze a proposed design (whether for a new or modified ship) in order to predict its economic merit. Our approach requires certain minimum initial inputs, notably length between perpendiculars (L), beam (B), depth (D), summer loadline draft (T), block coefficient (C_B), shaft horsepower (SHP), and ice class. Other important design parameters can then be derived -- or used as inputs if already known. The sequence of the analysis follows:

1. Prismatic Coefficient

$$C_P = \frac{C_B}{C_M} \qquad [1]$$

where

C_M = midship coefficient

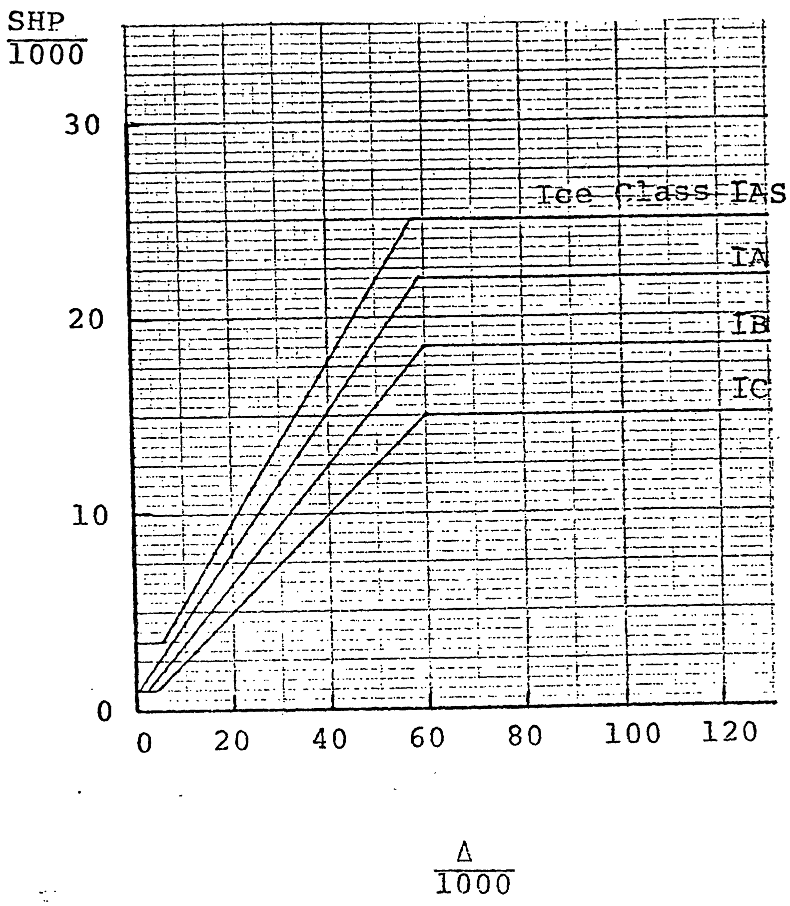


Figure 1: Minimum Horsepower vs. Displacement (LTFW) for Finnish Ice Classes

In Great Lakes ore carriers C_M varies between 0.990 and 0.999. We will use an average value, 0.993, at this stage.

2. Length Overall

$$L_{OA} = fL \qquad [2]$$

where

$f \simeq 1.0115$ for transom stern ships
$f \simeq 1.026$ for cruiser stern ships

3. Displacement

The summer load line dispacement(Δ) is based on the length between perpendiculars and long tons of fresh water:

$$\Delta = C_B \frac{LBT}{35.9} \qquad [3]$$

The corresponding number of metric tons is 1.6% greater.

4. Minimum Horsepower

Regulation 3 of the Finnish rules on ice (6) applies the following formula for minimum horsepower:

min. SHP = $(1.016q\Delta + X)$ or Y, whichever is less, and where q, X, and Y have the values shown in the following table:

Ice Class	q	X	Y
IA Super	0.40	1500	25,000
IA	0.35	1000	22,000
IB	0.30	500	18,500
IC	0.25	0	15,000

Figure 1 puts the above expression into graphical form.

The rules stipulate that SHP should in no case be less than 1000 for any ice class and not less than 3500 for class IA Super. The minimum required power and the lower limits may be reduced by 10% "if the ship is fitted with a controllable pitch propeller and reversible main machinery." The astern power in steam turbine ships must be at least 70% of the ahead SHP.

As stated earlier, we are separating hull and machinery requirements, so we are not confined to the rules given above.

5. Cubic Number

The cubic number (CN) is defined in the usual way:

$$CN = \frac{LBD}{100} \qquad [4]$$

6. Freeboard, Draft, and Displacement

Given the summer freeboard and corresponding draft, T, the drafts at other loadlines will be as follows:

$$T_{MS} = \text{mid-summer draft} = 1.025T \qquad [5]$$

When L exceeds 550 feet, the intermediate draft, T_I, and winter draft, T_W, will be:

$$T_I = 0.9625T \qquad [6]$$

and

$$T_W = 0.9177T \qquad [7]$$

At drafts, T_X, close to the summer loadline condition, the block coefficient, C_{B-X}, can be approximated as follows:

$$C_{B-X} = C_B + 0.002\ (T_X - T) \qquad [8]$$

Given these modifications to draft and block coefficient, we can easily derive the displacements at the mid-summer, intermediate, and winter freeboards. The mid-summer displacement, for example, would be:

$$\Delta_{MS} = C_{B-MS} \frac{LBT_{MS}}{35.9} \qquad [9]$$

where

C_{B-MS} = block coefficient at mid-summer freeboard draft, T_{MS}

B. Weights

For estimating both weights and costs we divide the ship into the three traditional categories:

Structural hull (including erections)
Outfitting (including hull engineering)
Machinery (complete propulsion system including liquids)

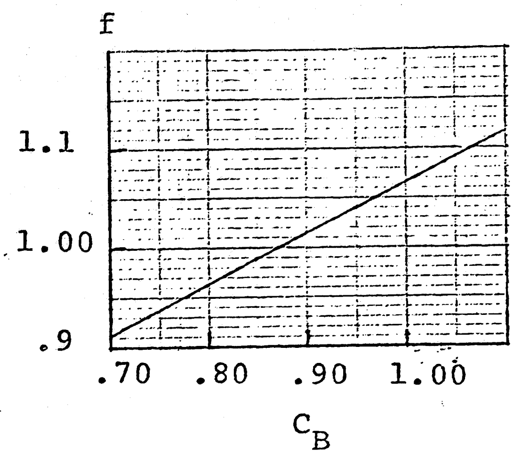
Extra features, notably self-loading capability, are treated as appended weights and costs.

1. Structural Hull Weights

The basic (i.e. Ice Class IC) structural hull weight can be estimated using Figure 2, which is based on a modified version of Krappinger's formula (7) :

$$W_S = 668 \left(\frac{CN}{1000}\right)^{0.75} \left(\frac{\frac{L}{D} + 2}{20}\right)\left(0.565 + \frac{C_B}{2}\right) \qquad [10]$$

The added weight of steel for further ice strengthening (either new construction or modification) can be estimated from Figure 3. The curves are from (8) and carry the caution that there are bound to be large individual departures. Moreover, the curves are still tentative in nature and should be checked and refined in future studies. Despite these shortcomings,



Correction Factor for C_B

Structural hull weight:

$W_s = f \cdot F$

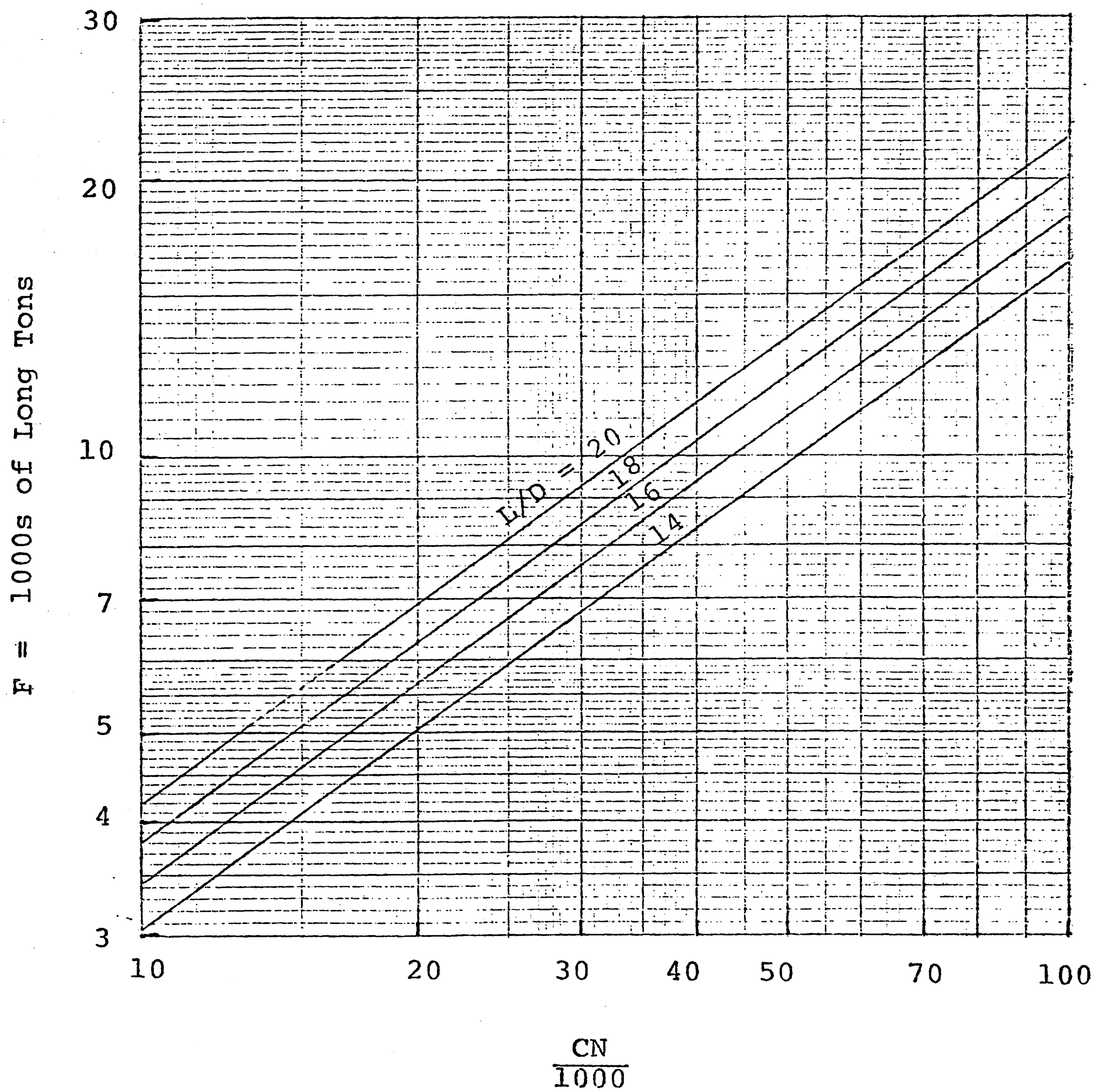


Figure 2: Structural Hull Weight (Eqn.10)

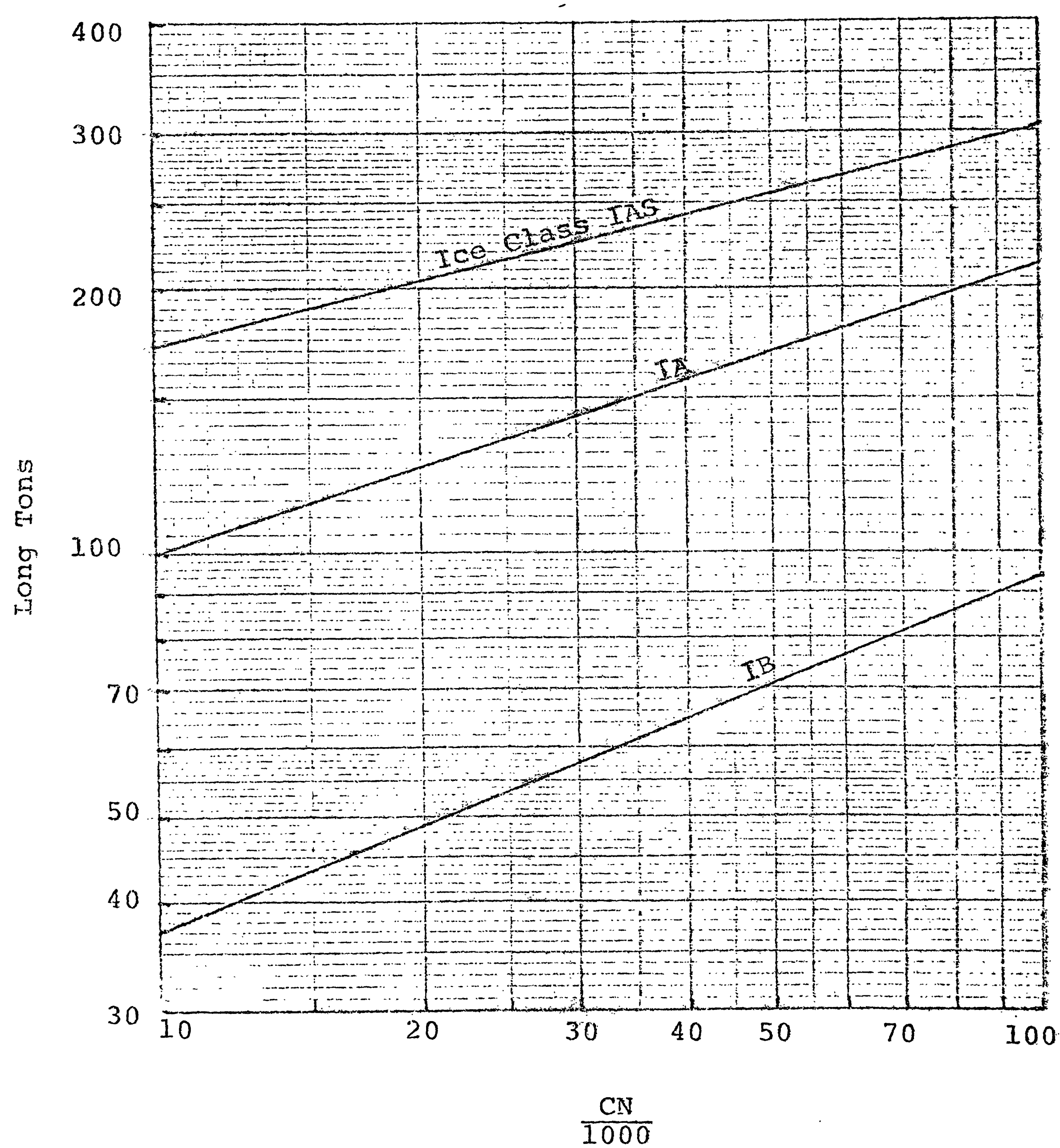


Figure 3: Net Added Steel Weight for Various Degrees of Ice Reinforcement

we believe the curves reflect the trends with a degree of accuracy suitable for this stage of development.

If the ship is a self-unloader with A-frame and boom, the structural weight will be increased by about 2%. For a simple shuttle conveyor without A-frame, the increase would be about 1%.

2. Outfitting Weight

The weight of outfitting (including hull engineering) will be but little affected by the ice class or intended length of operating season. One estimate (9) indicates an addition of only ten tons for a class IA Super design. For our purposes, we can ignore such small increments.

The outfitting weight can be estimated from Figure 4, based on this expression:

$$W_O = 233\left(\frac{CN}{1000}\right)^{0.3} \qquad [11]$$

The weight of conveyor systems may be estimated from Figure 5 and 6, based on the equation:

$$W_C = a\left(\frac{CN}{1000}\right)^{b} \qquad [12]$$

where

W_C is the weight of the complete conveyor system (exclusive of A-frame and hoppers) in long tons,

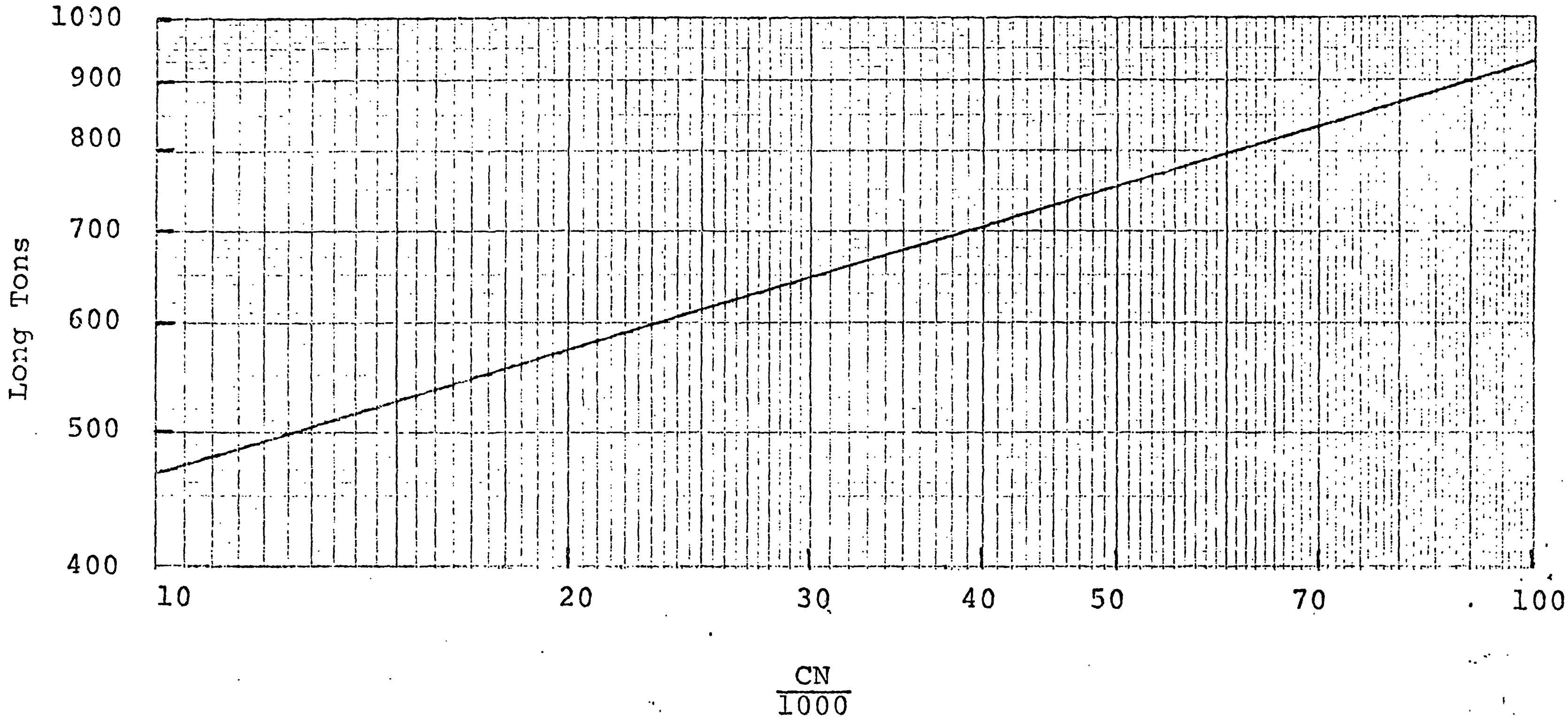


Figure 4: Outfitting Weight
(Eqn, 11)

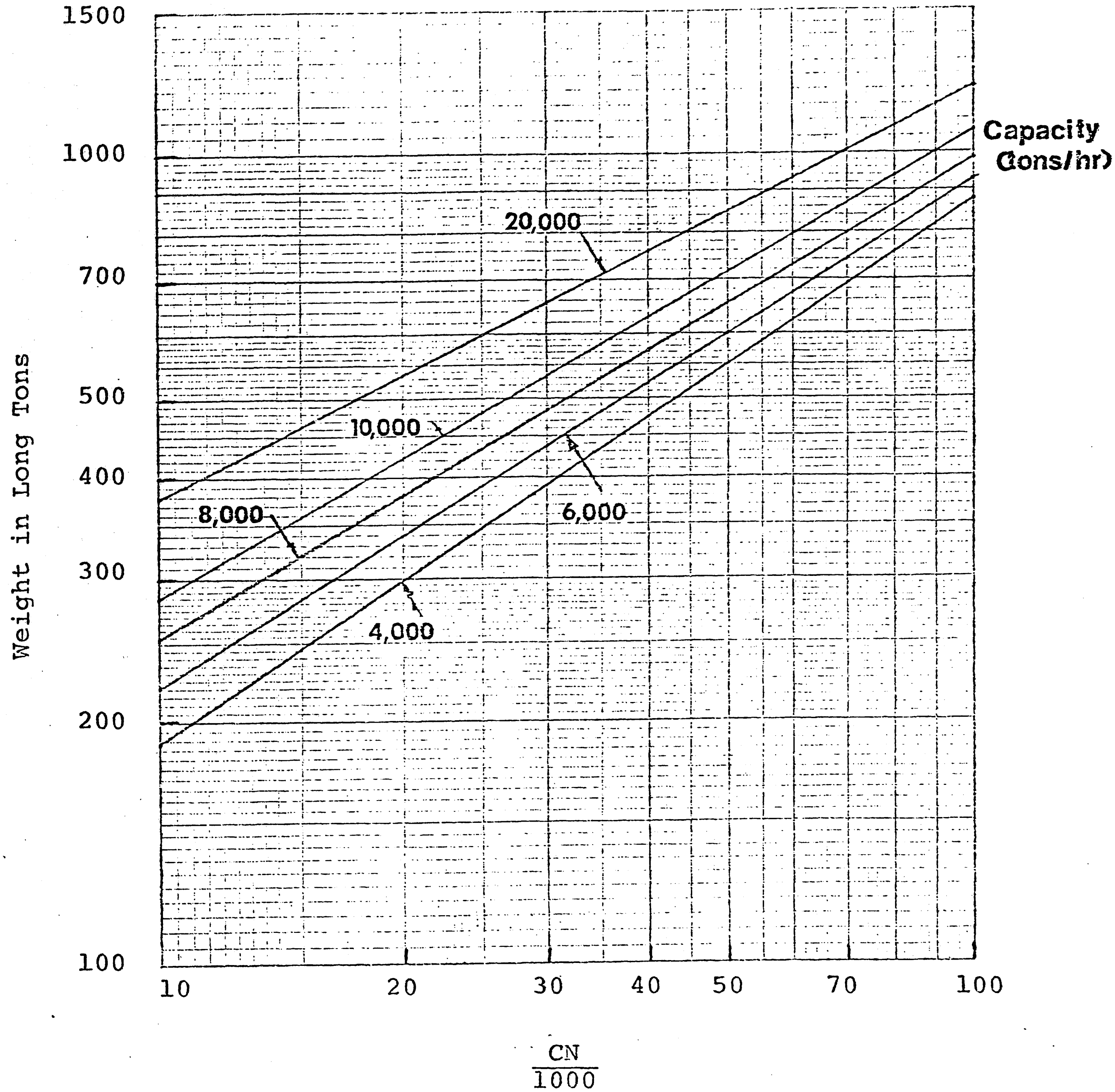


Figure 5: Shuttle Type Conveyor System Weight (Eqn. 12)

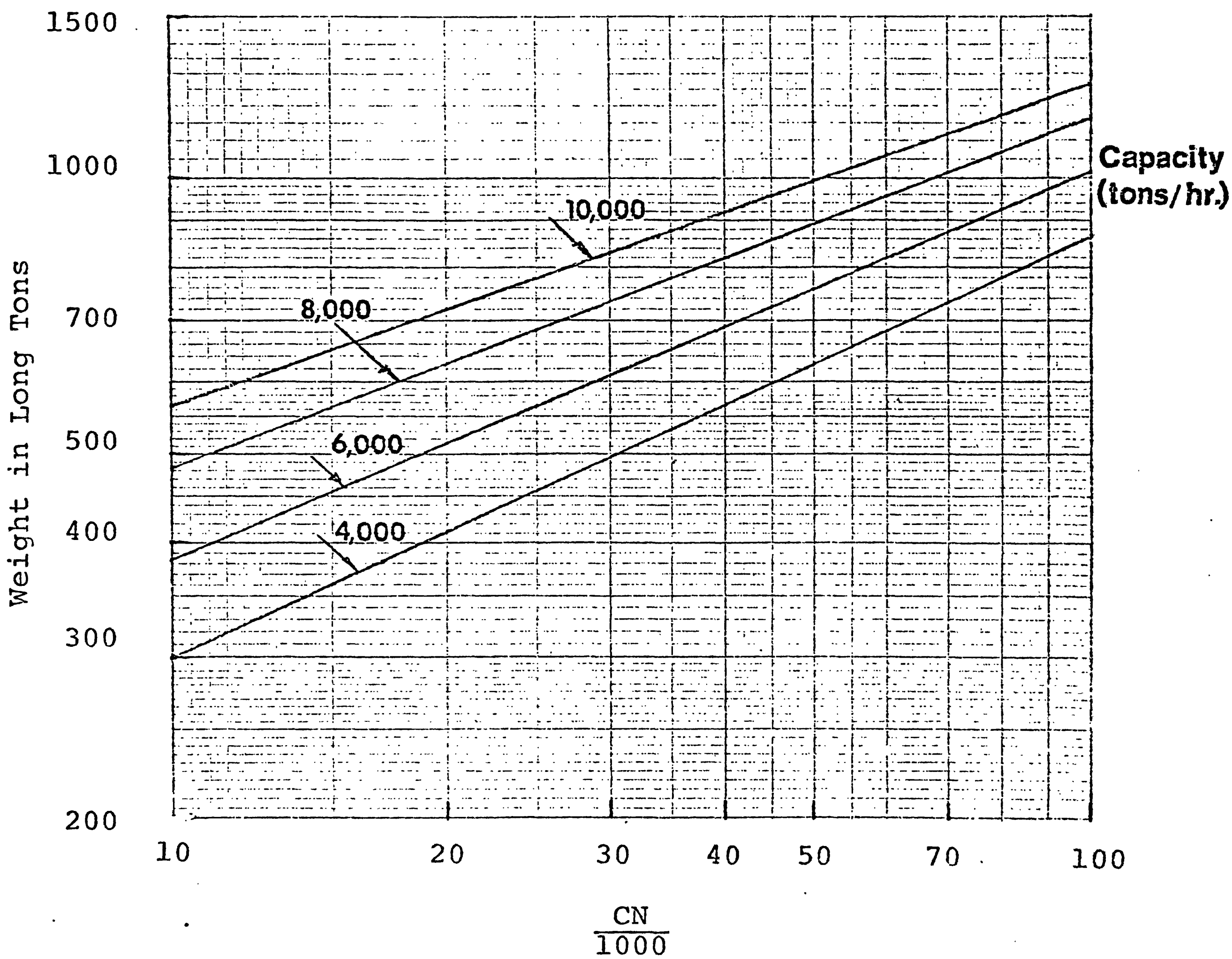


Figure 6: Boom Type Conveyor System Weight (Eqn. 12)

and where

a and b have the values shown below:

Capacity in 1000 tons per hour	Shuttle Conveyor a	Shuttle Conveyor b	Boom Conveyor a	Boom Conveyor b
4	40	0.67	104	0.46
6	53	0.62	147	0.42
8	65	0.59	202	0.38
10	77	0.57	252	0.35
20	120	0.50	---	----

The added weight and lost buoyancy of bow thrusters are treated under section 5, which follows.

3. Machinery Weight

The wet weight of single screw machinery plants can be estimated from Figure 7, based on:

$$W_M = a\left(\frac{SHP}{1000}\right)^{0.5} \qquad [13]$$

where

a = 200 for geared steam turbine installations

b = 180 for twin, medium speed geared diesels

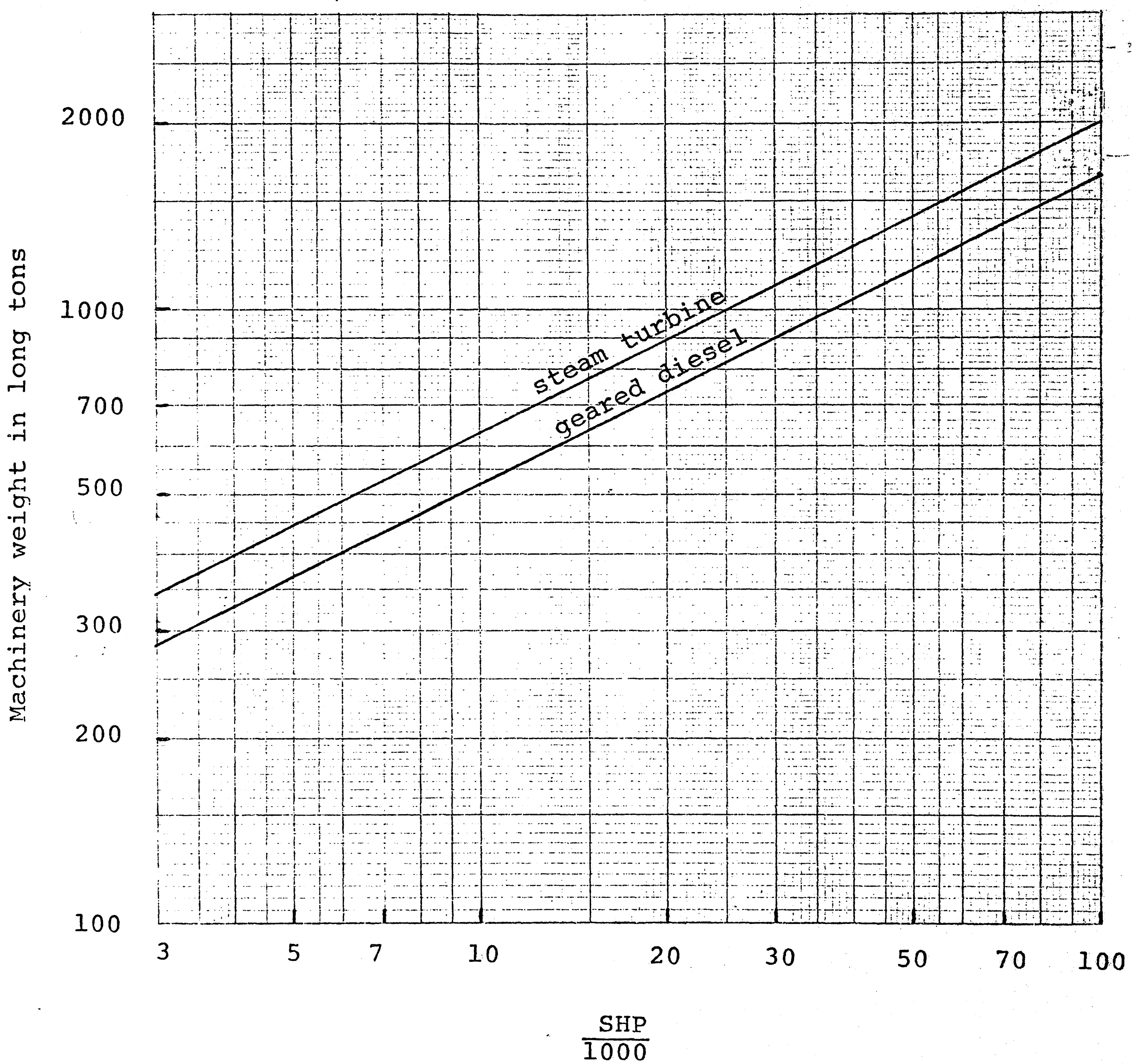


Figure 7: Machinery Weights
(Eqn. 13)

The ice rules dictate minimum requirements for propeller blade thickness, shaft diameters, reduction gears, etc. In addition, special appurtenances are needed to ensure a flow of cooling water to the condenser. The resulting increase in weight is minor and is therefore ignored in this analysis.

4. Light Ship

The light ship weight is simply the sum of the three component weights discussed above plus any added weights for self-unloaders. No margin need be added in studies of this kind.

5. Deadweight

The basic deadweight is that corresponding to the freshwater displacement at the summer loadline draft:

$$DW = \Delta - LS \qquad [14]$$

where

LS = light ship weight

Subtract 70 tons for a typical bow thruster installation. This comprises both added weight of hardware and loss of displacement.

6. Variable Weights

Weights of fuel, fresh water, etc. are dealt with under section F, Annual Transport Capability.

C. Investments

In a parametric study such as this, cost estimates must be made as a step in helping to choose between alternatives. Our principal aim, then, is to establish a procedure that illuminates cost trends as influenced by the major design and operating variables.

Nevertheless, because the outcome of the present report is intended for use in broad studies of the overall transport system, the cost estimates must be as accurate as possible in absolute as well as relative terms. This does not mean, however, that our cost estimates are intended as being suitable for bidding purposes. They should be continually scrutinized and modified before further application.

All cost figures shown are based on 1971 conditions and dollar values.

1. New Construction

Table 1 summarizes the cost estimating relationships that we propose for structure, outfit, and machinery. The figures apply to non-self-unloading ships (bulkers) with single screw and fixed propeller blades. The costs of such miscellaneous items as engineering, planning, staging, temporary lights, cleaning, and trials are recognized in the cost

TABLE I

COST ESTIMATING RELATIONSHIPS

Ship Component		Cost Component: Material ($)	Cost Component: Labor (man-hours)
Structure		$\$236\ W_S$	$130{,}000\left(\frac{W_S}{1000}\right)^{0.85}$ See Figure 8
Outfit		$\$2400\ W_O$	$280\ W_O$
Machinery See Figure 9	Steam Turbine	Material, Labor, Overhead $\$900{,}000\left(\frac{SHP}{1000}\right)^{0.60}$ add 3% if 70% backing power is specified	
	Intermediate-speed Diesel	$\$550{,}000\left(\frac{BHP}{1000}\right)^{0.70}$	

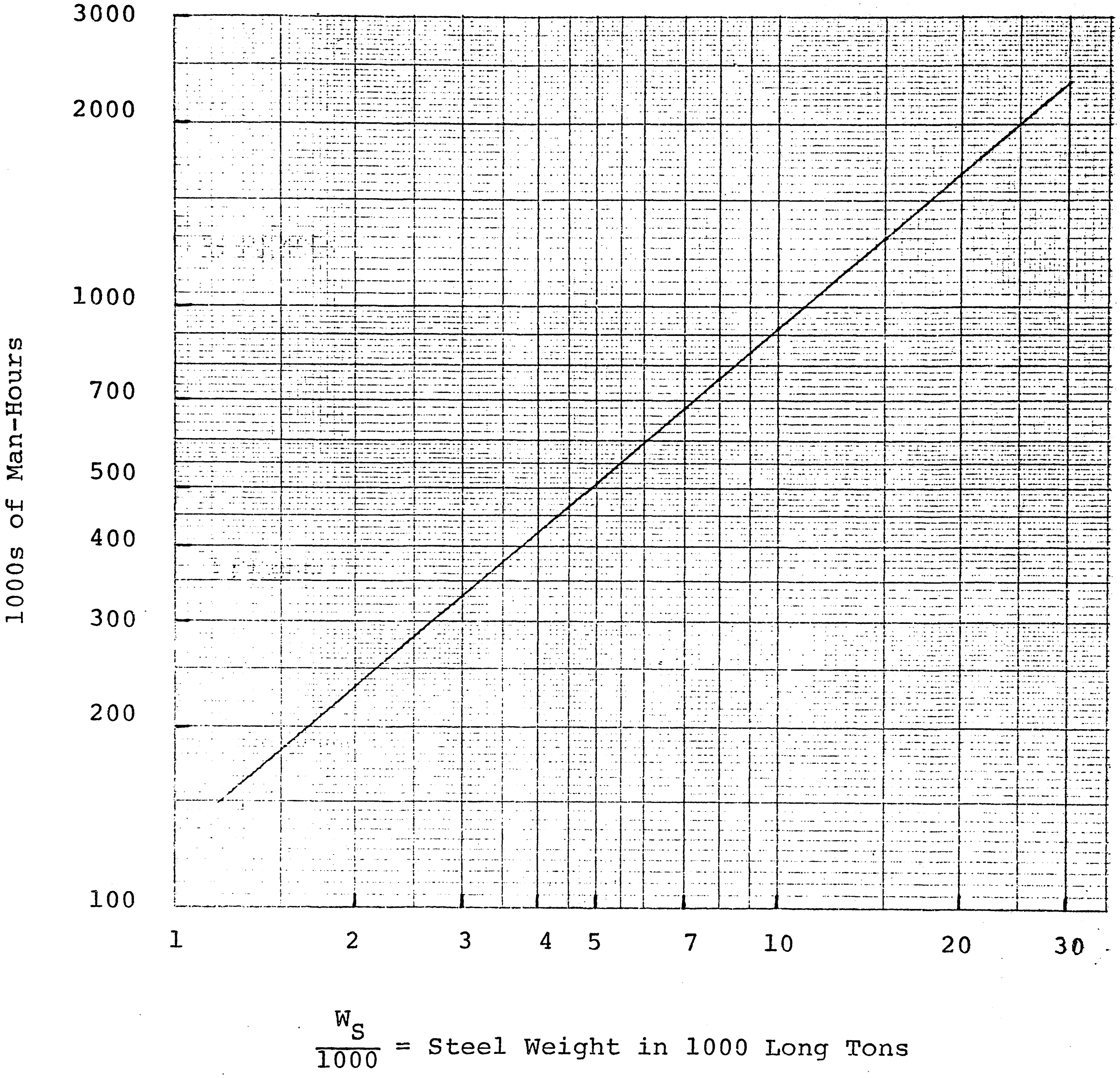


Figure 8: Structural Hull Man-Hours
(Table I, page 23)

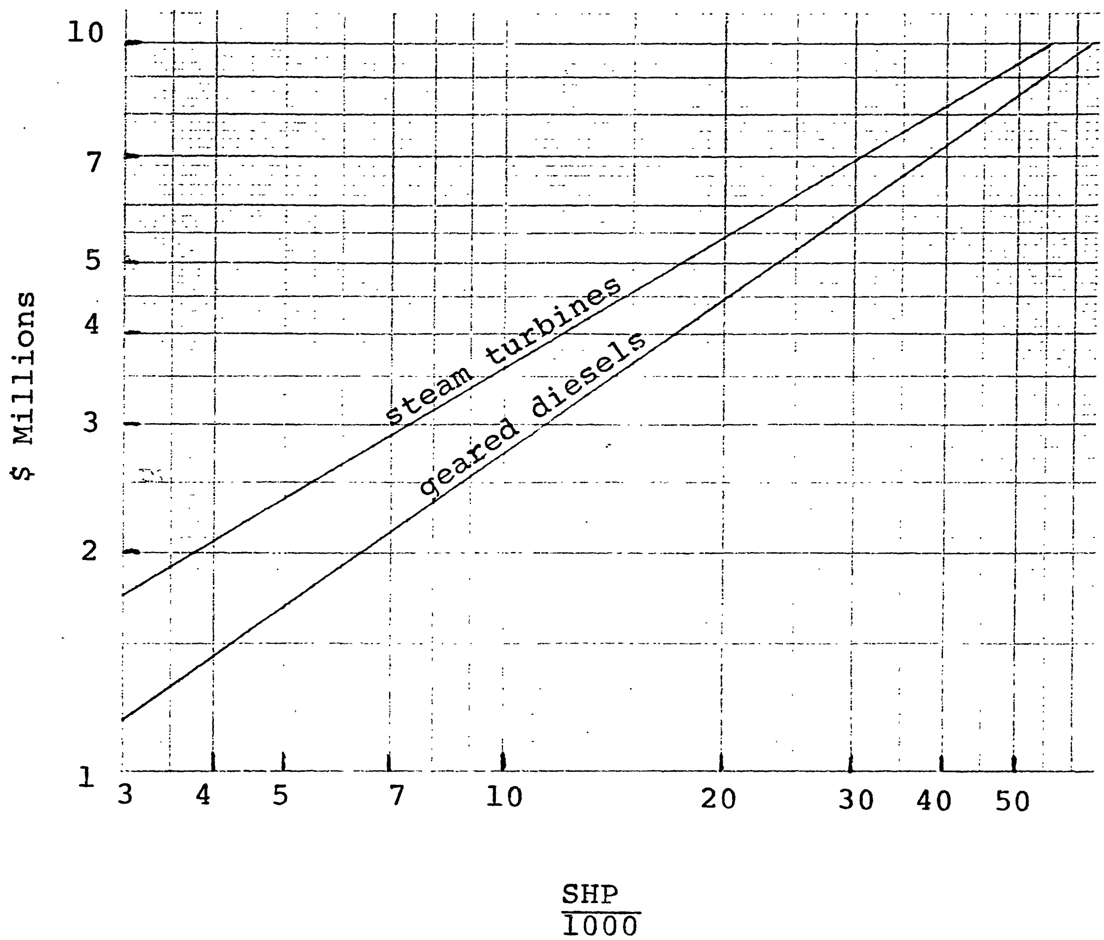


Figure 9: Machinery Costs
(Table I, page 23)

coefficients shown in the table. We use the following additional assumptions in estimating the total cost:

Overhead: 75% of labor cost
Average hourly rate: \$4.10
Profit: 5% mark-up on total cost to shipyard

The cost of the hull (structure and outfitting) can be taken as the sum of the two material costs plus \$7.175 per total man-hour of labor. Adding the cost of machinery gives the total cost to the shipyard. The invested cost is found by increasing that figure by the assumed profit mark-up, or 5%.

3. Ice Strengthening, New Construction

In the case of new construction, there are no appended costs for structure or machinery because of ice strengthening. Those costs are already recognized in the weight and horsepower estimates which automatically affect the cost estimates. In the outfitting category, however, there will be modest increases for strengthened rudder and steering gear. We propose the following:

$$C = a \frac{LB}{100} \qquad [15]$$

where

C = added cost to the owner for winter outfitting

a = 0 for class II or IC
= \$15 for class IB

= \$30 for class IA

= \$45 for class IA Super

3. Extra Features

The investment cost figures cited above should be increased for special features such as self-unloading gear, bow thrusters, or controllable pitch propellers. These extras are discussed next.

Self-unloading systems will add to the cost approximately as shown in Figures 10 and 11, based on this expression:

$$C = a\left(\frac{CN}{1000}\right)^{b} \qquad [16]$$

where

C = Cost of conveyor system (including shipyard profit) in dollars

and

a and b have the values shown below:

Capacity in 1000 tons per hour	Shuttle Conveyor a \$1000	Shuttle Conveyor b	Boom Conveyor a \$1000	Boom Conveyor b
4	224	0.31	442	0.23
6	280	0.31	597	0.22
8	337	0.30	794	0.19
10	395	0.30	922	0.19
20	800	0.30	___	___

The foregoing figures exclude extra costs of hull

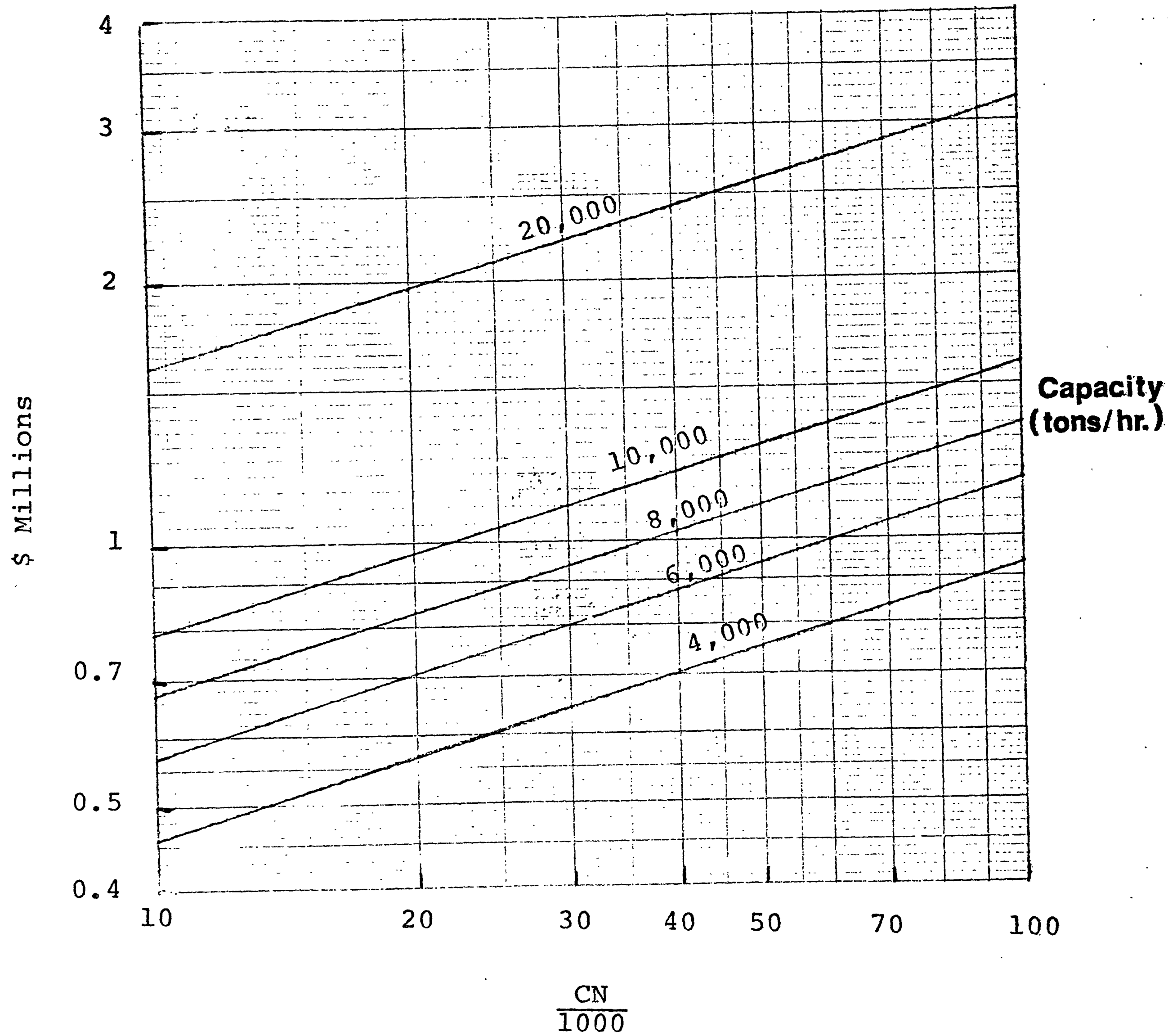


Figure 10: Shuttle Type Conveyor System Cost (Eqn. 16)

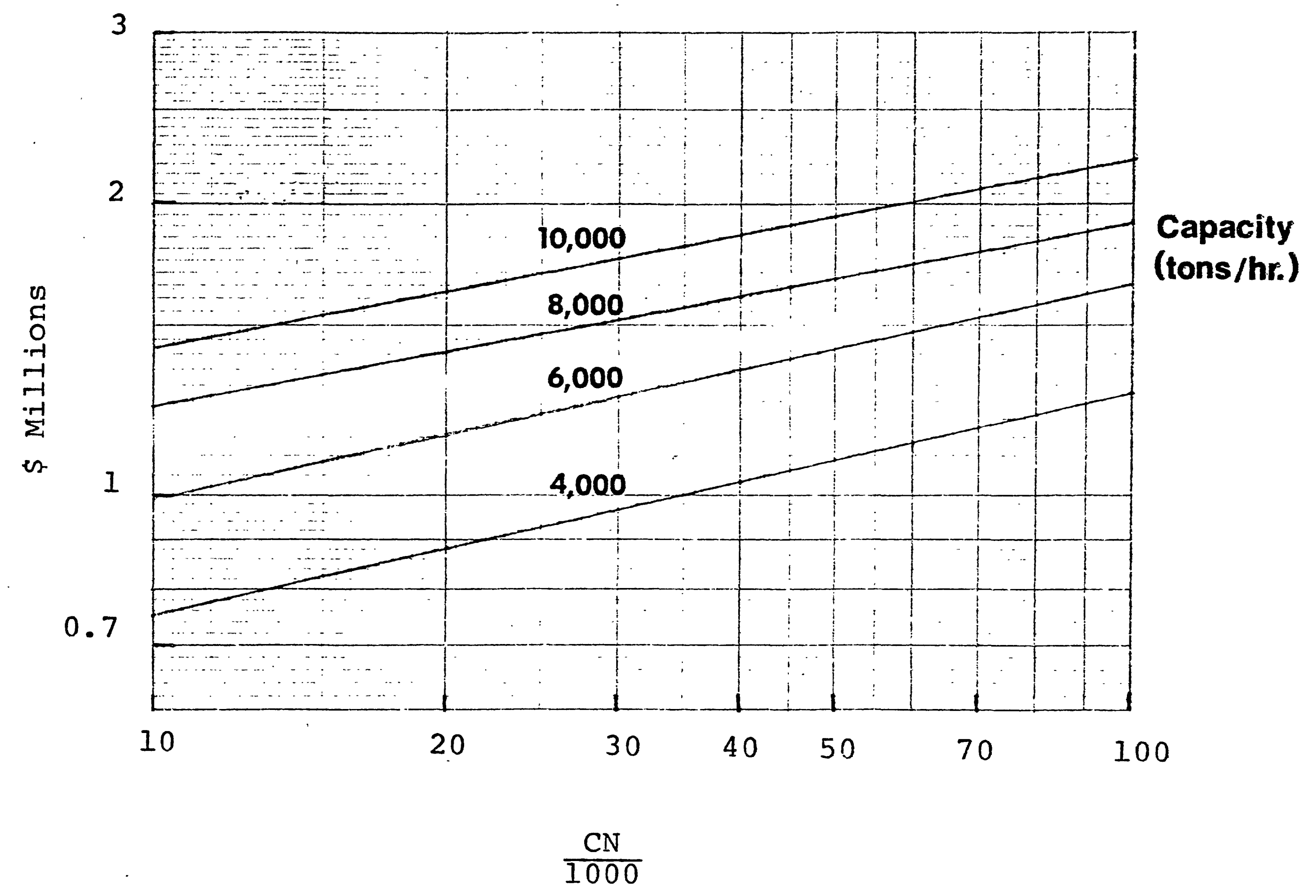


Figure 11: Boom Type Conveyor System Cost (Eqn. 16)

structure, which are already recognized in the added weight (hence cost) of the structure.

The complete installed cost of a typical 800 BHP diesel driven bow (or stern) thruster is about \$150,000. This would include shipyard profit.

Controllable pitch propellers imply a redesign of many features of the propulsion plant. Estimating the added cost is therefore difficult. In meeting ice class requirements, fitting a CP propeller may allow a reduction in required horsepower. That saving, however, is already factored into the design and cost estimates. What we need here is an estimate of the added cost for any given horsepower. We make the following tentative proposal:

$$C = a \left(\frac{SHP}{1000}\right)^{0.60}$$

where

C = added cost for a CP propeller installation, including shipyard profit

and

a = \$20,000 for steam turbine plants

= \$13,500 for geared diesel plants (see Fig. 12)

We have not taken up two other complications: the cost savings from multi-ship contracts and the owner's added first costs for legal fees, design agent's fees, and owner's furnished equipment.

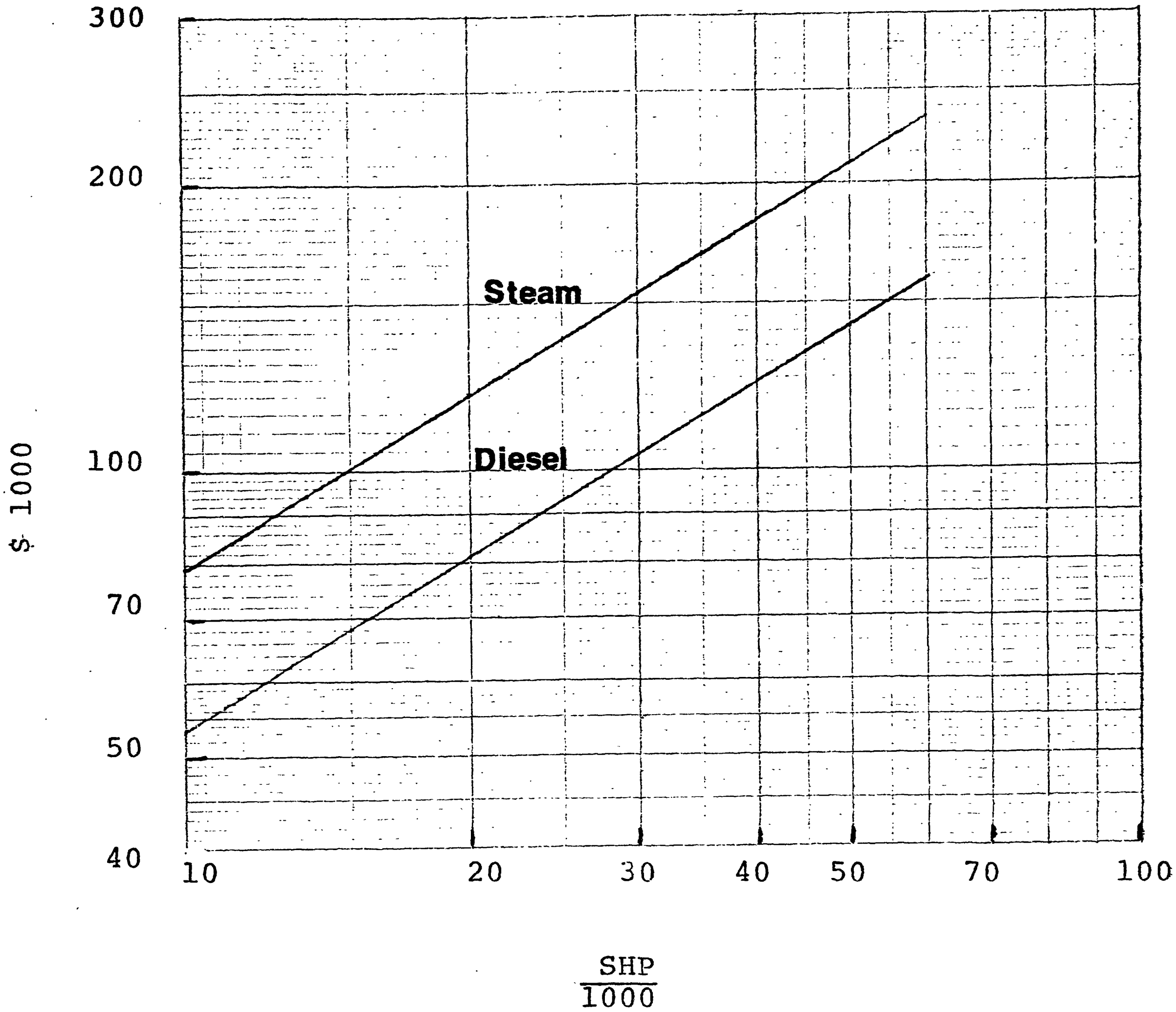


Figure 12: Added Cost for Controllable Pitch Propeller (Eqn, 17)

For purposes of this study we shall specifically ignore both of those countervailing factors.

4. Existing Ships

In the case of an existing ship that is to be operated without modification, the invested cost should be taken as the net resale value on the current market.

There are several variations that can be tried in ice-reinforcing the structure of typical Great Lakes ships. The more successful approaches will, we believe, tend to cost about the same.

Figure 13, from reference 8, indicates approximate costs for structural conversions. The cost of modifying the outfitting for winter operations can be estimated by increasing by 25% the "a" values previously shown for equation 15.

Where horsepowers are to be increased, we assume the existing plant will be replaced. The scrap value should be close to the cost of removal, so we can infer that the total machinery cost would be about the same as for new construction.

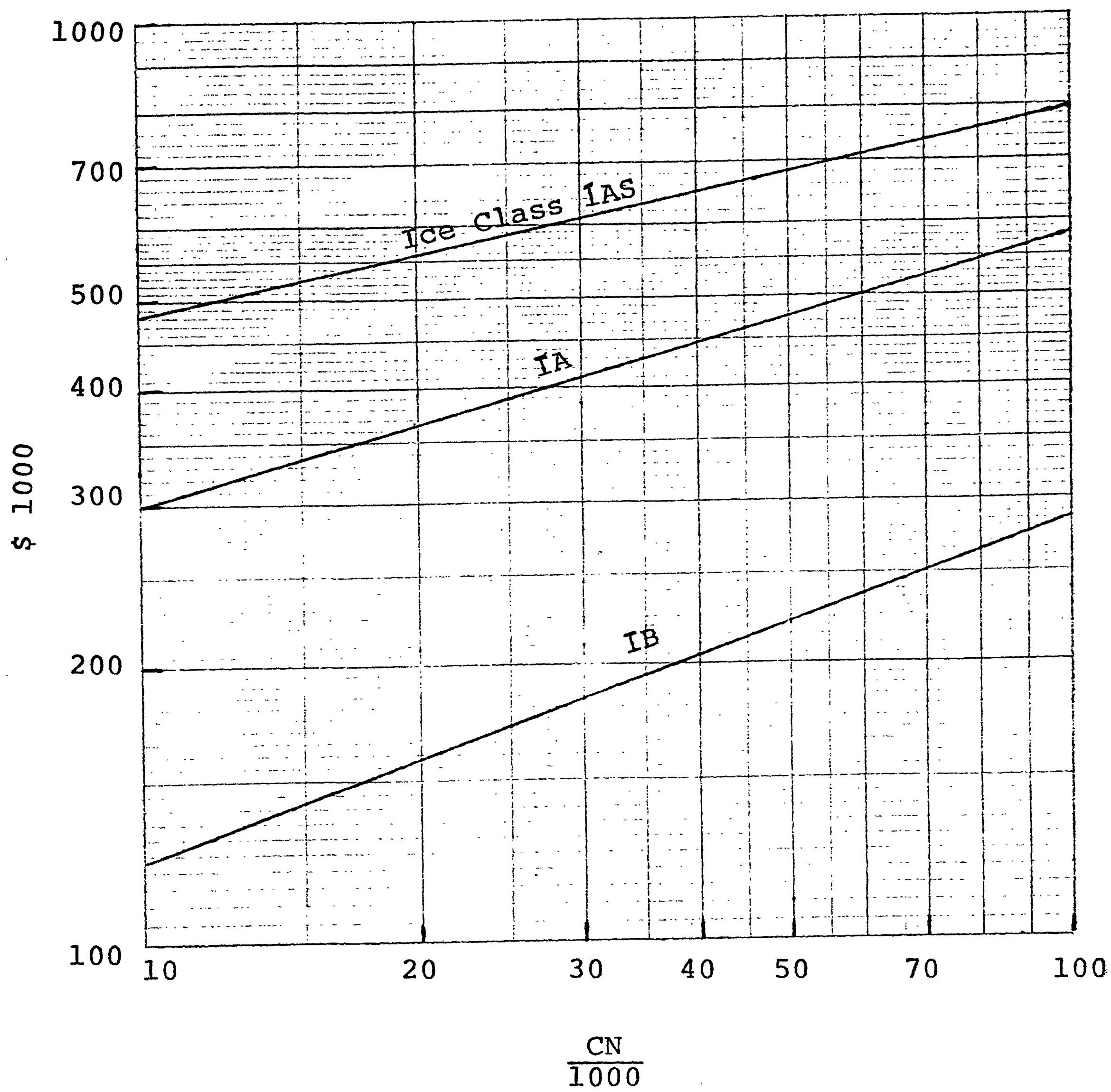


Figure 13: Cost of Structural Reinforcement for Conversions of Existing Ships

D. Operating Environment (Ice Conditions)

This section attempts to establish a convenient summary of the probable ice conditions that will be met in winter navigation. Ice survey statistics are still largely unavailable, few quantitative measurements having yet been made. This step in the overall procedure is one that will remain crude until extensive, methodical ice surveys are made over a period of years. As an interim step, intended only to illustrate the idea, we have asked Mr. Ernest Marshall to estimate the average ice conditions at various times of year on each of the major legs of the voyage between Two Harbors and South Chicago. His estimates are summarized in Tables 2 to 6. The values are based on data derived from aerial photographs and ice thickness measurements, the latter taken at shore stations rather than in way of the ship channels. This is only a rough stab, but it is the best that can be done at this time. Mr. Marshall's estimates apply to ice conditions during a winter of normal severity, which would occur in about 50% of the years during the life of a ship. Milder conditions and more severe conditions can be assumed to obtain with equal probability during the remaining 50% of the years. Means for assessing these variations are explained in section F (Annual Transport Capability).

A run from Escanaba to Indiana Harbor has also been added to the program repertoire. This involves a

TABLE 2

JANUARY 15 ICE CONDITIONS

BETWEEN TWO HARBORS AND SOUTH CHICAGO

Leg (see Frontispiece)	Total Distance (st. miles)	Class I (<70% ice cover)	Class II (70%-90% ice cover)					Class III (>90% ice cover)				
			Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes	Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes
1. W. end L. Superior	47	41						6	15	sheet	10	
2. W. basin L. Superior	137	137										
3. Central basin L. Superior	150	150										
4. Whitefish Bay	22	11	11	8	brash	20						
5. Upper St. Mary's	17	7						10	11	sheet	20	
6. Lower St. Mary's	49							49	11	sheet	20	
7. Upper L. Huron	33	33										
8. Straits	20	4						16	8		25	1
9. Upper L. Mich.	51	16	5	8		25	1	30	8		25	1
10. Island area	49	49										
11. N. basin L. Michigan	90	90										
12. S. basin L. Michigan	146	146										
Total	811	684	16					111				

Notes: See table 6

Table 2 January 15

TABLE 3

FEBRUARY 15 ICE CONDITIONS

BETWEEN TWO HARBORS AND SOUTH CHICAGO

Leg (see Frontispiece)	Total Distance (st. miles)	Class I (<70% ice cover)	Class II (70%-90% ice cover)					Class III (>90% ice cover)				
			Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes	Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes
1. W. end L. Superior	47	3	18	18	sheet	10	2	26	18	sheet	10	7
2. W. basin L. Superior	137	116	21	18	sheet	25	3					
3. Central basin L. Superior	150	150										
4. Whitefish Bay	22	4						18	18	sheet	20	8
5. Upper St. Mary's	17							17	18	sheet	20	9
6. Lower St. Mary's	49							49	18	sheet	20	9
7. Upper L. Huron	33		25	17		10	4	8	17		10	10
8. Straits	20							20	17		10	10
9. Upper L. Mich.	51		11	17		10	5	40	17		10	10
10. Island area	49	44	5	17	sheet	10	6					
11. N. basin L. Michigan	90	90										
12. S. basin L. Michigan	146	136						10	5	refr. brash	20	11
Total	811	543	80					188				

Notes: See Table 6

Table 3 February 15

TABLE 4

MARCH 15 ICE CONDITIONS

BETWEEN TWO HARBORS AND SOUTH CHICAGO

Leg (see Frontispiece)	Total Distance (st. miles)	Class I (<70% ice cover)	Class II (70%-90% ice cover)					Class III (>90% ice cover)				
			Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes	Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes
1. W. end L. Superior	47							47	18	sheet	32	13
2. W. basin L. Superior	137		137	18	sheet	32						
3. Central basin L. Superior	150	106	44	15	sheet	32						
4. Whitefish Bay	22							22	18	sheet	32	
5. Upper St. Mary's	17							17	15		32	14
6. Lower St. Mary's	49							49	15		32	
7. Upper L. Huron	33	20						13	15		30	15
8. Straits	20							20	15		30	
9. Upper L. Mich.	51							51	15		30	
10. Island area	49		25	12	sheet	30	12	24	12	sheet	30	16
11. N. basin L. Michigan	90	90										
12. S. basin L. Michigan	146	132						14	6	brash	32	17
Total	811	348	206					257				

Notes: See table 6

Table 4 March 15

TABLE 5

APRIL 1 ICE CONDITIONS

BETWEEN TWO HARBORS AND SOUTH CHICAGO

Leg (see Frontispiece)	Total Distance (st. miles)	Class I (<70% ice cover)	Class II (70%-90% ice cover)					Class III (>90% ice cover)				
			Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes	Distance (st. miles)	Thickness (inches)	Type	Temp (F)	Notes
1. W. end L. Superior	47	39						8	14	sheet	32	
2. W. basin L. Superior	137	98	39	14	sheet	32						
3. Central basin L. Superior	150	150										
4. Whitefish Bay	22	15						7	12	sheet	32	
5. Upper St. Mary's	17	6						11	12	sheet	32	
6. Lower St. Mary's	49	5						44	12	sheet	32	
7. Upper L. Huron	33	33										
8. Straits	20	5						15	8	sheet	32	
9. Upper L. Mich.	51	10	17	8	sheet	32		24	8	sheet	32	
10. Island area	49	49										
11. N. basin L. Michigan	90	90										
12. S. basin L. Michigan	146	140	6	6	brash	32						18
Total	811	640	62					109				

Notes: See table 6

Table 5 April 1

TABLE 6

NOTES FOR TABLES 2-5

1. Windrowed sheet ice plus 10 inches snow cover.
2. Snow cover 3 inches.
3. Snow cover 17 inches, snow ice 3 inches, lake ice 15 inches.
4. Refrozen brash and windrowed sheet ice; possible ridges.
5. Snow cover 7 inches, snow ice 6 inches, lake ice 11 inches.
6. Snow cover 10 inches, snow ice 8 inches, lake ice 9 inches.
7. Snow cover 3 inches.
8. Snow cover 6 inches, snow ice 6 inches, lake ice 12 inches.
9. Snow cover 6 inches, snow ice 6 inches, lake ice 12 inches.
10. Basic ice cover 17 inches with 7 inches of snow on 6 inches snow ice, and 11 inches lake ice. There will also be loose ice beneath. Pressure ridge may extend 20-30 feet downward. Windrows over about half the area.
11. No snow on ice.
12. Snow ice 5 inches, lake ice 7 inches.
13. 1 inch of snow.
14. Snow ice 6 inches, lake ice 9 inches.
15. Snow ice 5 inches, lake ice 10 inches. Windrows over about half the area.
16. Snow ice 5 inches, lake ice 7 inches.
17. Loose brash.
18. Possibly some delays due to brash close to shore and to packing.

round trip distance of about 576 statute miles. The voyage consists of two principal legs: The run up and down almost the full length of Lake Michigan, where open water can be found throughout the year except in a severe winter, and the generally icebound cut across Green Bay, a one-way distance of about 25 miles.

The ice data for this run are estimated on the basis of information by the Detroit Weather Bureau and from the Corps of Engineers ice maps. Several periods are not covered by the data, and the estimates had to be obtained by extrapolation. The estimated ice data for a normal winter are shown in Table 7. Leg 1 corresponds to the open water segment of the voyage, Leg 2 is in ice.

* * * * *

We must assume that ice conditions will present impassable barriers at various points and at different times following break-up of the ice cover in the spring. This condition will set physical upper limits on the length of the operating season that will vary with the overall weather conditions, the level of federal assistance, and the particular trade route. In general, however, the blockage time will seldom exceed the minimum two-week period required for annual overhaul and repair of ships, locks, and shoreside equipment.

Other environmental factors that must be considered in assessing schedules and risks include:

Pressure ridges
Winds

TABLE 7

ICE CONDITIONS BETWEEN ESCANABA AND INDIANA HARBOR DURING NORMAL WINTER

Period	Leg of Voyage	Round Trip Distance (miles)	Average Ice Thickness (in.)	Surface Coverage (%)	Temp. (°F)
Dec. 15	1 2	566 10	0 10	-- 100	25
Jan. 1	1 2	526 50	0 15	-- 100	15
Jan. 15	1 2	486 90	0 22	-- 100	10
Feb. 1	1 2	481 95	0 28	-- 100	10
Feb. 15	1 2	478 98	0 32	-- 100	15
March 1	1 2	476 100	0 34	-- 100	20
March 15	1 2	481 95	0 30	-- 100	30
April 1	1 2	521 55	0 20	-- 100	32

TABLE 8

FORCE COEFFICIENTS

Ship	e_1	e_2
24,000 HP icebreaker	1.9	3.13
12,000 HP icebreaker	2.17	3.40
J. Stalin	2.03	3.25
Ermak	2.41	3.52
Timber freighter	0.33	1.83
Timber freighter	0.54	2.28
Timber freighter	0.80	2.71
Far East cargo ship	0.41	2.34
Typical Great Lakes ore carrier	0.21	1.55

Note: Last line is derived from University of Michigan study; all others are from Shimanskij (10).

Long nights
Aids to navigation
Drifting ice (and risk of grounding any trapped ship)
Harbor ice and docking problems
Locks
Freezing spray
Density of traffic

These factors are not overlooked in the scheduling estimates presented in section F: Annual Transport Capability.

E. Speed and Power in Open Water and in Ice

The economic analysis of Great Lakes bulk carriers operating in an extended season requires reasonably facile, yet sufficiently accurate procedures for estimating speed and power in open water and in ice. These procedures must be adaptable to analyzing ships operating in diverse conditions of ice and ship loading. The same set of estimating relationships will be used whether the horsepower of the ship is given and the speed is to be found or vice versa.

1. Open Water

The resistance of Great Lakes bulk carriers in smooth, open water for the purpose of this study is estimated on the basis of a formula obtained by statistical regression of model test data. This regression analysis of a large set of available Great Lakes bulk carrier test data was performed in a separate study at the University of Michigan under sponsorship by R. A. Stearn, Inc. The results of this work have now been published.*

The estimate of the residuary resistance (C_R) in our computer program at present is derived from a version of the regression equation involving 64 terms at each of six speeds (Froude numbers between 0.11 and 0.16). For speeds below this range a linear extrapolation to the origin is carried out, for speeds above the range the extrapolation is quadratic.

In the meantime we have found a considerably simpler, but still reasonably accurate regression formula with only eleven terms, covering a range of Froude numbers from 0.11 to 0.18. This new formula will be substituted in the computer program shortly. Details are included in the previously cited reference.

The frictional resistance (C_F) is estimated from the ITTC line with a model ship correlation allowance (C_A) of 0.0002. The estimate of the shaft horsepower follows conventional practice using in part empirical relationships, in part the Wageningen propeller data.

Details of the power estimating procedure are given in Appendix II.

---

* Estimation of Great Lakes Bulk Carrier Resistance Based on Model Test Data Regression, by Swift, Nowacki, and Fischer, Great Lakes and Great Rivers Section, SNAME, October 4, 1972 (available from Department of Naval Architecture and Marine Engineering University of Michigan).

2. Speed and Power Constraints

Whenever regulatory speed limits exist, the program calculates the shaft horsepower requirement for the restricted speed. If shallow water is also indicated an appropriate correction is made.

In other instances a ship with a high ice classification may have a machinery installation whose full power cannot be economically exploited in open water. At present we assume that the full installed horsepower will nevertheless be used in open water. This is a weakness in our program that we shall correct in the next cycle of refinement.

3. Speed in Ice: Introduction

Estimating the powering requirements for Great Lakes bulk carriers operating in ice is a difficult task owing to the scarcity of full scale observations, model measurements, and theoretical foundations.

A semi-empirical method of power estimation was developed in the initial phase of the present study. At that stage the only available, pertinent evidence consisted of some observations in the Baltic fleets and voyage records taken from a few Great Lakes ships during the 1970-71 extended season. However, this information was crude and meager so that we had to resort to unproven, theoretical considerations to estimate the parametric influences of hull shape, power plant and propulsion system, as well as ice condition.

Most of the theoretical information had to be drawn from studies for different ship types and operating conditions and had to be adapted to the Great Lakes environment. This was done by calibrating the estimating formulas derived from the icebreaking literature against a few rough full scale observations of the icebreaking performance of Great Lakes ships.

The whole approach was permeated with crudities, but in the initial phase of our work was a necessary compromise due to the almost complete lack of ice powering information for Great Lakes ships. Meanwhile a series of model test results for Great Lakes bulk carriers has become available from programs sponsored by the Maritime Administration at the Wärtsilä and the ARCTEC ice basins. The former deals with ice resistance in sheet ice, the latter with the resistance through broken ice in channels. New formulas for ice powering estimates based on these model data will be introduced in the computer program shortly.

4. Resistance in Sheet Ice

The performance of a ship in solid, virgin sheet ice represents an important reference base since it is defined precisely enough to be amenable to experimental and theoretical study, even though it may not be the dominant operating mode in ice in a well planned operation with ships like bulk carriers. However, it may well be the determining factor as to when a ship without escort comes to a stop.

II: DETAILED ANALYTICAL METHODS

Theoretical data on sheet ice resistance were available to us firstly from the Russian ice literature, notably the results based on Shimanskij's and Kashteljan's work. This work dealt with icebreakers and to some extent with arctic cargo ships, References (10) and (11).

Secondly, we had access to the ice resistance information published by Lewis, Edwards, Melberg and other U. S. Coast Guard investigators, References (12), (13), who had extended and improved the Russian work, largely in application to icebreakers. No specific theoretical or experimental evidence for Great Lakes ship forms was available to us at the initial stage.

We, therefore, devised a semi-empirical ice resistance formula which was closely akin to the Russian and the U. S. Coast Guard approach, but lent itself to being adapted to Great Lakes observations. We did not have the pertinent data to follow the Russian or Coast Guard procedure in full without further empirical reference points. For this purpose we used the performance limits of Great Lakes ships in ice observed in the extended season of 1970-71.

The following formula was used for the total resistance of a ship moving through solid sheet ice (all in metric tons):

$$R_{ice} = R_1 + R_2 + R_3 + R_4 \qquad [18]$$

where:

R_1 = icebreaking resistance, corresponding to work done in breaking the ice.

R_2 = resistance due to submergence of broken ice, turning the broken ice, and other effects proportional to the weight of the broken ice.

R_3 = resistance due to cleaning broken ice out of the channel laterally by accelerative forces.

R_4 = water resistance, friction and wave-making, computed as if ice were not present.

Further, according to Kashteljan

$$R_1 = k_1 B m_o s h \qquad [19]$$

$$R_2 = k_2 B m_o g_i h^2 \qquad [20]$$

and

$$R_3 = k_3 B^{k_4} \frac{hV}{e_2} \qquad [21]$$

where the k coefficients have the values shown below (derived from model and full-scale tests on the Russian icebreaker <u>Ermak</u>):

$k_1 = 0.004$

$k_2 = 3.6$

$k_3 = 0.25$

$k_4 = 1.65$

and where

B = ship beam in meters

m_o = Kashteljan's vertical ice force

coefficient (a function of bow shape). See comments below.

s = ice strength in metric tons per square meter

h = ice thickness in meters

g_i = specific weight of ice in metric tons per cubic meter

v = ship speed in meters per second

e_2 = Shimanskij's lateral ice pressure coefficient. See Table 8, page 41.

Kashteljan's vertical ice force coefficient, m_o, is intended as a measure of hull form efficiency in generating vertical forces. However, his definition

$$m_o = 1 + \frac{1}{e_1}, \qquad [22]$$

in which e_1 represents Shimanskij's vertical ice pressure coefficient (Table 8), is not suited to measuring the icebreaking effectiveness of a blunt bow as in a bulk carrier where the ice failure mechanism is not exclusively vertical bending.

It was therefore decided to treat the factor m_o in Kashteljan's equation as an empirical constant, renaming it as m, which had to be determined from observation of the ice performance of Great Lakes ships. At zero speed, for the limiting sheet ice thickness a ship can break:

$$R_3 = R_4 = 0 \qquad [23]$$

and

$$R_1 + R_2 = T\ (1 - t), \qquad [24]$$

i.e. the maximum available thrust, adjusted for thrust deduction effects, equals the zero speed ice resistance. For a given power plant and propeller the available bollard thrust can be calculated, and for the observed limiting ice thickness being broken by this ship the empirical constant m can be found by equating

$$R_1 + R_2 = mB\ (k_1 sh + k_2 g_i h^2) = T\ (1 - t) \qquad [25]$$

At the present time we conclude from observations taken aboard the ore carriers of the U.S. Steel fleet, AAA class, during the last two winters that these vessels cannot under normal full power conditions break regular sheet ice thicker than 18 inches. From these values one can derive

$$m = 0.669 \qquad [26]$$

In summary, we adopted as a tentative ice resistance formula for a bulk carrier moving through solid sheet ice

$$R_{ice} = R_1 + R_2 + R_3 + R_4 \qquad [27]$$

with

$$R_1 = k_1 sBhm = 0.004sBhm \qquad [28]$$

$$R_2 = k_2 g_i Bh^2 m = 3.6\ g_i Bh^2 m \qquad [29]$$

$$R_3 = K_3 B^{k4} \frac{hV}{e_2} = 0.25B^{1.65} \frac{hV}{1.55} \qquad [30]$$

$$R_4 = \text{open water resistance}$$

These relationships are currently under thorough revision and will be eventually replaced by power estimates based on Wärtsilä model test data for Great Lakes ships that have become available.

5. Resistance in Broken Ice

The complex physical process of a ship moving through broken ice in the track of an icebreaker or another vessel or through open pack ice has been studied by numerous authors (11, 14-19).

In the absence of any specific test data for Great Lakes ships, Bronnikov's (18) approach to estimating the resistance of cargo ships going through pack ice appears to be best suited for the present purpose. Bronnikov proposes an equation expressing the pure ice resistance in terms of the parametric influences of ice condition and principal ship characteristics:

$$R_{ip} = \left(R_{ip}\right)_o \left(\frac{D}{D_o}\right)^s \left(\frac{h}{h_o}\right)^m \left(\frac{S}{S_o}\right)^n \left(\frac{T}{T_o}\right)^p \left(\frac{(L/B)_o}{L/B}\right)^q \left(\frac{C_{Bo}}{C_B}\right)^r \left(\frac{(B_1/B)_o}{B_1/B}\right)^k \qquad [31]$$

where the subscript zero denotes a standard arctic cargo ship that was tested by Bronnikov, and the quantities without subscript are for the actual ship in question.

All quantitites are in metric units and are defined as follows:

R_{ip} = pure ice resistance, metric tons

D = displacement, metric tons

h = ice thickness, meters

S = ice state, surface coverage in percent

T = draft of vessel, meters

L = length of vessel, meters

B = beam of vessel, meters

C_B = block coefficient

B_1 = width of channel or lead in pack ice, meters.

The pure ice resistance of the standard reference vessel, $(R_{ip})_o$, was originally given in Bronnikov's article for an arctic cargo vessel. However, since new data directly applicable to Great Lakes ships operating in broken ice channels have become available from model tests performed by ARCTEC, Inc. for a model of the S.S. Ryerson, it was preferred to substitute the results for this vessel as the basic reference case in the Bronnikov formula. The use of the formula for other Great Lakes ships is supported by a much closer reference point that way.

The ARCTEC test data for the Ryerson were approximated by

$$(R_{ip})_o = h(50 + 146.2\ V)/2205. \qquad [32]$$

where

h = ice thickness, inches

V = ship speed, knots

Since this expression already allows for the influence of ice thickness, the corresponding term, $(h/ho)^m$, must be omitted from equation [31] in this context.

The following data belong to the new standard case:

D_o = 33600 tons

S_o = state 8 = 0.8

T_o = 8.08 meters

$(L/B)_o$ = 9.5

C_{Bo} = 0.864

$(B_1/B)_o$ = 1.5

Bronnikov found the values of the exponents for his ice resistance equation from model tests as,

$$s = 0.753\ F_n^{0.278} \qquad [33]$$

$$m = 0.308\ F_n^{-0.61} \qquad [34]$$

$$n = 0.79\ F_n^{-0.49} \qquad [35]$$

$$p = 1.759\ F_n^{0.75} + 0.35 \qquad [36]$$

$$q = 2.5\ F_n^{0.455} - 0.60 \qquad [37]$$

$$r = 38.36\ F_n^{2.356} + 1.25 \qquad [38]$$

$$k = 0.039\ F_n^{-1.24} \qquad [39]$$

The values of D, h, t, L/B, will be derived from the actual ice conditions and bulk carrier characteristics.

The surface coverage and width of channel ratio in the track of an icebreaker or other bulk carrier may be reasonably estimated as

$$S = 0.8$$

$$B_1/B = 1.5$$

This summarizes the relationships for the estimation of broken ice resistance presently in use.

6. Practical Considerations

To this point we have proposed rational methods for estimating the speed of Great Lakes bulk carriers in sheet ice and in channels cut through the ice. Our methods are derived from work done principally in connection with Baltic operations. Baltic ice is relatively stable, being generally anchored by the many islands of that region. On the Great Lakes, however, there are few islands and the ice is therefore less well behaved. It is likely to drift, giving alternately the advantages of open water and the disadvantages of jams in constricted areas. Drifting ice under the influence of strong winds is also an obvious impediment to navigation. Under those conditions available theoretically derived methods are anything but satisfactory. Pending later development of some more rational approach to this problem, we propose to divide the sailing distance, D, through partially ice-covered waters into two components:

$$D = D_i + D_W$$

in which

D_i = distance through equivalent sheet ice

and

D_w = distance in open water

We reason that the proportional distance that the ship must move through ice will be less than the fraction of ice coverage. Often the wind will carry the ice althogether clear of the ship's course, or the course can be modified to take advantage of open passages. Further, smaller blocks of ice, while adding to the fraction of ice cover, are easily broken or simply pushed aside and so do not contribute their theoretical share to the total resistance. In recognition of these considerations, we propose to estimate the equivalent distance through sheet ice as follows:

$$D_i = DS^3$$

where

S = fractional ice coverage in the region under consideration

Furthermore, in recognition of course modifications, as well as time lost in building up speed in open water, we propose an arbitrary increase of 10% in the open water distance.

F. Annual Transport Capability

1. Key Factors

In estimating the annual transport capability of any proposed Great Lakes ship, we must recognize variations in three important factors. The first is the time required per round trip -- which will be essentially uniform on any given route until ice begins to form, and will then progressively increase. Second is the changing cargo capacity per trip as a function of the freeboard requirements. The third factor, of course, is the length of the operating season. Variations due to fluctuating lake levels will be specifically ignored because they will have no real impact on the matter under study. We assume, too, that the designer has recognized channel depths in selecting his design drafts. (That is, the operator will always be free to load his ship to the load line appropriate to the season.)

2. Freeboard Seasons

The statutory freeboard seasons are as follows:

April 16-30: Intermediate (I)
May 1-September 15: Midsummer (MS)
September 16-30: Summer (S)
October 1-31: Intermediate (I)
November 1-April 15: Winter (W) or (I)

Recent research has led to a tentative relaxation of the freeboard rules, permitting application of the intermediate loadline during the winter months. Nevertheless, to be conservative, we shall assume the use of the winter draft from November 1 to April 15. The analytical procedure will be kept flexible, however, permitting either choice.

3. Combined Influence of Schedule and Trip Capacity

Figure 14 shows how the annual transport capacity is affected by the three previously mentioned factors.

As a matter of convenience, we have arbitrarily set the start of the navigating season at April 16 throughout this study. We assume, too, that extensions of the operating season will apply to delayed lay-up rather than early starts. This is logical because the worst ice conditions usually obtain in early spring. There is nothing in our analytical procedure, however, that would prevent the use of other assumptions.

We have stopped our analysis one-half month shy of year-round navigation. Ships, locks and shore cargo gear all need periodic overhauls. We assume the majority of that work would be done just before the start of the new operating season, that is, at the end of March or early in April.

4. Proforma Ice-Free Round-Trip Time

The time required for a normal (ice-free) round trip can best be found by estimating the time needed for each of several discrete segments of the voyage. These are:

a. Time at full speed, loaded
b. Time at full speed, ballast

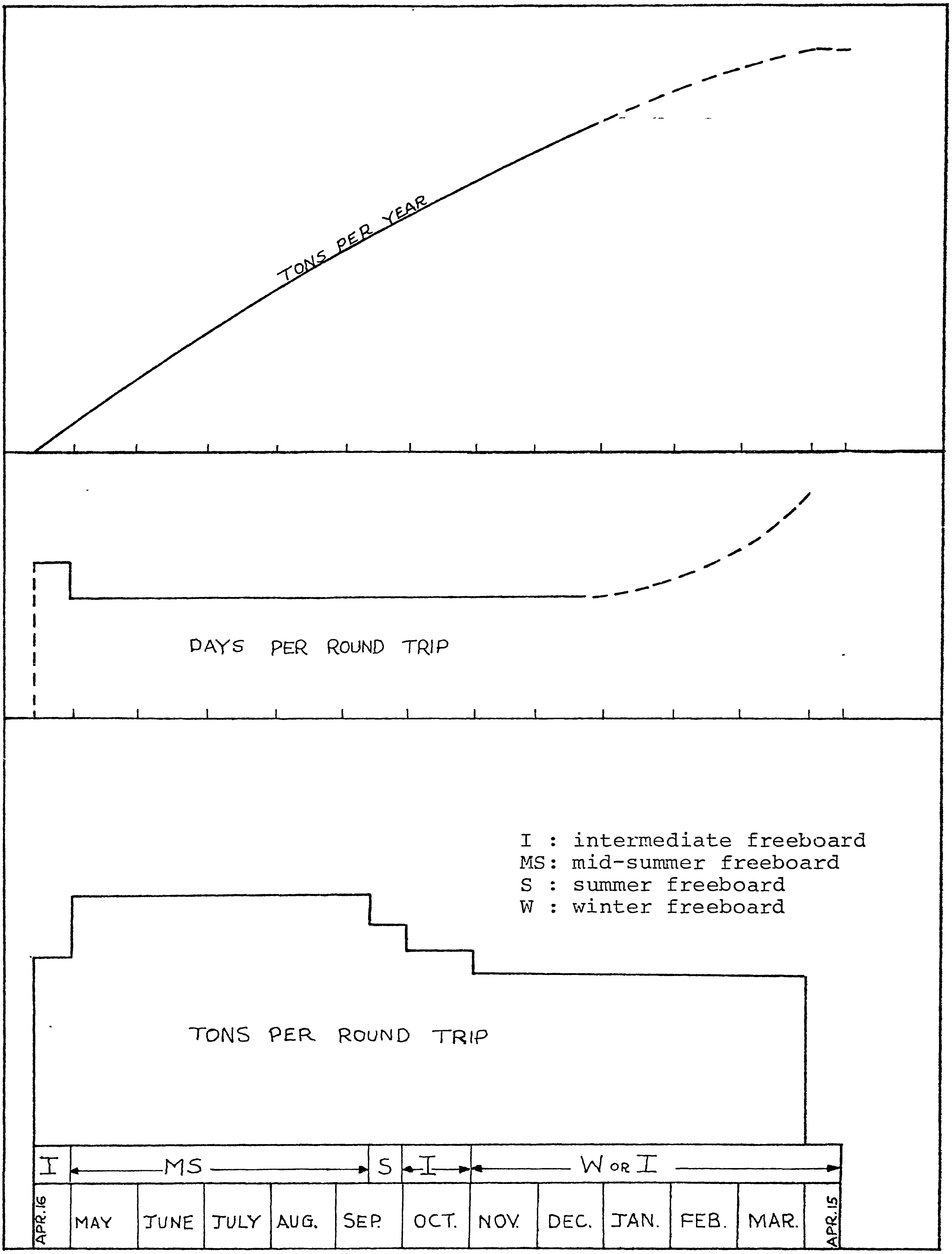


Figure 14: Influence of Cargo Capacity and Round Trip Time on Annual Transport Capacity

c. Time in speed-restricted waters
d. Loading time
e. Unloading time
f. Docking and undocking time
g. Time in lock passage
h. Waiting (queuing) time at locks and docks
i. Weather delays

The following assumptions can be made:

a. The open-water ballast speed will be 6% greater than the loaded speed at full power.

b. The ship will average 10 mph in all speed-restricted waters.

c. The loading and unloading rates will vary considerably between different ships and different ports, and will therefore be treated as input variables. Rates used should be adjusted in recognition of time lost during shifting, adjusting gear, etc. The average rate will be only about 85% of the maximum continuous rate.

d. Docking and undocking time in hours per round trip will equal $0.5\ (L/100)^{0.5}$

e. Locking through the Soo will require 3 hours per round trip.

f. Queuing delays will average 5 hours per round trip if passage through the Soo is required, otherwise 4 hours.

Alternative assumptions can of course be made to suit specific circumstances.

While estimating the voyage time requirements, we can also find the fuel consumption per round trip and the required weight of fuel on board at the loading port. This information will be needed at a later step in the analysis.

5. Proforma Winter Schedule

The delays during the winter shipping season depend to a significant extent on the level of icebreaker support available to shipping and other factors in the operational scenario on the Great Lakes. We are in the process of generalizing our model to allow a greater variety of possible scenarios to be investigated.

For the time being in trying to obtain a description of the past winter we have modified the winter delay assumptions as shown in Tables 9 and 10. These assumptions are consistent with current icebreaker escorting practice. For the Lake Superior through Lake Michigan voyage we assume that there will be one icebreaker stationed in each of the two critical icebound areas: the Straits of Mackinac and the St Mary's River - Whitefish Bay. We assume that the ship will purposely

TABLE 10

ADDED DELAY TIMES IN NORMAL WINTER WEATHER FOR ESCANABA TO INDIANA HARBOR ROUTE

PART 1: Delays in hours per round trip

Cause of Delay	Date: Dec 15	Jan 1	Jan 15	Feb 1	Feb 15	Mar 1	Mar 15	Apr 1
Loading Time	0	1	1	1	1	1	1	0
Unloading Time	0	1	1	1	1	1	1	0
Locks	0	0	0	0	0	0	0	0
Docking and Undocking	0	1	1	1	1	1	1	1
Weather	2	2	2	2	2	2	1	1

PART 2: Delays due to ship getting beset in ice, in hours per occurrence

Cause of Delay	Date: Dec 15	Jan 1	Jan 15	Feb 1	Feb 15	Mar 1	Mar 15	Apr 1
Waiting for Ice-breaker	2	3	3	3	3	3	3	2

For mild winters: Reduce total delay time by 33%.

For severe winter: Increase total delay time by 50%.

stop and wait for icebreaker support whenever its unescorted speed drops to 4 mph. After that, we assume the ship will be escorted through the entire critical area, generally in a convoy. The same sequence of events may subsequently occur again on the same voyage as the ship enters the second of the two critical areas mentioned above. Average convoy speed is fixed at 5 mph for the time being. The waiting delays in Table 9 were estimated on the assumption that the icebreaker on the average will be near the other end of the icebound area and will be assisting another convoy moving in the opposite direction. The logistics of the operation can probably be greatly improved over this pattern, but as the traffic gets denser this would be partially offset by other delays.

For the Escanaba voyage we assume that a cutter or icebreaker would be stationed in the Green Bay area, and that the operation of waiting for icebreaking assistance, forming convoys, etc. would follow a pattern similar to that described above. However, because of the shorter distance through ice the delays will be smaller.

6. Trip Capacity

Turning next to the cargo capacity per trip, we start with the summer loadline condition and modify that value to suit other freeboard and fuel weight requirements.

The cargo capacity at the summer loadline, C_S, is found in the usual way:

$$C_S = DW - Q$$

where

DW = deadweight at summer loadline (see section B)

and

Q = miscellaneous deadweight items, largely fuel

Note: All weights are in long tons.

For purposes of this analysis, the weight of the miscellaneous deadweight items is taken as the weight of fuel required for a one-way trip, plus a margin of 50% from April 15 to December 14 and 100% from December 15 to April 14. All other variable weights (i.e., fresh water, stores, supplies, and fuel for miscellaneous services and self-unloading) will add another 150 long tons. (In the case of diesel machinery, the weight of lubricating oil is taken as part of the light ship.)

The weight of bunkers required for a one-way trip and the fuel consumed per round trip are both based on the SHP-hr figures derived from the scheduling analysis outlined in the preceding paragraphs. For new steam plants with 1450G - 950F reheat cycles, the daily fuel consumption, in long tons, at full power will be close to $4(\frac{SHP}{1000}) + 8$. The corresponding figure for intermediate speed geared diesels burning blended oil will be $3.8\ (\frac{BHP}{1000}) + 4$. When operating at reduced powers (as when in speed-restricted areas), the specific fuel consumption will increase according to these ratios:

Percent of Maximum Power	Relative Fuel Consumption per SHP - hr	
	Steam	Diesel
100	1.000	1.000
90	1.007	1.014
80	1.025	1.028
70	1.051	1.042
60	1.089	1.056
50	1.143	1.070

All of the above figures apply to the main propulsion unit alone. Incremental consumption for auxiliaries, hotel services, etc. are discussed in section G, Operating Costs.

7. Seasonal Variations

As discussed in section C, we must recognize that winter weather conditions will be unusually mild or unusually severe during some years. We have assumed that such extremes will each occur during about 25% of the years over the life of the ship. We shall further assume, pending development of data, that the ice cover and ice thickness during mild seasons will be only two-thirds of the figures applicable to normal seasons. Similarly, during severe seasons, the ice cover and thickness will be 50% greater than normal.

Of course the ice cover percentage in any given area will never exceed 100%.

8. Recapitulation

In summary, the estimate of annual transport capability requires:

a. A proforma voyage analysis representing a typical voyage during the ice-free season. This will determine time requirements, bunker weight, and fuel consumption.

b. Individual proforma voyage analyses appropriate to each of several key dates during the winter season.

c. Calculation of cargo capacities per trip as a function of changing freeboard seasons and bunker requirements.

d. Summary calculations leading to the annual transport capability attainable during various lengths of operating season.

G. Operating Costs

Operating cost estimates are based on 1971 conditions and dollar values. We have specifically ignored inflation. If all prices rise together, a recognition of inflation will have no appreciable effect on design decisions (20). If some elements of cost are expected to rise faster than others, the relative increase of that particular element may deserve recognition. For this particular investigation, however, we feel there is little to gain from such complexities.

1. Fuel

Current average cost levels on the Lakes are about $30 per long ton for No. 6 fuel oil (bunker C) suitable for steam propulsion and $33.50 per long ton for No. 4 oil (blended) suitable for medium-speed diesels.

Section F outlines a procedure for estimating propulsion plant fuel requirements per voyage and per year. These should be increased by about 2% for steam plants and 1% for diesels for fuel burned during idle status. Further additions for the hotel and miscellaneous services can be estimated as follows:

Service	Pounds Fuel per Hour
Domestic	85
Heating or cooling	85
Auxiliary machinery	80
Total	250

With self-unloaders, add 0.12 pound of fuel per ton of cargo handled during the year.

2. Wages and Benefits

During the normal 8-month operating season, the daily cost for crew wages including benefits, can be taken as \$380 + \$46 per crew member. For 8 months, the total becomes:

$$C_W = \$92{,}500 + \$11{,}200\ K \qquad [41]$$

where

K = number in crew

As ships are operated into the winter season, daily crew costs may well tend to increase. This could result from bonus wages, from crew rotation plans, or from combinations thereof. For purposes of this study, we tentatively assume a 15% increase in daily crew costs after December 15. (This is not to be interpreted as a recommended wage policy, but only as a guess about the future.) The costs would then be:

$$\$\text{per day} = 440 + 53K \qquad [42]$$

$$\$\text{per month} = 13{,}400 + 1630K \qquad [43]$$

3. <u>Subsistence</u>

Average subsistence costs can be taken as \$2.70 per man-day, or \$82.50 per man-month.

4. <u>P & I Insurance</u>

Protection and indemnity insurance rates will be influenced by these factors: crew size, ship size, and length of season. During the regular season, we can estimate the monthly P & I cost as:

$$\text{P \& I per month} = \$11K + \$8.4\ \frac{CN}{1000} \qquad [44]$$

where

K = number in crew

CN = cubic number

During the winter months, we shall tentatively assign a 25% increase in the cost of P & I insurance.

5. H & M Insurance

Hull and machinery insurance is a critical factor in evaluating the economics of winter operation. To begin with, we can estimate the normal season costs as follows:

$$\text{H \& M per month} = \$1000 + \frac{P}{1000} \qquad [45]$$

where

P = initial investment in the case of a new design or the resale value in the case of an existing ship (or book value, if preferred).

Based on experience gained to date in winter operations on the Lakes, plus knowledge of insurance costs for Baltic winter operations, we propose using the foregoing relationship, equation 45, for operations between April 16 and January 16. After January 16 we propose the increased costs shown in Figure 15. These correspond to:

$$\text{Annual cost of H \& M} = M(\$1000 + \frac{P}{1000})\ (a)^{M-9} \qquad [46]$$

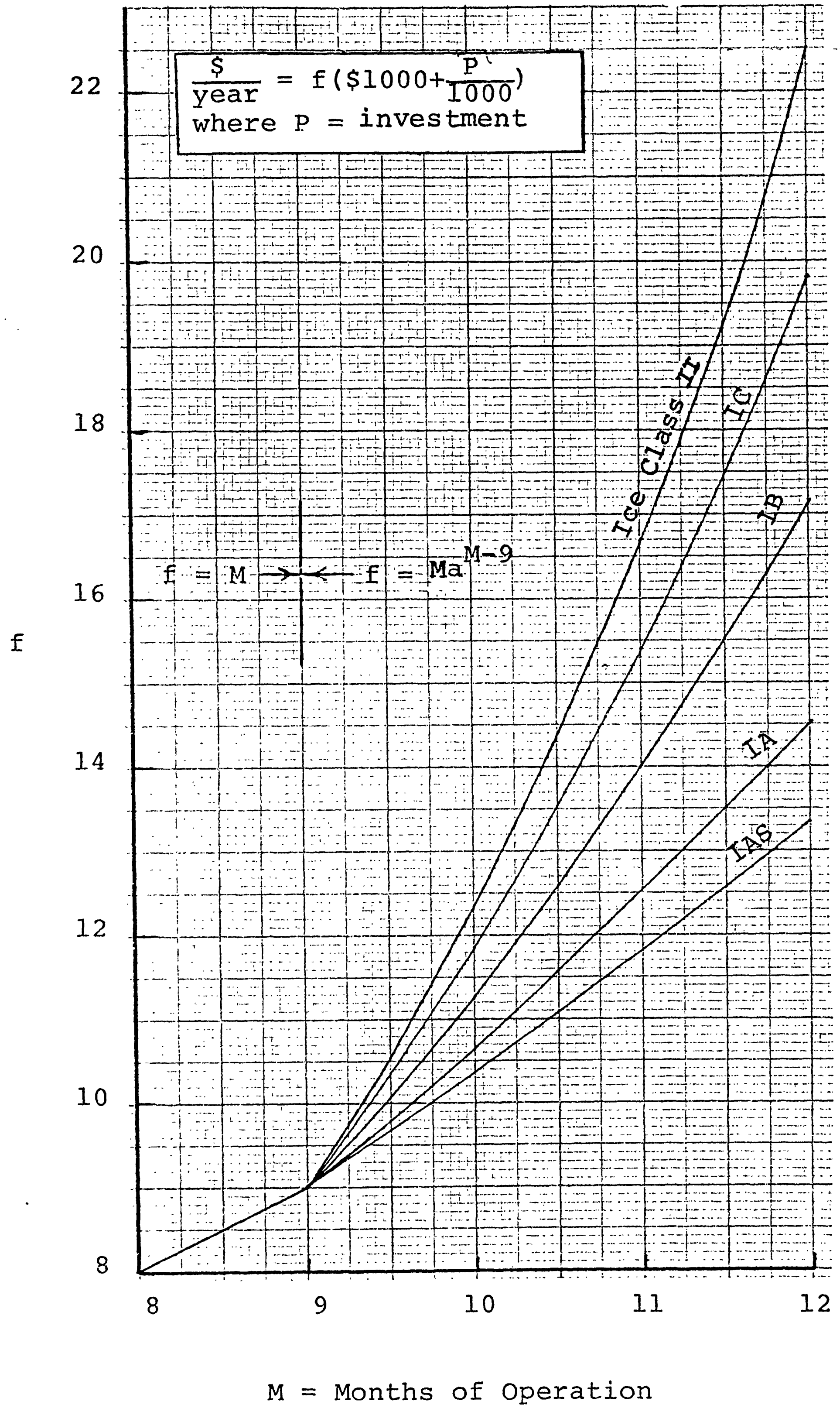


Figure 15: Cost Factors for Hull and Machinery Insurance (Eqn, 45 and 46)

where

$$M = \text{months of operation per year}$$

and

$$a = \begin{array}{l} 1.234 \text{ for ice class II} \\ 1.184 \text{ for ice class IC} \\ 1.129 \text{ for ice class IB} \\ 1.068 \text{ for ice class IA} \\ 1.039 \text{ for ice class IA super} \end{array}$$

These figures imply that a ship operating on a 12-month basis (i.e. a 50% increase in length of season) would experience a 150% increase in costs of H & M insurance -- based on an unstrengthened hull (Ice Class IC). The contour labeled Ice Class II is meaningless in the present context for reasons already discussed.

Let us illustrate with an example. Assume a class IB ship with a first cost of $12 million operating for 11 months. If there were no winter weather problems, the annual cost of H & M insurance would be:

$$11(\$1000 + \$12{,}000) = \$143{,}000$$

Recognizing added winter risks, however, the annual cost becomes:

$$\begin{aligned} & 11(\$1000 + \$12{,}000)1.129^{11-9} \\ &= (\$143{,}000)1.129^{2} \\ &= (\$143{,}000)1.276 = \$182{,}000 \end{aligned}$$

6. Maintenance & Repair

Figures 16 and 17 show trends for the total cost of maintenance and repair during the normal season. Contours

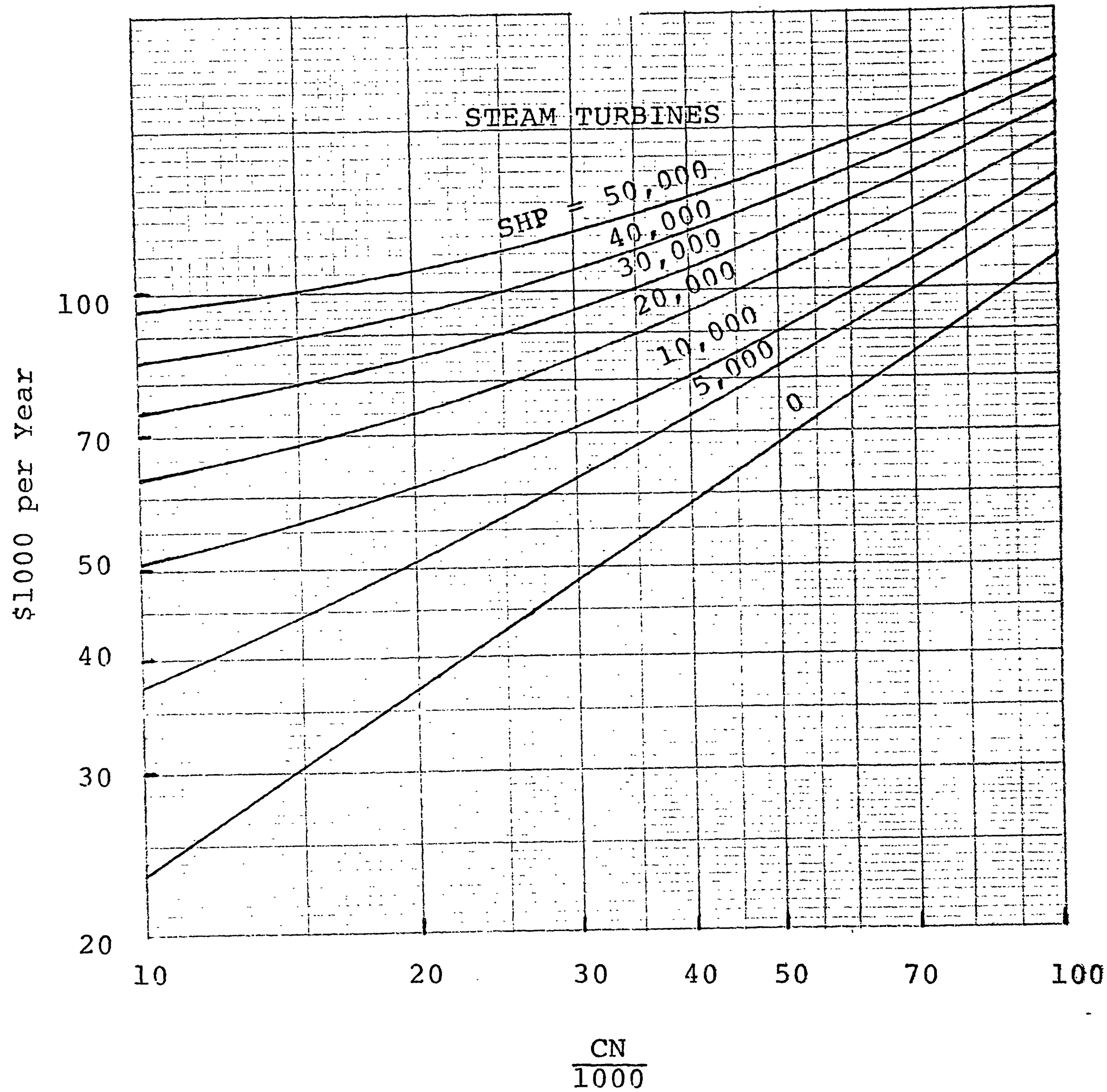


Figure 16: Annual Costs of Maintenance and Repair for 8-Month Season, Steam Turbine Machinery. Add $50,000 for Self-unloaders.
(Eqn. 47)

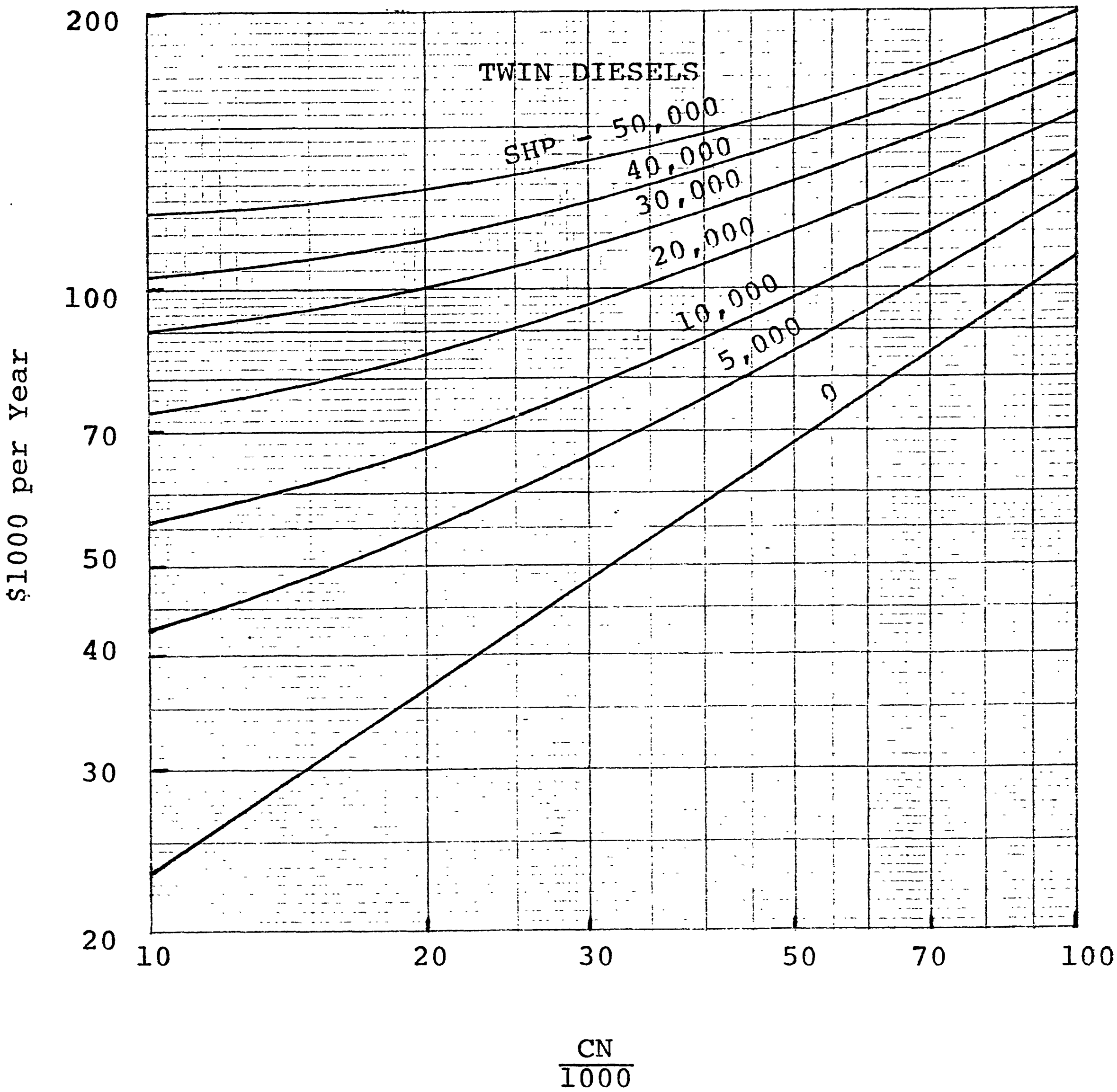


Figure 17: Annual Costs of Maintenance and Repair for 8-Month Season, Twin Diesel Machinery. Add $50,000 for Self-unloaders. (Eqn. 47)

are based on:

$$M \& R = \$5000 \left(\frac{CN}{1000}\right)^{2/3} + f_1\left(\frac{SHP}{1000}\right)^{2/3} + Z \qquad [47]$$

where

CN = cubic number

$f_1 \doteq \$6600$ for diesel plants
$= \$5000$ for steam plants

and

$Z = 0$ for bulkers
$\$50,000$ for self-unloaders

Experience may well prove that ice-strengthened hulls will have considerably lowered costs for maintenance and repair incurred during the normal season. For now, however, we shall ignore that potential benefit.

Until further experience is gained in winter operations, we propose that total annual M & R costs be handled according to the following:

$$M \& R \doteq \frac{M}{8}\left\{(a)^{M-9}\left[\$5000\left(\frac{CN}{1000}\right)^{2/3} + f_1\left(\frac{SHP}{1000}\right)^{2/3}\right] + Z\right\} \qquad [48]$$

where a has the same values shown under H & M insurance (equation 46).

The relative severity of the winter season will have its influence on M & R costs. The figures cited above are intended to represent average values. Figure

18 shows the above expression in graphical form. As before, the contour labeled Ice Class II is meaningless in the present context.

7. Towing

During the normal season, towing costs per round trip can be estimated as follows:

$$\text{Cost per round trip} = a \frac{LB}{1000} \qquad [49]$$

where

$$a = \$13.50 \text{ for ships without bow thrusters}$$
$$= \$4 \text{ for ships with bow thrusters}$$

During the winter months, more tug service will be required. We estimate the increases would average 50% of the figures shown above, that is:

$$a = \$20.25 \text{ for ships without bow thrusters}$$
$$= \$6 \text{ for ships with bow thrusters}$$

8. Stores and Supplies

The monthly cost of stores and supplies is a function of two principal factors: ship size and crew size. There will be little if any increase in monthly cost for winter operation. We propose the following relationship as being valid for any length of operating season:

Monthly cost of stores and supplies

$$= \$50 \left(\frac{CN}{1000}\right) + \$37 \,(K-10) \qquad [50]$$

where

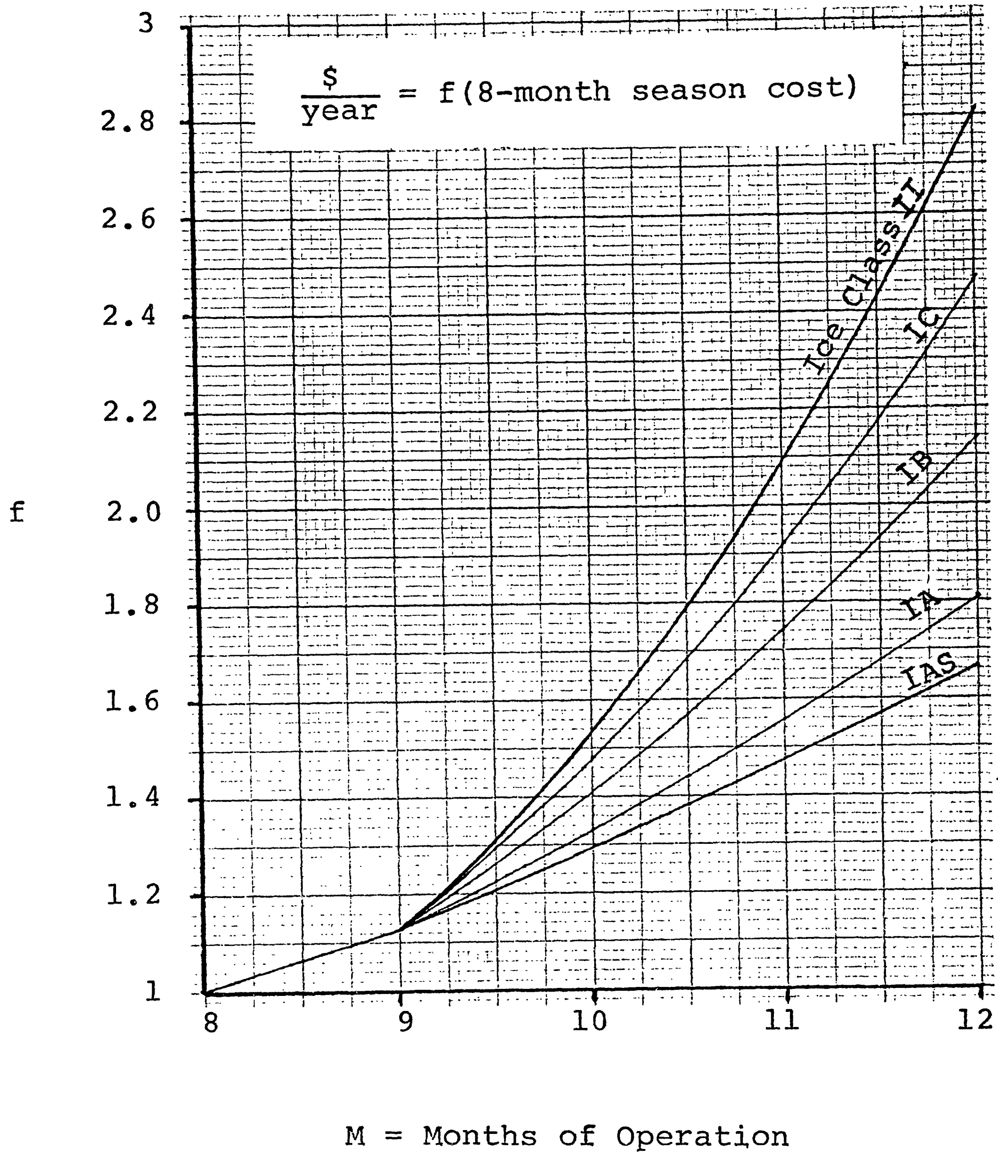


Figure 18: Factors for Increasing Annual Costs of Maintenance and Repair with Extended Season.

Add $6250 per month of extended season for self-unloaders.

K = number of men in crew

These figures include cost of lubricating oil in the case of steam driven ships. For diesel installations, the cost of lube oil should be added. The quantity used can be taken as 0.5% of the fuel burned, by weight. The average cost is about $0.12 per pound.

9. Winter Lay-up

There are three main factors to consider in estimating the cost of winter lay-up: the lay-up cost itself, the cost of wharfage and winter watch force, and the cost of fitting out in the spring. Since the total cost is relatively small, we shall simply set it at $75,000 regardless of ship size.

As winter operations approach the year-round maximum, the lay-up operation will involve mooring a live ship rather than a dead one. Wharfage costs will be less, but there will be a skeleton crew on board. We suggest the following scale of costs:

Months of Operation	Cost
up to 10	$75,000
11	$25,000
11.5	$10,000

10. Overhead & Miscellaneous

The overhead and miscellaneous category is one that is difficult to analyze. Some costs should vary with ship size, and some with length of operating season. Most, however, will remain fixed regardless of those factors. We propose the following:

$$\text{Overhead cost per year} = \$50{,}000 + \$2000M + \$1250\left(\frac{CN}{1000}\right) \quad [51]$$

where

M = operating months per year

11. Summary

The ten cost categories above constitute the entire annual operating cost of the ship. (Annual costs of capital recovery are included elsewhere.) Total figures should be found for normal, mild, and severe winters. Total costs arrived at should not be interpreted as predictions of absolute costs for any given ship or owner, but only as indicators of industry-wide trends. They are intended mainly to express realistically the dependence of costs on operating schemes and design variables.

H. Measures of Merit

In selecting a measure of merit we must consider the circumstances involved as well as what use we intend to make of the number once we find it. In a typical season, as winter approaches, a shipowner will have to decide how long to keep his ship operating. If there is plenty of cargo to carry, he need only ask himself if the income from each added voyage exceeds the incremental costs of providing that added service.* As long as the answer is yes, he should keep his ship going and thereby increase his company's profits.

In this study we are faced with a more difficult circumstance than that sketched above. We are dealing with imaginary ships or imaginary modifications to existing ships. Our aim is to examine the economics of alternative investments (i.e., ships varying in degrees of ice strengthening) and to find for each the relative profitability that would result from different lengths of operating season. The big difference here is that the investment is no longer a fixed amount and capital costs must be factored into our measure of merit. Moreover, we cannot confine our analysis to the added costs and added incomes of each winter voyage. The different degrees of ice strengthening will produce changes in speed and cargo capacity that will affect cash flows throughout the year. Each alternative must be assessed on its total annual merits, not on any shortcut method of cost differences incurred during an extended season. Any of our proposed criteria can be applied to existing ships as well as to ships that are still in the design stage. In the former case, any degree of ice strengthening conversion can be considered, including leaving the ship unchanged (essentially Ice Class IC).

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*If the shipowner is carrying cargo for a parent corporation, income can be taken as equal to the cost that would have been charged by an independent operator providing the same service.

Each criterion involves an initial investment, P. How that value is found depends on the status of the ship. If still in design stage, P is simply the estimated shipyard bill, which can be found as explained in Chapter IIC. For existing ships, P is the estimated net resale value, which the owner should provide as an initial input to the computation. If the existing hull is to be reinforced to a higher ice class, the resulting costs (Figure 13) should be added to the net resale value.

Where an owner is considering an investment in ice reinforcement for an existing ship, he may base his economic analysis on the resulting differences in cash flow. That is, he can treat the conversion cost as his investment and balance it against the increased future cash flow that would result. Any of our recommended criteria can be applied to such a cash flow pattern.

A difficult complication arises because the new tax deferral plan applies only to new investments. Thus, if an owner chooses to reinforce an existing ship, he could presumably exploit the tax-deferral privileges only to the extent of the investment in ice reinforcement. This, however, would have much less impact than would be true with new construction. Until the mechanics of the new law are more completely established, we must recognize that accurate assessment is impossible.

Without engaging in a discussion of their relative virtues, we propose three different measures of merit: (a) required freight rate, (b) net present value, and (c) yield. These are explained below.

II: DETAILED ANALYTICAL METHODS

1. Required Freight Rate

The required freight rate, RFR, is the unit cost an owner must charge his customer if the owner is to earn a reasonable interest rate of return (i.e., yield) on his investment. The alternative that promises the lowest RFR is presumably the one that is ideal for the trade.

The RFR criterion may seem out of place in a steel corporation's fleet. It is logical, nevertheless, because each subsidiary division of a corporation should justify its investments on a basis of contributing its share to the corporation's overall profits.

Where the annual transport capability is essentially constant year after year, the required freight rate takes the following form:

$$RFR = \frac{(CR)P + Y}{C} \qquad [52]$$

where

CR = capital recovery factor
P = initial investment
Y = annual operating costs
C = annual transport capacity

The capital recovery factor, CR, merits discussion. It is the factor by which the initial investment is multiplied in order to find the annual cost of capital recovery. The latter comprises the owner's stipulated yield (return of investment plus profit) and the corporate income tax. The numerical value is a function of those two factors and many others -- among which the new tax deferral privilege looms large. See appendix I.

For new construction, a before-tax capital recovery factor of 11% appears to be a generally suitable figure. For existing ships, the figure should be higher for two reasons: the remaining economic life will be shorter and the impact of the corporate income tax will be higher. (Existing ships do not qualify for tax-deferral privileges and may already be fully depreciated for tax purposes.) For any given set of circumstances, appropriate values of the capital recovery factor can be established using standard procedures [21]. As a first approximation, a before-tax factor of about 20% might be appropriate for a ship with 20 years of economic life remaining.

In our further studies, we plan to put all cash flows on an after-tax basis and so avoid the inaccuracies implicit in the methods discussed above.

Some ship owners are interested in finding the unit cost of service. This they define as the annual cost of operation plus annual straight line depreciation based on a 20-year life, all divided by the annual transport capability in long tons.

2. Net Present Value

The net present value, NPV, of an investment is found by discounting all future annual cash flows, both positive and negative, to "time zero," which is usually the time when cash begins to flow as a result of the decision. The discount factors are based on the timing of the cash flows and the owner's stipulated minimum acceptable interest rate. Because of the complexities of the tax laws, the cash flow pattern is also complex (even if we assume uniform annual returns before tax). These difficulties can be handled by methods developed in appendix I. They require many assumptions as to bank loan arrangements, depreciation plans, etc. Because of these considerations, we recommend the use of a simplified NPV procedure. The final numerical outcome, while slightly inaccurate, will nevertheless give reliable indication of the relative merits of alternative proposals.

The approach we recommend makes two major simplifying assumptions: (a) the investment is made in a single amount at "time zero," (b) an interest rate of 10% applied to the uniform before-tax returns will be equivalent to a rate of 9% applied to the non-uniform after-tax returns. (Appendix I shows why this difference is so small.)

Given the above assumptions, the expression for net present value becomes

$$NPV = (SPW - 10\% - N)A - P \qquad [53]$$

where

$(SPW - 10\% - N)$ = series present worth factor for 10% interest and a ship life of N years

= 9.425 for a 30-year life

$= 9.775$ for a 40-year life

$= 9.911$ for a 50-year life

A = annual return before tax

$= Cr - Y$

where

C = annual transport capacity

r = freight rate

Y = annual operating costs

The net present value criterion can be criticized because it is fundamentally biased in favor of large projects or over-design. Since investment funds are usually limited, finding NPV per dollar invested is a logical way of overcoming that bias. This leads to the net present value index, NPVI $(= \frac{NPV}{P})$. Net present value should not be used when comparing alternatives that have different expected lives. The same is true of NPVI and capital recovery factor.

In the case of existing ships, the effect of the corporate income tax will be more pronounced than would be true for new construction. This can be recognized in various ways. The simplest way would be to inflate the interest rate used to discound future cash flows. Whereas we suggest 10% for new construction, 18% might be more appropriate for an existing ship. For a ship with 20 years of life remaining, the net present value would be:

$$NPV = 4.87A - P \qquad [53A]$$

where

A = annual return before tax

P = net resale value at time of analysis

Given the assumptions of single investments and uniform returns, NPVI is exactly equivalent to the yield as a measure of merit. That is, it will rank alternatives in exactly the same order. This is explained in (20). This leads us, then, to our final measure of merit, explained below.

3. Yield

Yield is also called discounted cash flow rate of return, equivalent interest rate of return, internally generated interest rate, etc. It is simply the interest rate that makes the net present value of investment and returns equal to zero. In complex cash flows it can be found only by trial-and-error. Given the assumptions made in finding NPV, however, we can easily simplify the task. We need only find the predicted capital recovery factor, CR, and then convert that figure to its corresponding interest rate:

$$CR = \frac{A}{P} \qquad [54]$$

All terms are as defined in the preceding paragraphs. The interest rate can be found from curves, as in (21) or from interest tables.

In the above procedure, note that we are deriving before-tax interest rates. The alternative promising highest yield before tax will also promise highest yield after tax, as long as all alternatives have equal lives. Going further, if we recognize that capital recovery factors and interest rates are near-linear in relationship, we can eliminate the final, awkward step in the calculation and use CR as a surrogate for yield. CR will, in short, put the various alternatives in the same ranking as would yield, given our usual assumptions as to uniform returns and equal lives.

I. Synthesis

A. Handling Annual Variations

The foregoing sections have explained proposed methods for systematically estimating the costs and benefits that may be expected from alternative ship designs and length of operating season. In each case, we come up with three numerical values for any selected measure of merit: one for normal winter weather conditions, one for mild conditions, and one for severe conditions. The intent of this section is to propose a rational method for integrating these differing results.

Our proposed method is based on the reasonable assumption that a shipowner will want to operate his ship longer in mild winters than in severe winters. We assume then that he will choose a length of operating season that would in each case correspond to the optimum value of whatever measure of merit he chooses to use. For example, suppose that the required freight values for a class IA design on a given trade route are as follows:

		Closing Date				
Weather Condition	Probability	Dec 15	Jan 15	Feb 15	Mar 15	April 15
Mild	25%	$2.00	1.95	1.90	1.85*	1.90
Normal	50%	$2.00	1.97	1.95*	1.98	2.05
Severe	25%	$2.00	1.98*	2.00	2.05	2.15

*Minimum value for assumed winter condition

Note: Values shown are arbitrary and are only for purposes of illustration.

In comparing this design with its alternatives, we would use the weighted average (expected) value of the required freight rate based on the probabilities of mild, normal, and severe winters. In this particular case, the expected value would be:

$$\begin{aligned} RFR &= 0.25\$1.85 + 0.50\$1.95 + 0.25\$1.98 \\ &= \$0.4625 + \$0.975 + \$0.495 = \$1.9325 \\ &\qquad \text{say } \$1.93 \end{aligned}$$

This approach accords with the general policy that an owner would naturally follow. That is, he keeps on operating his ship until the out-of-pocket costs for one more voyage equal or exceed the income to be derived from that voyage. That will lead to maximum profit for the year. Since the investment is a fixed amount for a ship already built, maximum profit then also means minimum total cost per ton carried.

B. Income

In using either net present value or yield as a criterion, we need to use current freight rates to convert annual transport capacity to annual gross revenue. Current freight rates* (based on docks suitable for drafts over 23 feet and with unloading times under 24 hours) are as follows:

Head of Lakes to Lower Lakes: $2.43 per long ton

Marquette to Lower Lakes: $2.02 per long ton

Escanaba to Lake Erie or Detroit: $1.69 per long ton

Escanaba to Lake Michigan: $1.35 per long ton

The rates shown above are exclusive of cargo off-loading. Current dock charges are $0.76 per long ton for unloading into a rail car or $1.02 per long ton for unloading into a stockpile. We suggest that the former figure be used for self-unloaders with shuttle conveyors and the latter for self-unloaders with boom conveyors.

C. Macro-Economics

A typical shipowner will have old, inefficient ships as well as newer, more economical units in his fleet. Winter operation with the newer ships will allow him to dispose of his less economical ships at an earlier date. Alternatively, he may simply put the older ships into idle status until business picks up or disposal values rise. These are complexities to which this study report can be applied to suit individual circumstances.

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* Rates shown are subject to individual negotiation and change.

III. COMPUTER PROGRAM

A complete analysis of extended season economics is too cumbersome to be made manually for more than a limited number of alternative proposals. We have therefore developed a computer program derived from the analytical procedure explained in chapter II. The program is flexible and can be readily modified to suit individual requirements as to ship design, cargo, trade route, and preferred measure of merit. Such requirements are fed into the computer, along with appropriate assumptions as to delay times, freight rates, interest rates, etc. The computer does the necessary calculations and prints out the estimated value of the three measures of merit for the standard 8-month season, for 8.5 months, 9 months, 9.5 months, etc. through 11.5 months. It also indicates derived values of various key parameters such as hull form coefficients, a breakdown of weights and costs, and round trips per season.

The computer program is written in Fortran IV and a typical run costs around $1.50 on the University's IBM model 360/67 computer.

Chapter II section E mentions two alternatives to estimating speed and power in open water: Krappinger's approximation (7) and a more rigorous method recently developed by Nowacki and others under a grant from R.A. Stearn, Inc. The latter approach is used in the program.

The rest of this chapter specifies the necessary inputs, outlines the major implied assumptions and explains how to interpret the outputs.

A. Inputs

The inputs presuppose a notional or preliminary design of a ship generally suited to the intended trade route requirements. Alternatively, an existing ship may be the subject of analysis. The following specifications are required (and shown here in the sequence recorded in the print-out).

1. Trade Route

Each trade route requires its own sub-routine recognizing differences in distances through ice, ice conditions, delays in ice, ice temperature, etc. The only data prepared to date are those for the trade route between Two Harbors, Minnesota, and South Chicago. Other trade routes can be analyzed when data become available.

2. Cargo

Any kind of cargo can be assumed. Some will be more difficult to handle in the winter, however.

3. Ship Status

The program needs to be instructed as to whether it is analyzing a proposed ship or an existing one.

4. Ice Class

The Finnish ice class number must be given. Class IC indicates an ordinary, unstrengthened Great Lakes bulk carrier.

5. Winter Weather Conditions

The alternative weather condition inputs are:

Mild
Normal
Severe

6. Principal Dimension

The follwoing dimensions must be given:

Length between perpendiculars
Beam
Depth
Draft at summer load line

7. Block Coefficient

The block coefficient must be given. If the midship coefficient is known it can be used as an input, otherwise a value of 0.993 is assumed.

8. Speed and Power

In new designs the service speed in open water at summer draft should be specified. The computer will find the required SHP. It can also work in the opposite direction but at slightly added cost.

In existing ships, both speed and SHP are presumably known. Both should be used as inputs.

9. Machinery Type

The type of machinery must be given. Machinery code 1 indicates a conventional single screw geared steam turbine plant. Code 2 indicates a conventional single screw twin geared diesel plant.

10. Propeller Type

A code 1 propeller indicates fixed blades; code 2 indicates controllable pitch.

11. Self-Unloader

Code 0 indicates no self-unloading capability. Code 1 indicates a self-unloader.

12. Conveyor Type

A code 1 conveyor indicates a boom installation; code 2 indicates a shuttle conveyor.

13. <u>Cargo Handling Speed</u>

Any loading and unloading rates can be used as inputs.

<u>Note</u>: The unloading rate used as an input should recognize that the theoretical rate will seldom be reached in practice. We suggest the nominal rate be reduced by 15%

14. <u>Bow Thruster</u>

The code 0 indicates no bow thruster. Code 1 indicates the installation of a thruster.

15. <u>Number in Crew</u>

The program will accept any number in the crew complement.

16. <u>Delays</u>

Queuing delays will vary from port to port and with general level of activity. As average figures, we suggest 4 hours per round trip if no canal locks are involved, or 5 hours if passage through the Soo is required. The program will accept any figure, however, and this input can be used to recognize other delays not explicitly covered elsewhere. (Note: delays in ice <u>are</u> covered elsewhere.)

17. Economic Factors

The program computes three measures of merit: net present value, capital recovery factor (as a surrogate for yield) and required freight rate. For net present value, the discount rate (before tax) should be specified, as should the freight rate and economic life in years. For capital recovery factor, the freight rate must be specified. For required freight rate, the capital recovery factor (before tax) will be needed. For existing ships, an approximate book value must be given.

B: Implicit Assumptions

In its present form, the program contains several assumptions that should be widely applicable to bulk carriers on the Great Lakes. If the user wants to modify any of them, however, that can be done with small trouble. Most of the assumptions can be inferred from reading through chapter II. Indeed, we urge that the program not be used without prior knowledge of the procedures explained in that chapter.

The key assumptions of the program are the following:

1. Ships are U. S.-built and operated.
2. Ships are conventionally arranged Great Lakes type bulk carriers with only moderate degree of automation.
3. Hulls are constructed largely of mild steel.
4. Ships are fitted with single screw propulsion systems.

5. Steam plants burn residual fuel oil; diesel plants burn blended oil.
6. We have used a modest scenario with respect to federal assistance and level of traffic. See section II F 5 for details. In brief, the present assumptions are close to today's reality, but are pessimistic with respect to what we expect within the foreseeable future.

In addition to the above, there are many assumptions regarding building and operating costs, and ice conditions, together with speed and delays in ice, that are critically important to the projected economics. These assumptions are stated in detail in chapter II. It is particularly important to note that the assumed ice conditions, speed in ice, and delays in ice are necessarily little better than guesses at this stage. Obviously, then, no strong reliance should be placed on the numerical results until reliable data are gathered and incorporated into the program.

Appendix IV shows the flow diagram for the computer program.

C. Output

The computer program can be modified to print out any figure used in the computation. We have selected a few key items and these are clearly indicated in the typical print-out sheets reproduced for the sample study described next.

TABLE 11

Ship Identification	AAA	Proposed Self-Unloader
Status	Existing	Proposed
LBP	647'	825'
B	70'	105'
D	36.0'	51.5'
T_{des}	25.5	26.0
DWT	19,860	43,140
SHP	7,000	18,000-24,000
Machinery	Steam	Diesel
Unloading	Shore cranes	Boom-type conveyor
Crew	38	24
Cargo	Iron ore pellets	Iron ore pellets
Winter Weather	Normal	Normal

D. Sample Study

The results of three new sample studies are presented, pertaining to the two ships described in Table 11. (The AAA ship is analyzed on two voyages, the other on one.)

The ship denoted as AAA class is similar to the ore carrier Philip R. Clarke and its sister ships, which were operating in the extended season the last two winters. The proposed self-unloader represents a new, modern design.

Sample Case 1

In the first new example, a AAA ship is analyzed for an extended season operation between Two Harbors and South Chicago in a winter of normal severity. The principal results are presented in Figure 19. The dashed lines correspond to the ship as it exists without any modifications (class IC). The solid lines are for a ship converted to the highest ice class IAS.

In interpreting the results we must keep in mind that the measures of merit according to their definition and the data sets used reflect different corporate goals and may lead to somewhat different conclusions. The following formulas and assumptions were used.

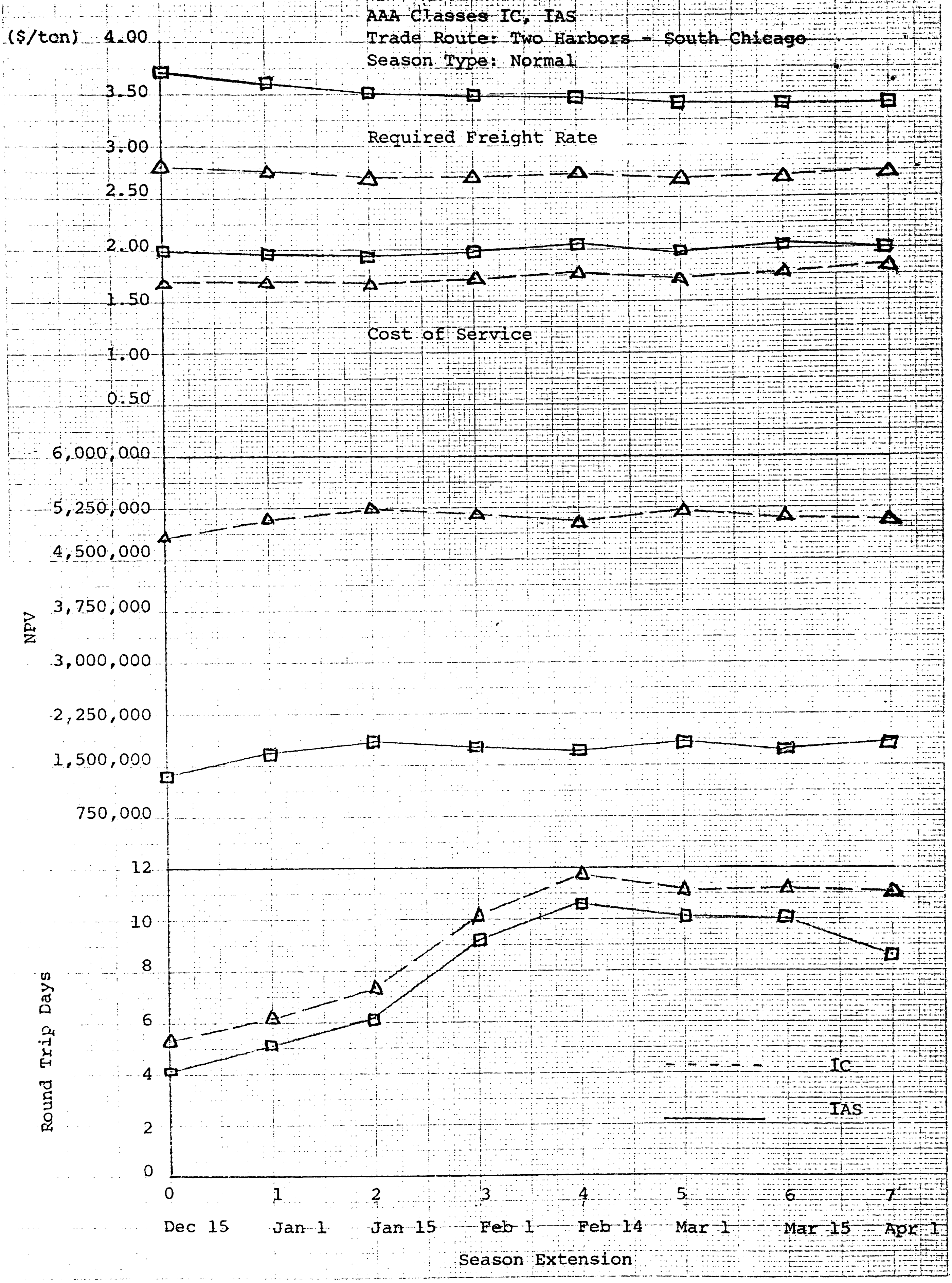


Figure 19: Measures of Merit and Round Trip Days, Sample Case 1.

III: COMPUTER PROGRAM

Required Freight Rate:

$$RFR = \frac{(CR)P + Y}{C}$$

where

SHIP	INVESTMENT, P =	LIFE (YRS)	INTEREST RATE
Existing ship (IC)	resale value	40	i
Conversion	resale value & conversion cost	40	i, i_T
New design	new construction cost	40	i_T

i = interest rate before tax = 20 percent

i_T = interest rate under tax deferral privilege = 11 percent

In the event of a conversion the tax deferral interest rate is applied to the conversion cost.

Cost of Service:

$$COS = \frac{P/N + Y}{C}$$

where P,Y,C as before, and N = 20 years

Net Present Value:

$$NPV = (SPW)\ (Cr - Y) - P$$

where: C, Y as before
r = $2.35 per L.T. of iron ore pellets, Two Harbors to South Chicago

SHIP	INVESTMENT, P =	LIFE (YRS)	INTEREST RATE
Existing ship (IC)	Zero	40	18%
Conversion	Cost of conversion	40	10%
New design	New construction cost	40	11%

In summary, it is important to understand that the three different measures of merit imply different levels of freight revenue and hence profitability. Cost of service is for zero interest, required freight rate for a reasonably attractive target interest, and net present value for an intermediate interest level implied by the market freight rates.

The trend in RFR is favorable for an extension of the season, while NPV and COS show rather neutral tendencies in the present sample. This means freight rates have to be at least as high as the present levels to make the season extension more than marginally attractive in this instance.

The existing ship (class IC) fares better than the conversion (class IAS), whatever the measure of merit, since the round trip time savings do not compensate for the extra investments. Incidentally, the voyage times for AAA, class IC, ships are in good agreement with those observed last winter through the closing date in early February.

Sample Case 2

Figure 20 presents the results for the case of a proposed 43,000 DWT self-unloader, conceived as a large, modern ship. It is assumed to operate on the same route under the same conditions as in the previous sample.

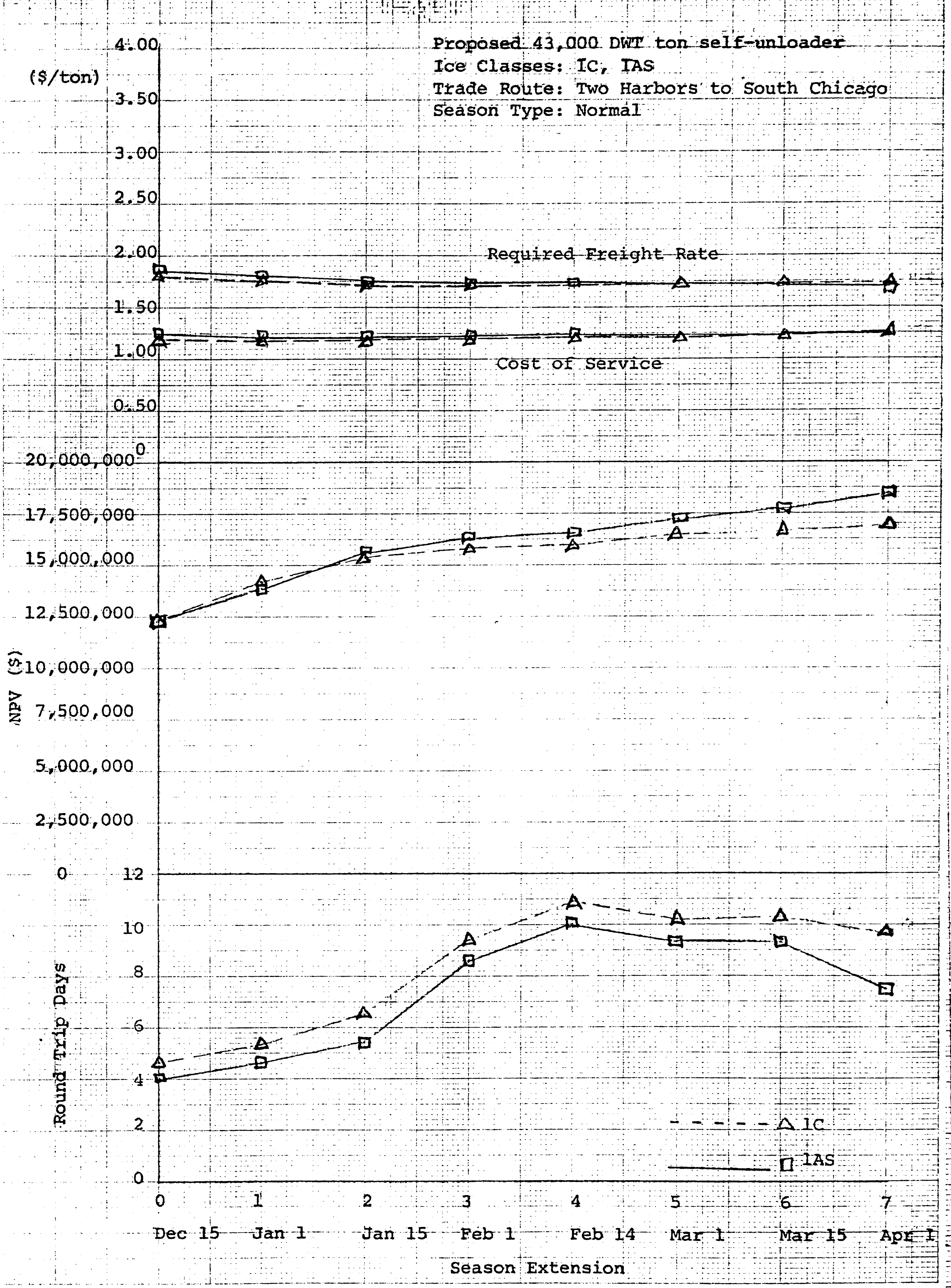


Figure 20: Measures of Merit and Round Trip Days, Sample Case 2.

The results demonstrate above all the economic advantages of increased size and capacity, and lead to considerably lower levels of cost of service and required freight rate. This makes these ships very competitive relative to current freight rate levels so that an extension of the season also becomes much more attractive. The increasing trend in NPV reflects this ability of the ships to earn more money as the season is lengthened.

The difference in investment cost levels between IC and IAS ice class standards is no longer too essential, and the higher technology ship does indeed look slightly superior.

Sample Case 3

On the Escanaba-Indiana Harbor run ice is concentrated in a relatively short stretch of Green Bay, and the ships operate predominantly in open water. A breaker or cutter is stationed near Escanaba, and the ice delays occurring there are only mild. The actual freight rate is $1.35 for this run at present.

Since current freight rates are barely above the cost of service, an extension of the season does not look attractive, Figure 21, COS and NPV. If summer operations were more profitable, say at the RFR level, a lengthened season would also look favorable.

The clement ice conditions prevent any ice adaptation of the ships from becoming economically attractive. In

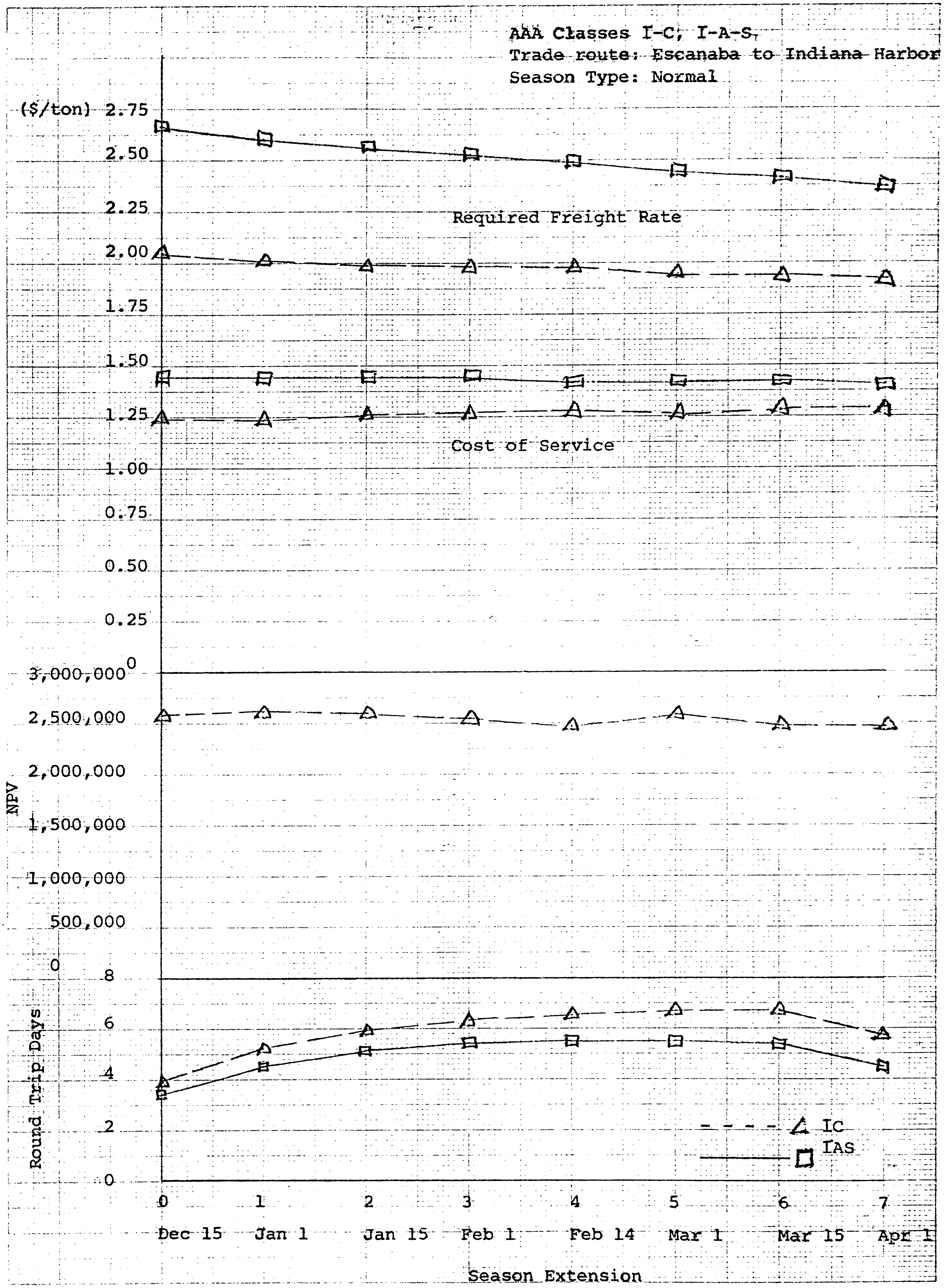


Figure 21: Measures of Merit and Round Trip Days, Sample Case 3.

fact, the NPV for the IAS class ship (converted AAA) is negative, and the curve is not shown.

IV. PRELIMINARY CONCLUSIONS

The results discussed in the previous section must still be interpreted cautiously since further work in validating the analysis model is still in progress, and the sample cases give a picture that is far from systematic and complete.

However, the trends observed in these samples suggest that for existing ships with present ice technology an extended season is just marginally attractive provided that the present level of icebreaking and escorting support is maintained.

On a fleet-wide basis, however, the extended season allows the more profitable ships to be fully exploited, at the expense of the older, less profitable vessels. Our analysis does not include these and similar benefits to the overall corporate activity.

Major ice adaptation of the ships in strength and power does not seem to pay off for the present scenario. But many minor measures of ship adaptation, especially in hull shape modification, have yet to be explored. For newly constructed, modern and more profitable ships, our tentative findings definitely support a longer season and a more advanced level of ice technology in the ships.

IV: PRELIMINARY CONCLUSIONS

The further work in progress now is aimed at substantiating these findings by a more systematic look at different scenarios, ice adaptation levels, trade routes and commodities.

APPENDIX I

THE NEW TAX LAW AND ITS EFFECT ON THE ANNUAL COST OF CAPITAL RECOVERY

The new U.S. merchant marine act contains special tax treatment for owners of U.S.-flag ships operating on the Great Lakes. In effect, corporate income taxes will be waived on any earnings that are set aside for the eventual construction of replacement tonnage. Payments on shipbuilding loans will be treated in like fashion. Many key details of the act have not yet been interpreted. Nevertheless, we may reasonably expect that a shipowner who allocates all of his operating profits to the construction fund or to repay a bank loan, will pay no income taxes during the initial years of operation of a new ship. This tax-free status will presumably continue until the cumulative amount deposited equals the initial investment. If financing is through a long-term bank loan, the years required to build the fund up to its limit may approach the useful life of the ship.

Under the new law, then, shipowners will be able to make important reductions in their annual costs of capital recovery. This will result in lower costs of transport on the Great Lakes. It will also stimulate marginal investments aimed at producing future marginal returns. In other words, under the new law, the added costs of making ships ice-worthy will be more easily justified by the added incomes to be produced in future years.

We can analyze the impact of this new tax treatment by assuming a uniform level of before-tax returns (A dollars per year), and then determining the after-tax returns (A') both with and without the special tax treatment. The task is complicated because the tax exemptions are not uniform over the life of the ship;

depreciation plans, depreciable life, and interest paid on loans will all modify the relative values of the returns before and after tax.

We have purposely omitted consideration of President Nixon's proposed first-year 5% investment tax credit. If the proposal is adopted, it would strongly encourage bigger investments. That, in turn, would tend to favor increased levels of ice strengthening. See (20) for details on handling the tax credit.

I. ANALYSIS UNDER PREVIOUS TAX PLAN

Let us look first at the general situation before the new law went into effect. We shall make a number of standard simplifying assumptions:

1. The investment (P) is made in a single payment upon delivery of the ship.
2. The annual before-tax returns (A) are uniform throughout the economic life of the ship (N).
3. A portion of the investment is financed from the owner's equity capital, the rest through a bank loan (P_B) payable in uniform annual amounts (A_B) at annual interest rate (i_B) over a period of H years.
4. The tax rate is t%, the depreciation period for taxes is Q years, and straightline depreciation is used with zero disposal value.

We shall assume, further, that the bank loan period (H) is shorter than the economic life of the ship (N) but longer than the tax life (Q). Actually, the latter assumption is not important; the final result comes out the same whether H is longer or shorter than Q (22).

Given all of these assumptions, we can show how the tax varies during each of the significant time periods shown in figure A1. This will allow us to relate returns before and after tax, because

$$A' = A - \text{tax} \qquad [A1]$$

We shall analyze the three time periods in reverse order, putting the simplest first. In period 3 there are no tax shields and the entire before-tax return is subject to tax:

$$\text{Tax} = tA$$

$$A' = A - \text{Tax} = A - tA = A(1 - t) \qquad [A2]$$

During period 2, the annual interest (I_B) paid on the bank loan is exempt from tax. This amount varies from year to year, but we shall make one more simplifying step and treat I_B as uniform and equal to the average annual amount.

$$I_B = A_B - \frac{P_B}{H}$$

$$I_B = (CR - i_B - H)P_B - \frac{P_B}{H}$$

$$I_B = P_B\left[(CR - i_B - H) - \frac{1}{H}\right] \qquad [A3]$$

Keeping this equation in mind, let us look at how I_B affects the tax:

$$\text{Taxable income} = A - I_B$$

$$\text{Tax} = t(A - I_B)$$

$$A' = A - \text{Tax} = A - t(A - I_B)$$

$$= A - tA + tI_B$$

$$= A(1 - t) + tI_B \qquad [A4]$$

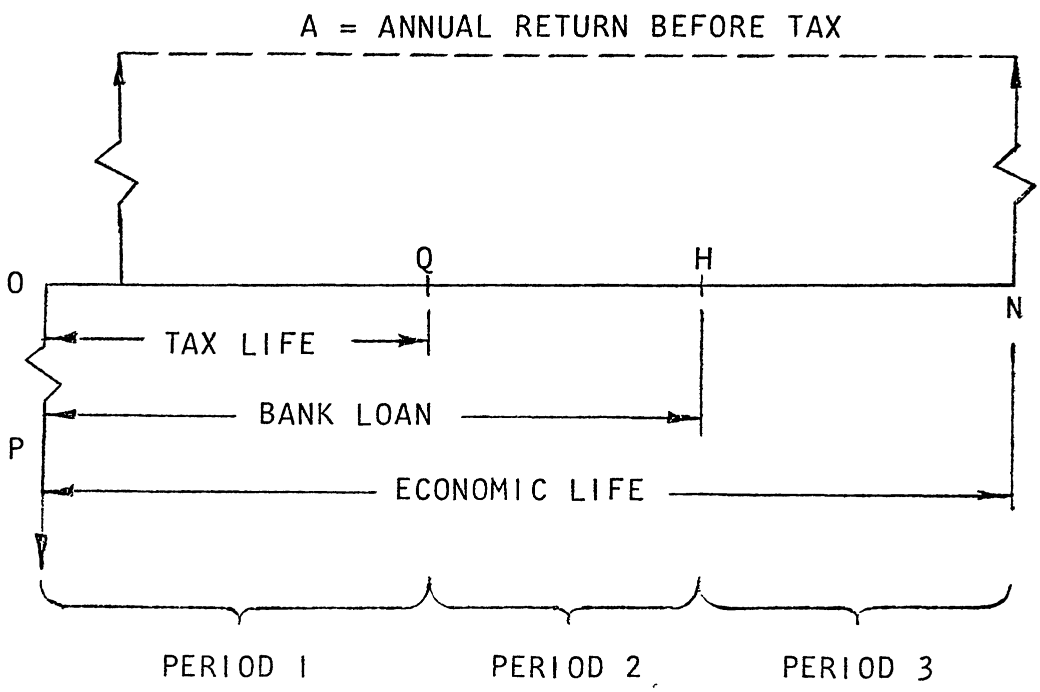


Fig. A1: Time Scale for Analysis Before New Tax Law

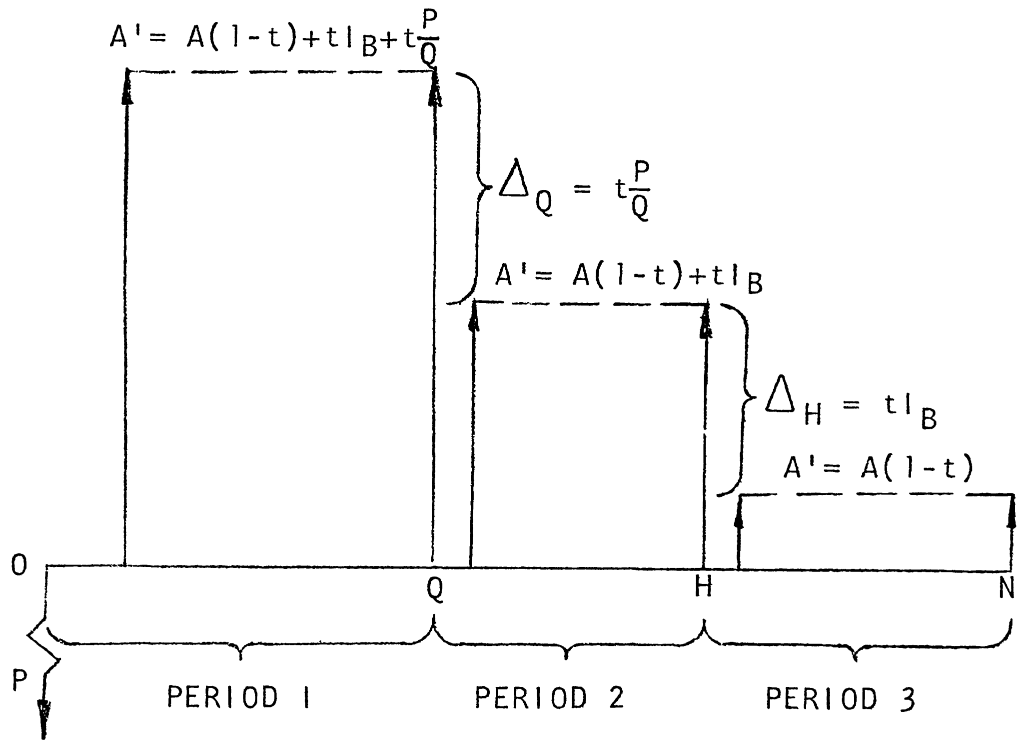


Fig. A2: Cash Flow Diagram Before New Tax Law

In period 1, both I_B and the annual depreciation charge $(\frac{P}{Q})$ reduce the tax base:

$$\text{Taxable income} = A - I_B - \frac{P}{Q}$$

$$\text{Tax} = t(A - I_B - \frac{P}{Q})$$

$$A' = A - \text{Tax} = A - t(A - I_B - \frac{P}{Q})$$

$$= A - tA + tI_B + t\frac{P}{Q}$$

$$= A(1 - t) + tI_B + t\frac{P}{Q} \qquad \boxed{A5}$$

We can summarize the solutions for A' on a cash flow diagram as in figure A2.

In any measure of merit we may care to use, we shall need to find the present value of the after-tax returns (A'). To do this, it will be convenient to find the differences (Δ) between the A' values during each of the time periods. This is easily done by inspection and the values are shown in figure A2.

If we now assume that we can predict the before-tax returns (A), we can find the net present value of our entire cash flow pattern as follows:

$$NPV = (SPW - i' - N)A(1 - t) + (SPW - i' - H)tI_B +$$
$$(SPW - i' - Q)t\frac{P}{Q} - P \qquad \boxed{A6}$$

In this case the interest rate (i') is a minimum acceptable value dictated by management. Conversely, instead of assigning a value to the interest rate, we can by trial and error find its one value that will make the net present value equal to zero. This derived value of i' is the DCF rate of return or yield. If NPV = 0, then we have:

$$P = (SPW - i' - N)A(1 - t) + (SPW - i' - H)tI_B + (SPN - i' - Q)t\frac{P}{Q} \qquad \boxed{A7}$$

If our measure of merit is required freight rate, then we must start with a specified target value for i' and find the corresponding required value of the before-tax returns (A). (This value of i' would normally be appreciably higher than that used in NPV.) Solving equation A7 for A, we find:

$$A = \frac{P - (SPW - i' - H)tI_B - (SPW - i' - Q)t\frac{P}{Q}}{(SPW - i' - N)(1 - t)} \qquad \boxed{A8}$$

In summary thus far, we have developed equations by which we can quantify the profitability of long-term investments despite the complexities of bank loans and short tax depreciation periods. Let us illustrate this by using equation A8 to find the annual return (A) required to meet an owner's specified yield (i') of 10% (based on total investment). Assume we have a \$20 million ship with a useful life of 50 years, a tax life of 20 years, a tax rate of 48%, and a bank loan equal to half the investment, payable in uniform annual installments over 30 years at 6% interest. Recapitulating:

A = unknown
i' = 10%
P = \$20 million
N = 50 yr

$$Q = 20 \text{ yr}$$
$$t = 48\%$$
$$P_B = \$10 \text{ million}$$
$$H = 30 \text{ yr}$$
$$I_B = 6\%$$

Before substituting these numbers into equation A8, we should solve equation A3 for the average annual interest paid to the bank (I_B):

$$I_B = P_B \left[(CR\text{-}i_B\text{-}H) - \frac{1}{H} \right] \qquad \boxed{A3}$$

$$= \$10M \left[(CR\text{-}6\%\text{-}30) - \frac{1}{30} \right]$$

$$= \$10M(0.0726-0.0333)$$

$$= \$10M \cdot 0.0393 = \$0.393M$$

$$M = \text{million}$$

Next, substituting known numbers into equation A8:

$$A = \frac{\$20M-(SPW\text{-}10\%\text{-}30)(0.48)\$0.393M-(SPW\text{-}10\%\text{-}20)(0.48)\frac{\$20M}{20}}{(SPW\text{-}10\%\text{-}50)(1-0.48)}$$

$$= \frac{\$20M-9.425(0.48)\$0.393M-(8.511)0.48}{9.911(0.52)}$$

$$= \frac{\$20M-\$1.777M-\$4.085M}{5.154} = \frac{\$14.14M}{5.154} = \$2.743M$$

Thus, the annual cost of capital recovery is \$2.743 million. Adding the annual operating costs will give the average annual cost. Dividing that by the annual tons of cargo carried will give the required freight rate. While we have the annual cost of capital recovery in front of us, let us find the capital recovery factor before tax (CR) and compare it to the capital recovery factor after tax (CR'):

$$CR = \frac{A}{P} = \frac{\$2.743M}{\$20M} = 0.137$$

$$CR' = (CR\text{-}10\%\text{-}50) = 0.1009$$

$$\frac{CR}{CR'} = \frac{0.137}{0.1009} = 1.36$$

(The corresponding yields before and after tax would show the same 36% difference in relative magnitude.)

II. ANALYSIS UNDER NEW TAX PLAN

As mentioned at the start, taxes will now be waived on funds that are set aside for the eventual construction of replacement tonnage or that go to repay loans used to finance an existing ship. We can assume that most shipowners on the Great Lakes will want to handle their returns in a way that will free them completely from taxes during the initial years of the life of the ship. We shall assume also that the Treasury Department will permit funds to be deposited at such a rate, but will limit the cumulative amount in the fund to the initial cost of the ship. (These points among others remain to be interpreted.) We shall assume further that income from external investments made with the funds will be handled in a way that will have no impact on the arrangements mentioned above.

Given the above suppositions, plus all of those discussed in the previous section, we now have four time periods to examine: the three that existed under the previous tax plan (see figure A1) plus a new initial period during which all discretionary income is put into the tax-deferred ship construction fund (TDSCF). The relationship between returns before and after tax are exactly the same as they were before except that during the new period 1 there are no taxes. The following table summarizes this:

Time Period	Span of Years	Returns Before and After Tax
1	0 to F	$A' = A$
2 (like old 1)	F to Q	$A' = A(1-t) + tI_B + t\frac{P}{Q}$
3 (like old 2)	Q to H	$A' = A(1-t) + tI_B$
4 (like old 3)	H to N	$A' = A(1-t)$

In the table above, F is the number of years required to bring the deposits in the TDSCF up to the initial investment. In short,

$$F = \frac{P}{D} \tag{A9}$$

where

D = discretionary income during initial period of operation.

Figure A3 indicates the distribution of income during the initial period.

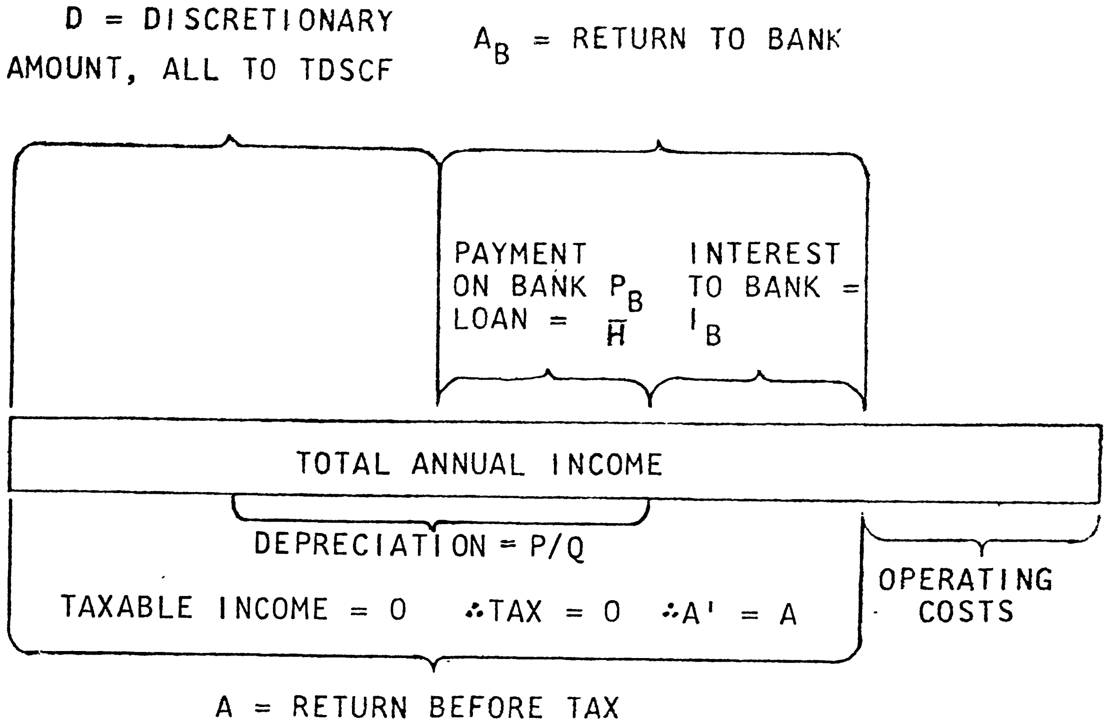


Fig. A3: Distribution of Annual Income During Initial Period (Under New Tax Law)

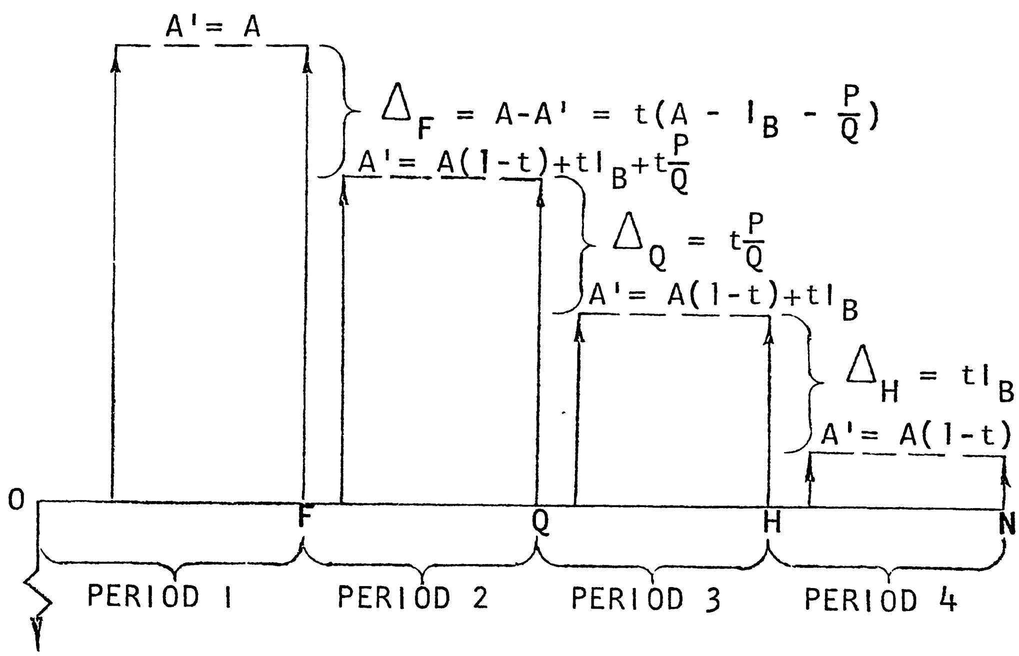


Fig. A4: Cash Flow Diagram Under New Tax Law

As we can see from Figure A3,

$$D = A - A_B$$

Substituting into equation A9:

$$F = \frac{P}{A - A_B} \qquad [A10]$$

or,

$$F = \frac{P}{(CR)P - A_B} \qquad [A11]$$

where

CR = capital recovery factor before tax

We can, as before, analyze the cash flow of figure A4 to find NPV, yield, or return before tax. To derive yield, for example, we set the investment equal to the present worth of the income:

$$P = (SPW\text{-}i'\text{-}N)A(1-t) + (SPW\text{-}i'\text{-}H)tI_B + (SPW\text{-}i'\text{-}Q)t\frac{P}{Q}$$

$$+ (SPW\text{-}i'\text{-}F)t(A - \frac{P}{Q} - I_B) \qquad [A12]$$

Putting all terms that include A on the right side of the equation, we have:

$$P - (SPW\text{-}i'\text{-}H)tI_B - (SPW\text{-}i'\text{-}Q)t\frac{P}{Q} = A(SPW\text{-}i'\text{-}N)(1-t)$$

$$+ (SPW\text{-}i'\text{-}F)t(A - \frac{P}{Q} - I_B)$$

$$= A(SPW\text{-}i'\text{-}N)(1-t) + A(SPW\text{-}i'\text{-}F)t - (SPW\text{-}i'\text{-}F)t(\frac{P}{Q} + I_B)$$

$$P - (SPW\text{-}i'\text{-}H)tI_B - (SPW\text{-}i'\text{-}Q)t\frac{P}{Q} + (SPW\text{-}i'\text{-}F)t(\frac{P}{Q} + I_B) =$$

$$A\left[(SPW\text{-}i'\text{-}N)(1-t) + (SPW\text{-}i'\text{-}F)t\right]$$

solving for A:

$$A = \frac{P-(SPW\text{-}i^{'}-H)tI_B-(SPW\text{-}i^{'}-Q)t\frac{P}{Q}+(SPW\text{-}i^{'}-F)t(\frac{P}{Q}+I_B)}{(SPW\text{-}i^{'}-N)(1-t)\ +\ (SPW\text{-}i^{'}-F)t}$$

regrouping terms in the numerator:

$$A = \frac{P-P(SPW\text{-}i^{'}-Q)\frac{t}{Q}+P(SPW\text{-}i^{'}-F)\frac{t}{Q}-tI_B\left[(SPW\text{-}i^{'}-H)-(SPW\text{-}i^{'}-F)\right]}{(SPW\text{-}i^{'}-N)(1-t)\ +\ (SPW\text{-}i^{'}-F)t}$$

and

$$A = \frac{P-P\frac{t}{Q}\left[(SPW\text{-}i^{'}-Q)+(SPW\text{-}i^{'}-F)\right]+tI_B\left[(SPW\text{-}i^{'}-H)-(SPW\text{-}i^{'}-F)\right]}{(SPW\text{-}i^{'}-N)(1-t)\ +\ (SPW\text{-}i^{'}-F)t} \qquad [A13]$$

If we divide both sides of the equation by the initial investment (P), we obtain the before-tax capital recovery factor.

$$\boxed{CR = \frac{1-\frac{t}{Q}\ (SPW\text{-}i^{'}-Q)+(SPW\text{-}i^{'}-F)+t\frac{I_B}{P}\left[(SPW\text{-}i^{'}-H)-(SPW\text{-}i^{'}-F)\right]}{(SPW\text{-}i^{'}-N)(1-t)+(SPW\text{-}i^{'}-F)t}} \qquad [A14]$$

Thus, if we start with an owner's specified yield ($i^{'}$), we can use equation A14 to find the required capital recovery factor before tax (CR) and the corresponding uniform annual return before tax (A). This is not easy, however, because both numerator and denominator contain the term $(SPW\text{-}i^{'}-F)$; and this means that we must know how many years are in period F before we can solve for A. But, if we turn to equation A11 we see that to find F, we must first know that which we set out to find in the first place, namely CR. All of which means that we have met ourselves coming back and so must use trial-and-error procedures to solve equation A14 for CR.

We can illustrate this by reworking the numerical example of section 1. The object is to find the required uniform annual return before tax (A), given the new tax law plus the other inputs, namely:

specified yield (i') - - - - - - - - - -	= 10%
investment (P) - - - - - - - - - - - - - -	= \$20 million
economic life (N) - - - - - - - - - - -	= 50 yr
tax life (Q) - - - - - - - - - - - - - -	= 20 yr
tax rate (t) - - - - - - - - - - - - - -	= 48%
bank loan (P_B) - - - - - - - - - - - - -	= \$10 million
bank loan period (H) - - - - - - - - - -	= 30 yr
bank interest rate (i_B) - - - - - - -	= 6%
annual interest payments to bank (I_B)	= \$0.393 million

If we substitute those numbers into equation A14, we have:

$$CR = \frac{1-\frac{0.48}{20}\,(SPW\text{-}10\%\text{-}20)-(SPW\text{-}10\%\text{-}F)-0.48\frac{\$0.393M}{\$20M}\Big[(SPW\text{-}10\%\text{-}30)-(SPW\text{-}10\%\text{-}F)\Big]}{(SPW\text{-}10\%\text{-}50)0.52 + (SPW\text{-}10\%\text{-}F)0.48}$$

$$= \frac{1-0.024\big[8.514-(SPW\text{-}10\%\text{-}F)\big]-0.00943\big[9.427-(SPW\text{-}10\%\text{-}F)\big]}{5.16 + 0.48(SPW\text{-}10\%\text{-}F)}$$

$$= \frac{0.707 + 0.0334(SPW\text{-}10\%\text{-}F)}{5.16 + 0.48(SPW\text{-}10\%\text{-}F)} \qquad \boxed{A15}$$

Now we must make a guess at CR in order to find a trial value of F. Our first intuitive guess is CR = 11%. Turning to equation A11:

$$F = \frac{P}{(CR)P-A_B} \qquad \boxed{A11}$$

Before going on, we must calculate the annual return to the bank (A_B):

$$A_B = (CR\text{-}i_B\text{-}H)P_B \qquad [A16]$$

In our case:

$$A_B = (CR\text{-}6\%\text{-}30)\$10M$$

$$A_B = 0.0726 \cdot \$10M = \$0.726M$$

so

$$F = \frac{\$20M}{0.11\$20M\text{-}\$0.726M}$$

$$F = \frac{\$20M}{\$2.2M\text{-}\$0.726M} = \frac{\$20M}{\$1.474M}$$

$$F \approx 13.5 \text{ years}$$

From interest tables:

$$(CR\text{-}10\%\text{-}13.5) = 7.23$$

Substituting into equation A15:

$$CR = \frac{0.707+0.0334(7.23)}{5.16+0.48(7.23)} = \frac{0.707+0.241}{5.16+3.46}$$

$$CR = \frac{0.948}{8.62} = 0.11$$

Error = intuitive CR-derived CR

= 0.11-0.11 = 0

(a fortunate coincidence)

We can now compare annual costs of capital recovery corresponding to the specified yield of 10% both before and after the new tax law:

	Before New Law	After New Law
CR	0.137	0.11
CR'	0.1009	0.1009
$\frac{CR}{CR'}$	1.36	1.09

Thus, under the old law, the tax required a 36% increase in annual costs of capital recovery whereas it now requires an increase of less than 10%.

In further illustration of the benefits of the new tax law, we have studied other typical financing schemes for the same $20 million ship dealt with in the foregoing sections. Given all of the aforementioned assumptions, we found the following before-tax capital recovery factors:

	Before New Law	After New Law	Ratio
All-equity investment	0.154	0.115	1.34
50% bank loan	0.137	0.110	1.24
100% bank loan	0.120	0.105	1.14

The corresponding annual costs of capital recovery would be:

	Before New Law	After New Law	Ratio
All-equity investment	$3,080,000	$2,300,000	1.34
50% bank loan	2,740,000	2,200,000	1.24
100% bank loan	2,400,000	2,100,000	1.14

APPENDIX II

POWERING ESTIMATE IN OPEN WATER

From the effective horsepower, P_E, derived by regression analysis from a sample of Great Lakes bulk carrier model tests a shaft horsepower estimate is obtained in the following manner:

Wake, thrust deduction, hull efficiency:

From empirical formulas

$$\left.\begin{aligned} w &= -0.42 + 0.73\ C_B \\ t &= 0.06 + 0.7\ w \end{aligned}\right\}\quad \text{for single-screw ships}$$

$$\left.\begin{aligned} w &= -0.1 + 0.59\ C_B \\ t &= 0.6\ w \end{aligned}\right\}\quad \text{for twin-screw ships}$$

Hence

$$\eta_H = \frac{1-t}{1-w}$$

Relative rotative efficiency:

$\eta_R = 1.02$ for single-screw ships

$\eta_R = 0.98$ for twin-screw ships

APPENDIX II: POWERING ESTIMATE IN OPEN WATER

Open-water efficiency:

Optionally, either from empirical formula

$$\eta_O = 1.0 - 0.55\ C_B$$

or from regression formula for Wageningen B 4.70 propeller series, Ref. 50, for a given diameter, speed, and number of revolutions. The possibility of choosing the propeller optionally from that series within a range of diameter and RPM is contemplated for future implementation.

Shaft horsepower (SHP):

$$P_S = \frac{P_E}{\eta_O\ \eta_H\ \eta_R}$$

APPENDIX III

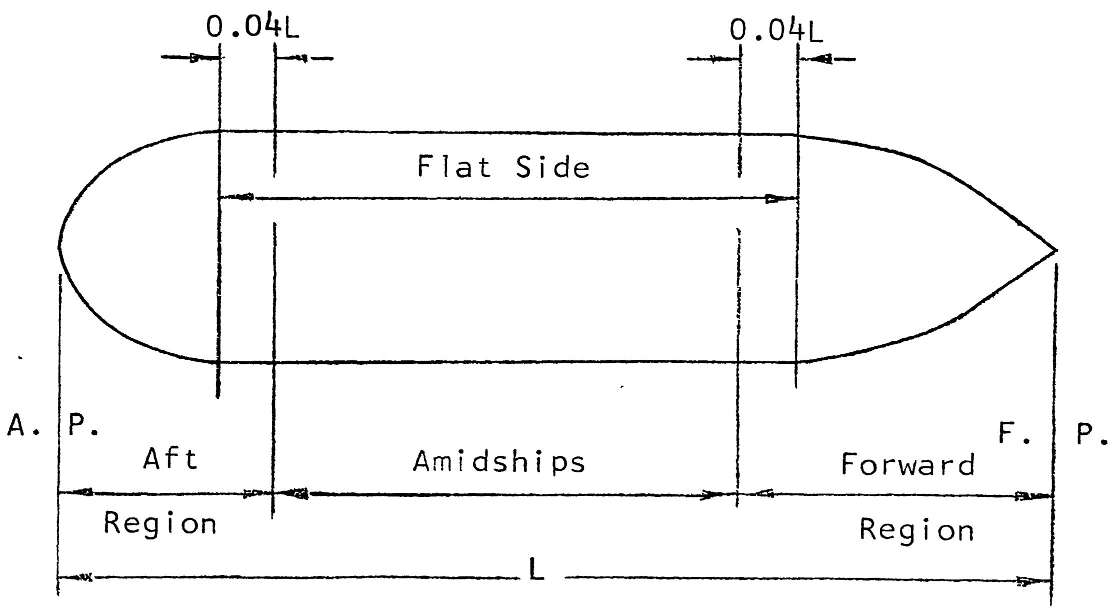
ICE STRENGTHENING AND STEEL WEIGHTS

In the present investigation, we assume that Great Lakes ships are to be reinforced or designed according to the Finnish Ice Class Rules (6).

There are four classes in the ice rules;

Class	Ice Condition
IA - Super	extreme ice
IA	severe ice
IB	medium ice
IC	light ice

The rules specify that the ship's hull (shell and framing) around the ice line be strengthened to withstand the additional pressure produced by ice. As the pressure varies from bow to stern, the ice belt of the ship is divided into three regions as shown below.



ICE BELT REGIONS

APPENDIX III: ICE STRENGTHENING

The vertical extension of the belt to be strengthened for ice is given as a function of the ice class as well as the ice region described above.

Scantlings of frames and shell plating are governed by the pressure between the ship's hull and the ice. This pressure is assumed to be a function of the ship's installed horsepower and displacement.

Although converting an existing ship into an ice class ship (machinery replacement included) is not always economically feasible, such a possibility is not ruled out in the present parametric study.

R.A. Stearn, Inc., and Marine Consultants and Designers were employed as consultants to estimate the extra weight and the corresponding costs to ice-strengthen the Great Lakes ships for all four classes, using the Finnish Rules.

The figures supplied by R.A. Stearn are based on the assumption that the cost for converting an existing ship to an ice class type, will be the same as the additional cost needed to ice strengthen a new ship for the same ice class type.

Marine Consultants and Designers investigated mainly the costs necessary to adapt (while still in the design stage) a 1000-ft Great Lakes bulk carrier to various ice class ships.

Optimization techniques may be applied to obtain the least amount of steel (plate and stiffeners) necessary to ice-strengthen a ship. It is however, of second order of importance and will not be included. The data provided by the consultants are considered adequate from a parametric point of view, and are used in the present study.

I. TWO ICE-BELT CONCEPT

According to the Finnish ice regulations, the vertical extension of the ice belt is to be as shown below:

Ice Class	Vertical Extent of Ice Belt
IA-Super:	from 750mm above LWL to 600mm below BWL
IA:	from 600mm above LWL to 500mm below BWL
IB&IC:	from 500mm above LWL to 500mm below BWL

In the above, LWL refers to the loadline in the loaded condition, BWL in the ballast condition.

In terms of total ice belt reinforcing plate width, b_w in ft, we have for:

Ice Class	
IA-Super:	$b_w = (LWL-BWL) + 4.43$
IA:	$b_w = (LWL-BWL) + 3.61$
IB&IC:	$b_w = (LWL-BWL) + 3.28$

Thus the smallest width of plate that would need reinforcing would vary between 3.28 to 4.43 ft, i.e. (LWL-BWL) = 0.

One way to accomplish the latter condition is to provide ballast capacity equal to the cargo deadweight. This will allow one to keep the ship moving always loaded at the same water line. The required maximum ice belt width will in this case always be less than 4.50 ft.

Great Lakes bulk carriers in general travel either fully loaded or in a relatively light ballast condition. As a result there are two major water lines to be considered. Thus, if b_w from the formulas above exceeds twice the constant term (i.e. 6.56 ft to 8.83 ft depending on the ship's ice class), two separate narrow ice belts could be used to provide more economically all the protection the hull needs.

For example if a ship of (LWL-BWL) = 12 ft is to be reinforced for ice class IB, then the saving in the area of thicker plating will be

$$\frac{(12 + 3.28) - (3.28 \times 2)}{(12 + 3.28)} = 56.7\%$$

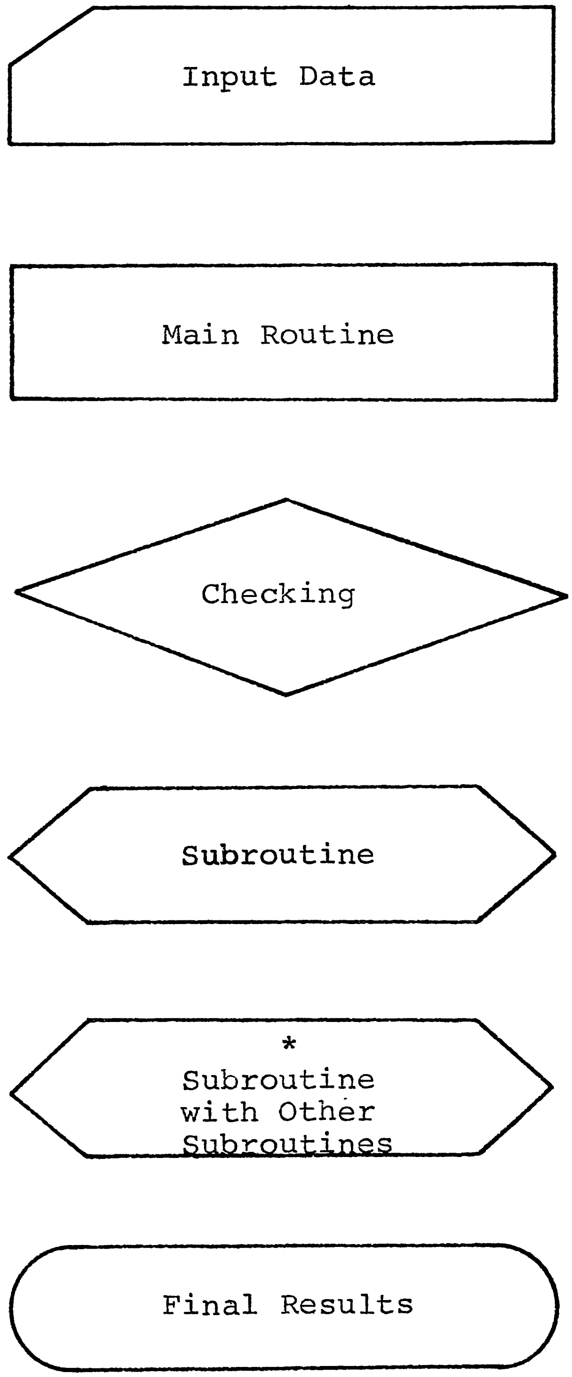
There will also be some savings in the framing requirements of the ship but not quite to the same degree as the plating.

The concept of two separate ice belts merits consideration in future studies.

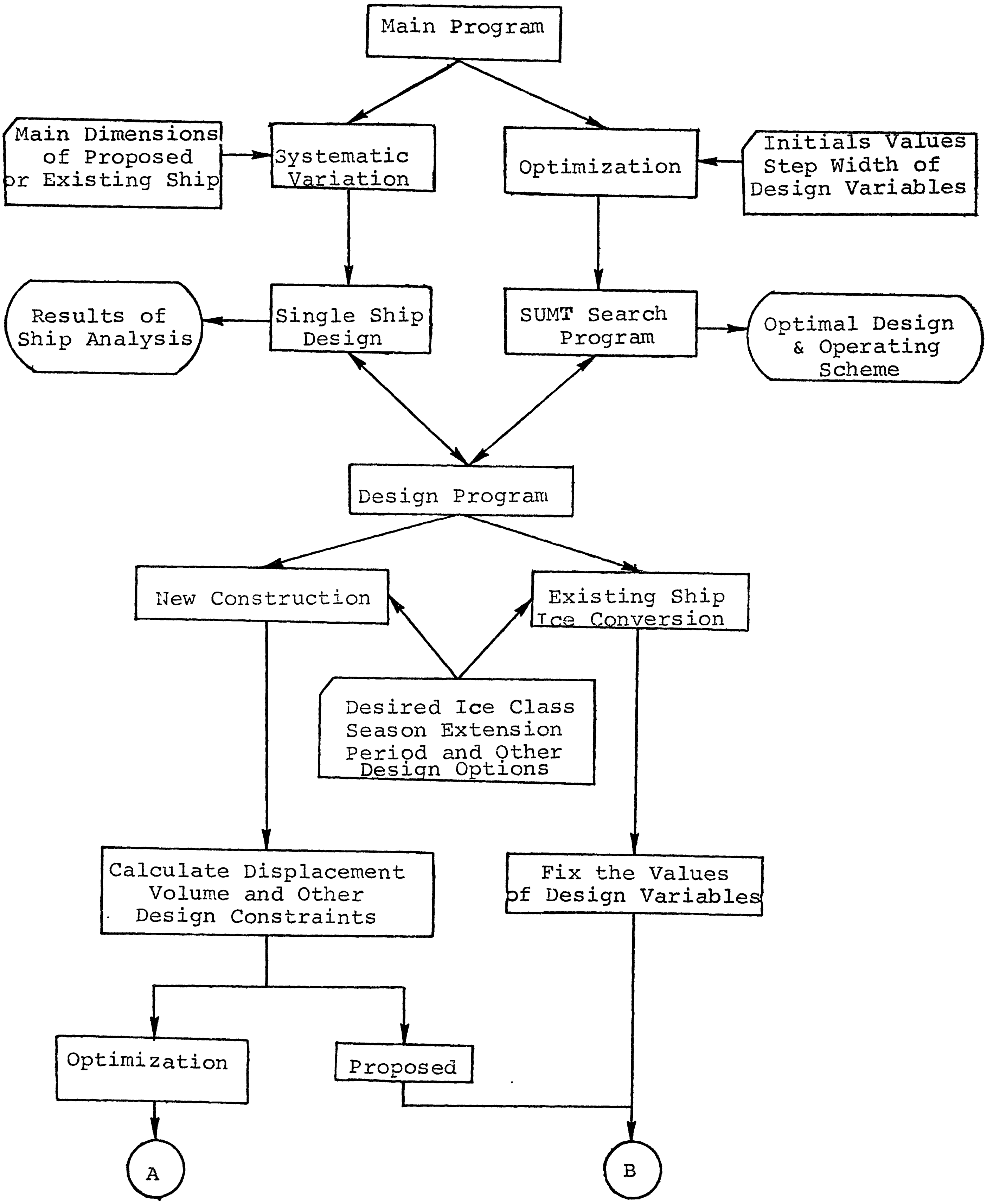
APPENDIX IV

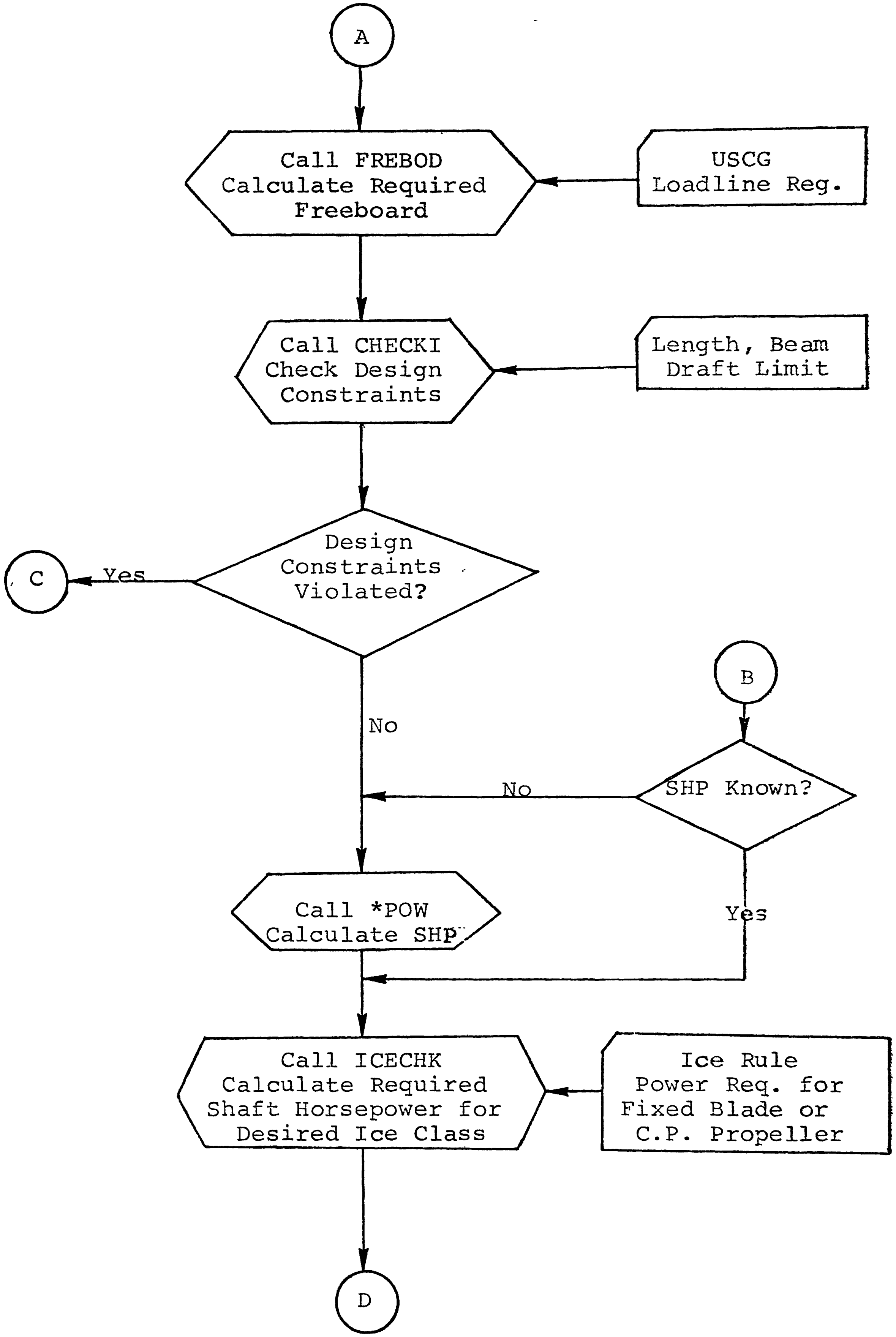
FLOW CHART

FLOW CHART ANNOTATION

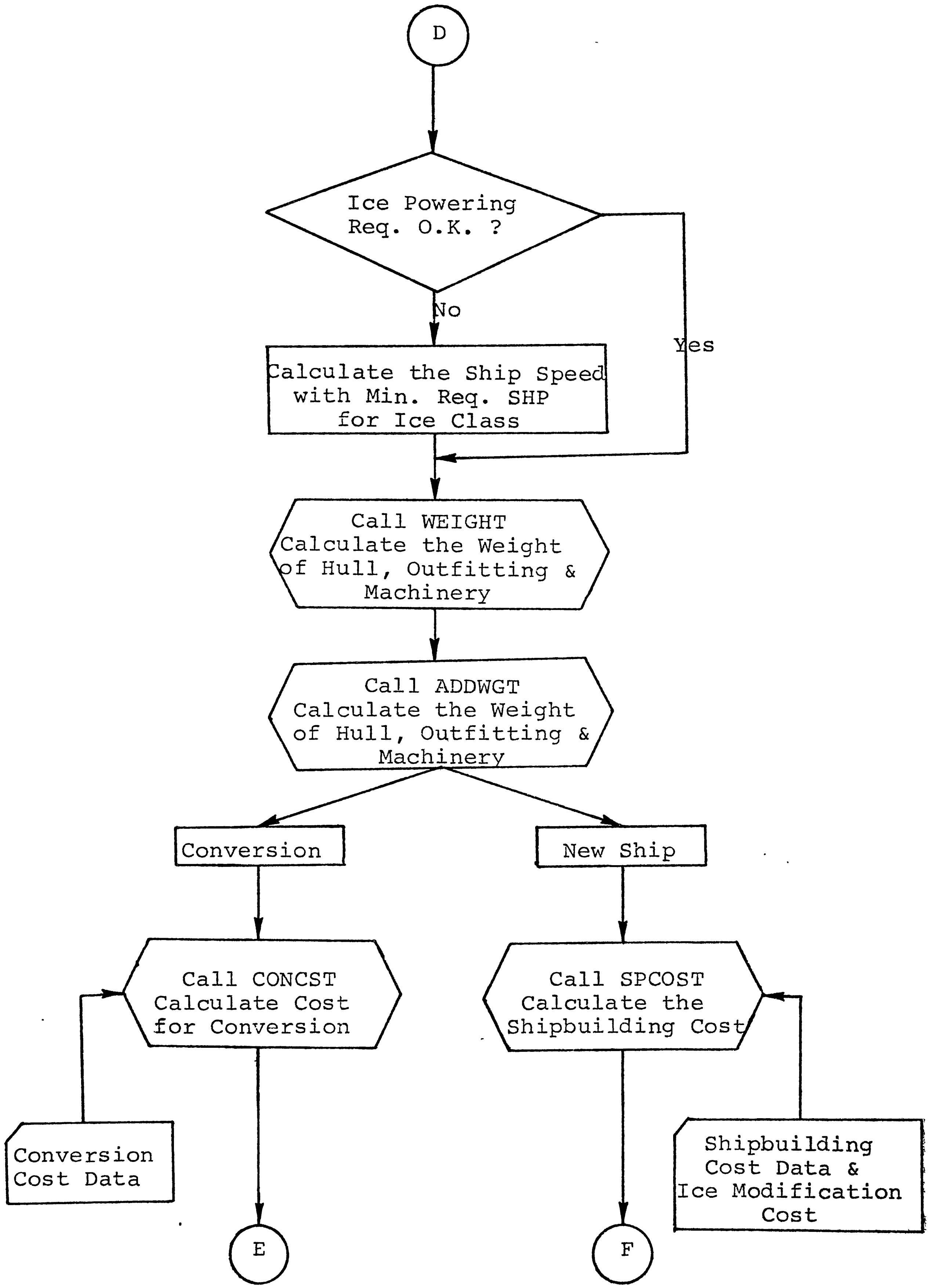


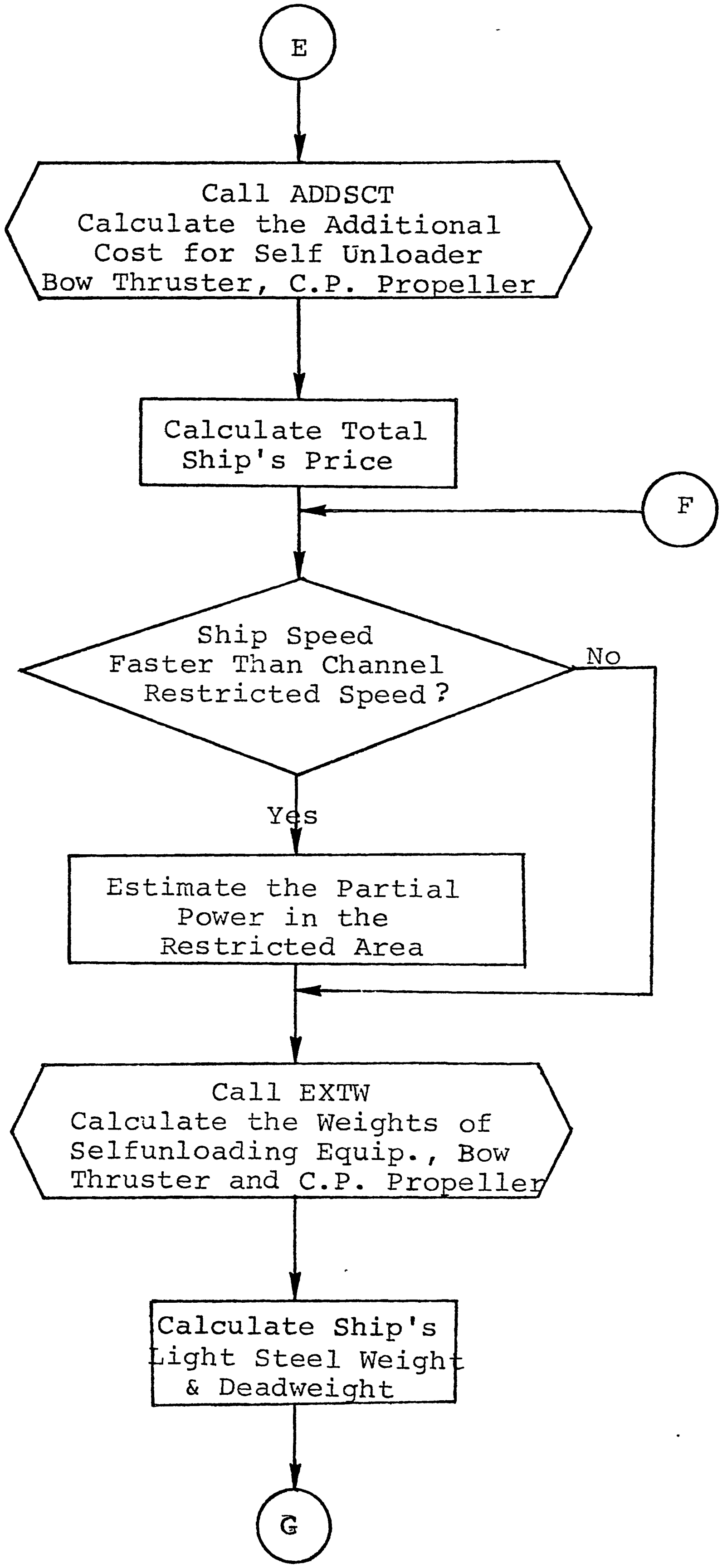
APPENDIX IV: FLOW CHART



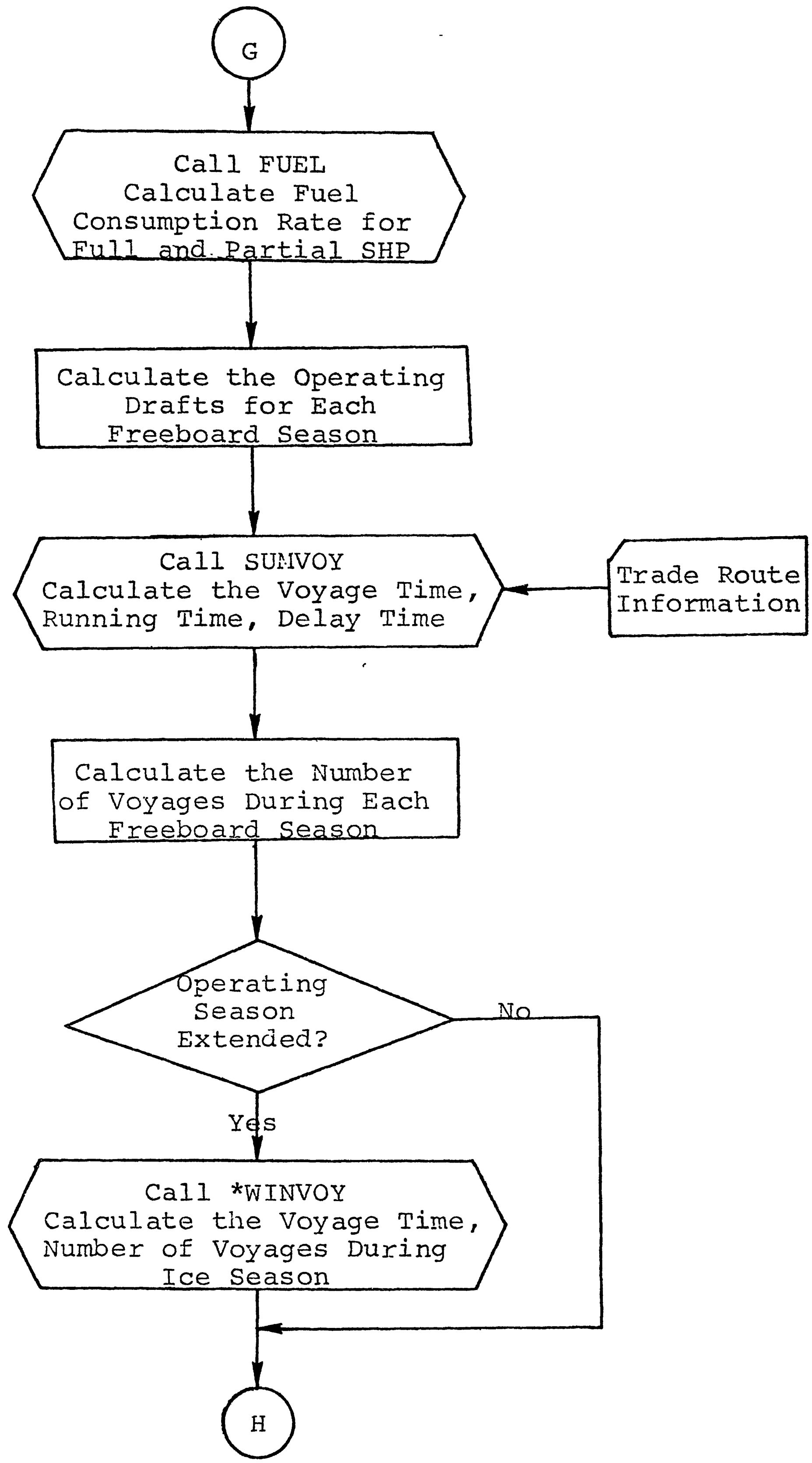

A
Call FREBOD
Calculate Required
Freeboard
USCG
Loadline Reg.
Call CHECKI
Check Design
Constraints
Length, Beam
Draft Limit
Design
Constraints
Violated?
Yes
C
No
B
SHP Known?
No
Yes
Call *POW
Calculate SHP
Call ICECHK
Calculate Required
Shaft Horsepower for
Desired Ice Class
Ice Rule
Power Req. for
Fixed Blade or
C.P. Propeller
D

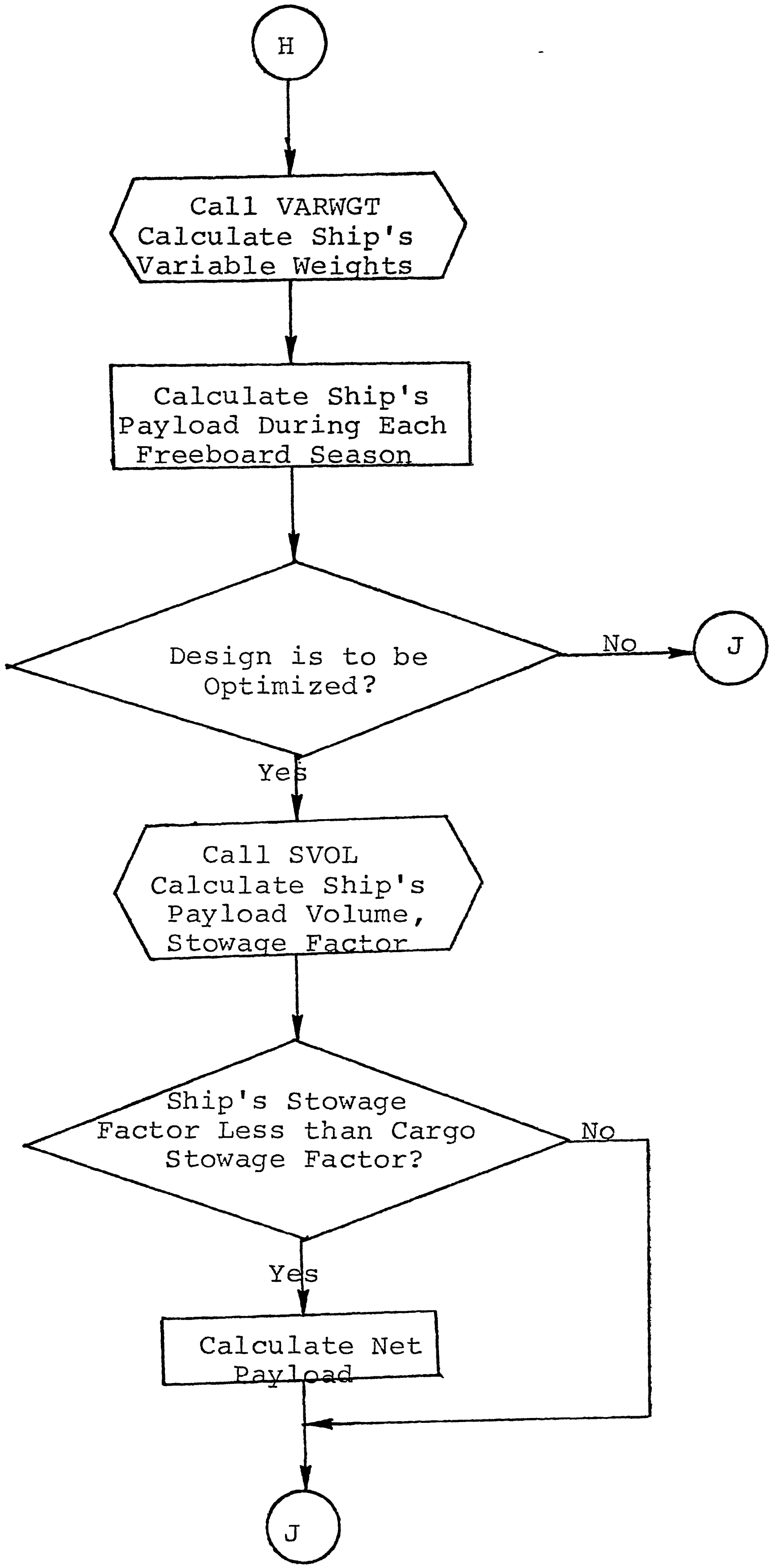
APPENDIX IV: FLOW CHART



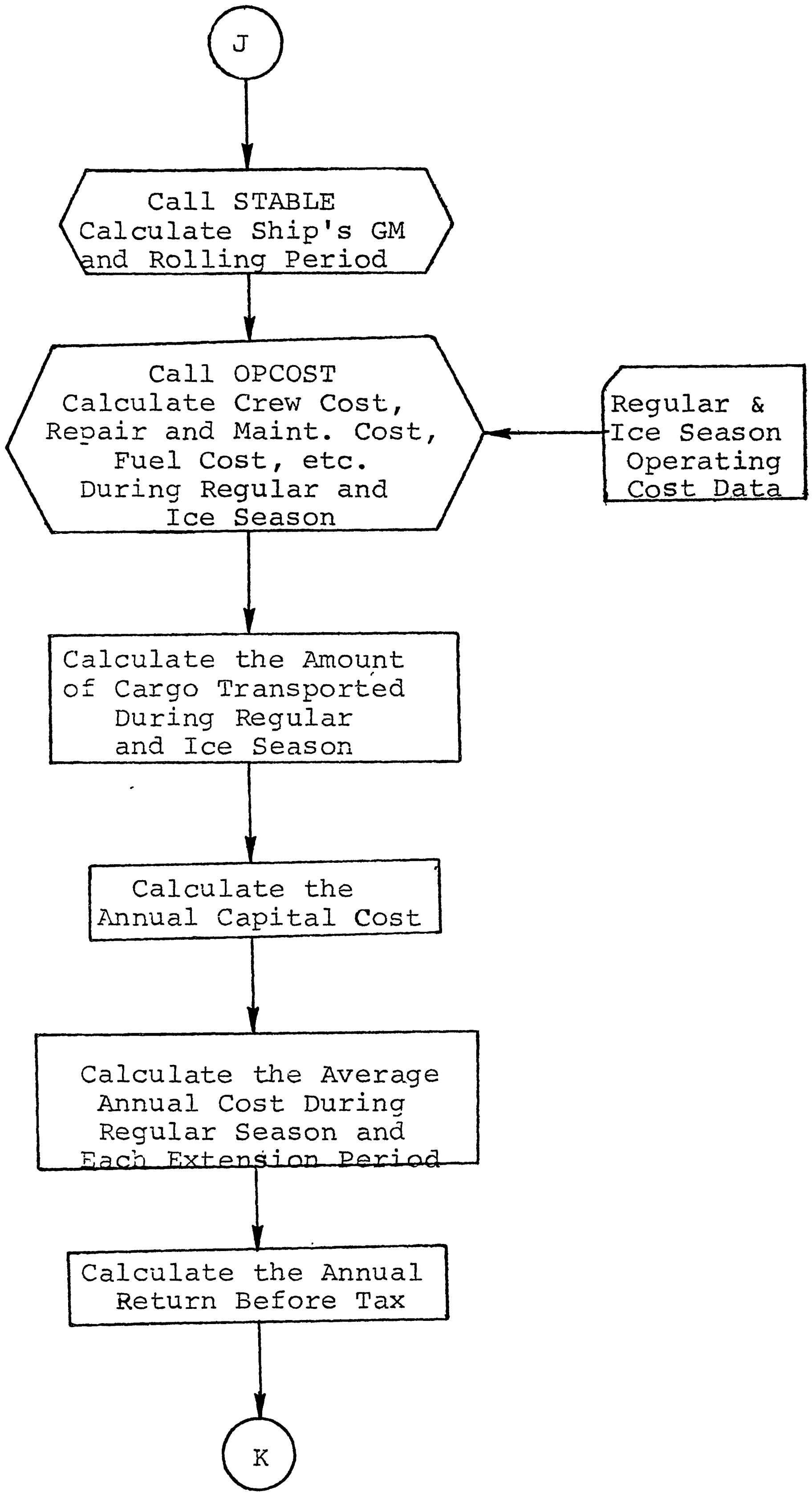

E
Call ADDSCT
Calculate the Additional
Cost for Self Unloader
Bow Thruster, C.P. Propeller
Calculate Total
Ship's Price
F
Ship Speed
Faster Than Channel
Restricted Speed ?
No
Yes
Estimate the Partial
Power in the
Restricted Area
Call EXTW
Calculate the Weights of
Selfunloading Equip., Bow
Thruster and C.P. Propeller
Calculate Ship's
Light Steel Weight
& Deadweight
G

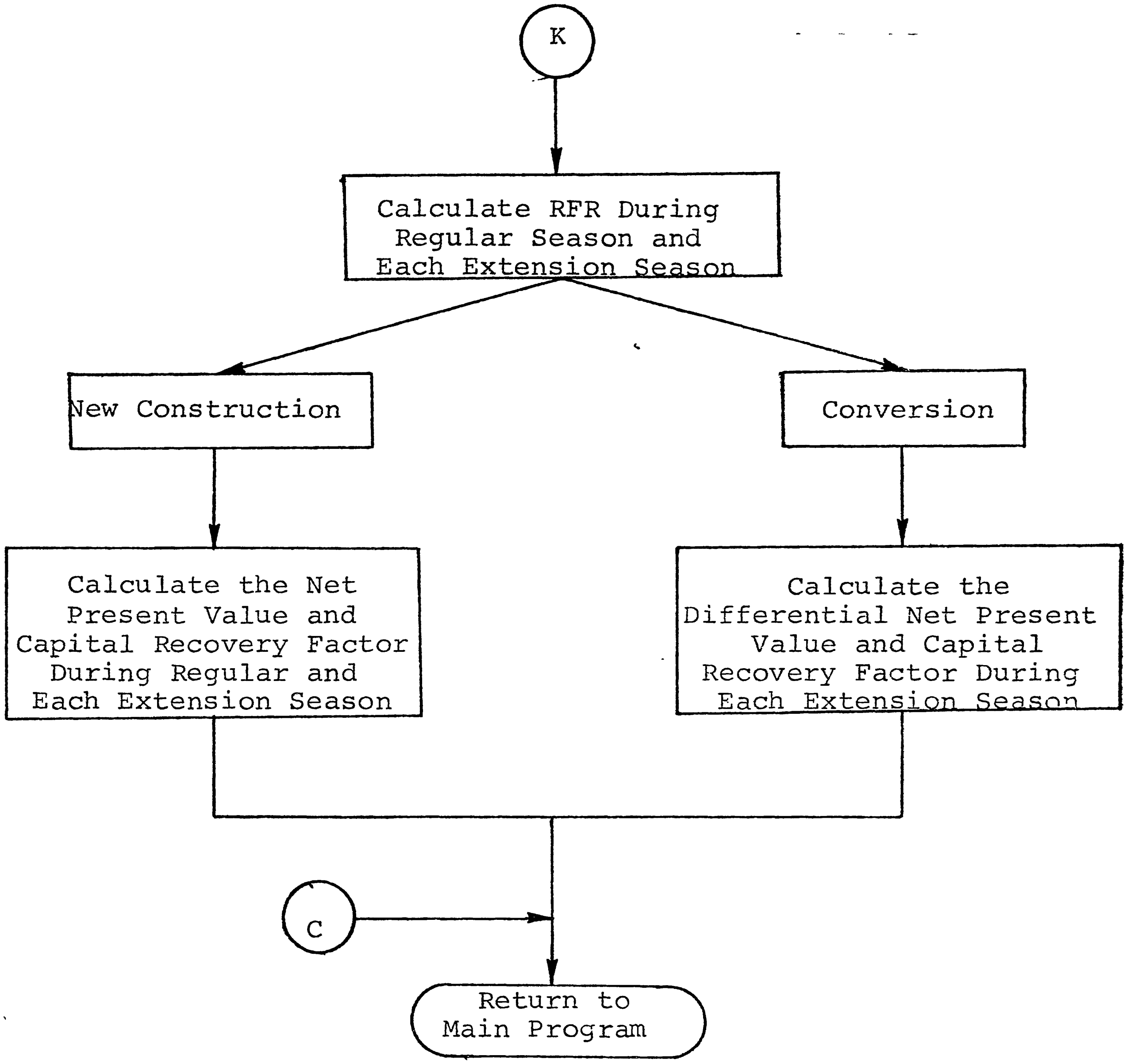
APPENDIX IV: FLOW CHART



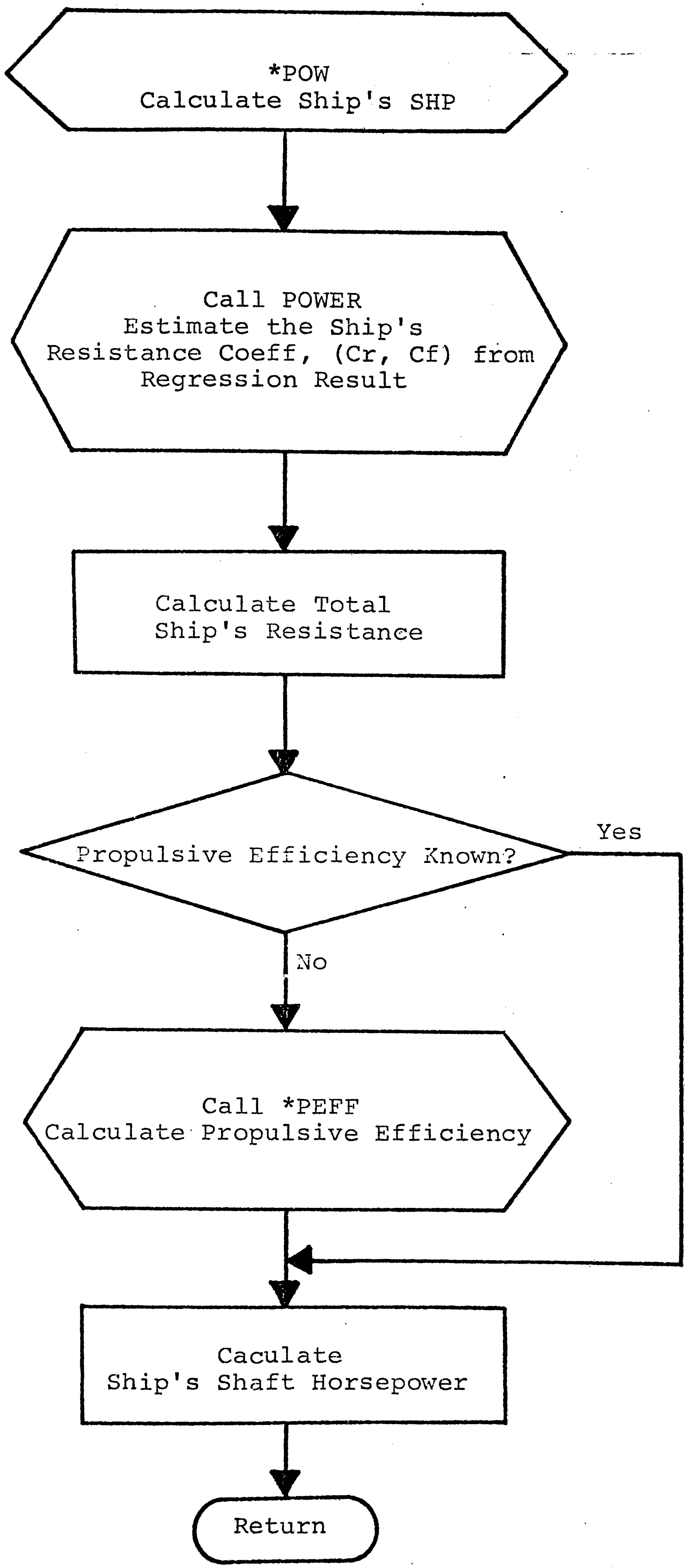

H
Call VARWGT
Calculate Ship's
Variable Weights
Calculate Ship's
Payload During Each
Freeboard Season
Design is to be
Optimized?
No
J
Yes
Call SVOL
Calculate Ship's
Payload Volume,
Stowage Factor
Ship's Stowage
Factor Less than Cargo
Stowage Factor?
No
Yes
Calculate Net
Payload
J

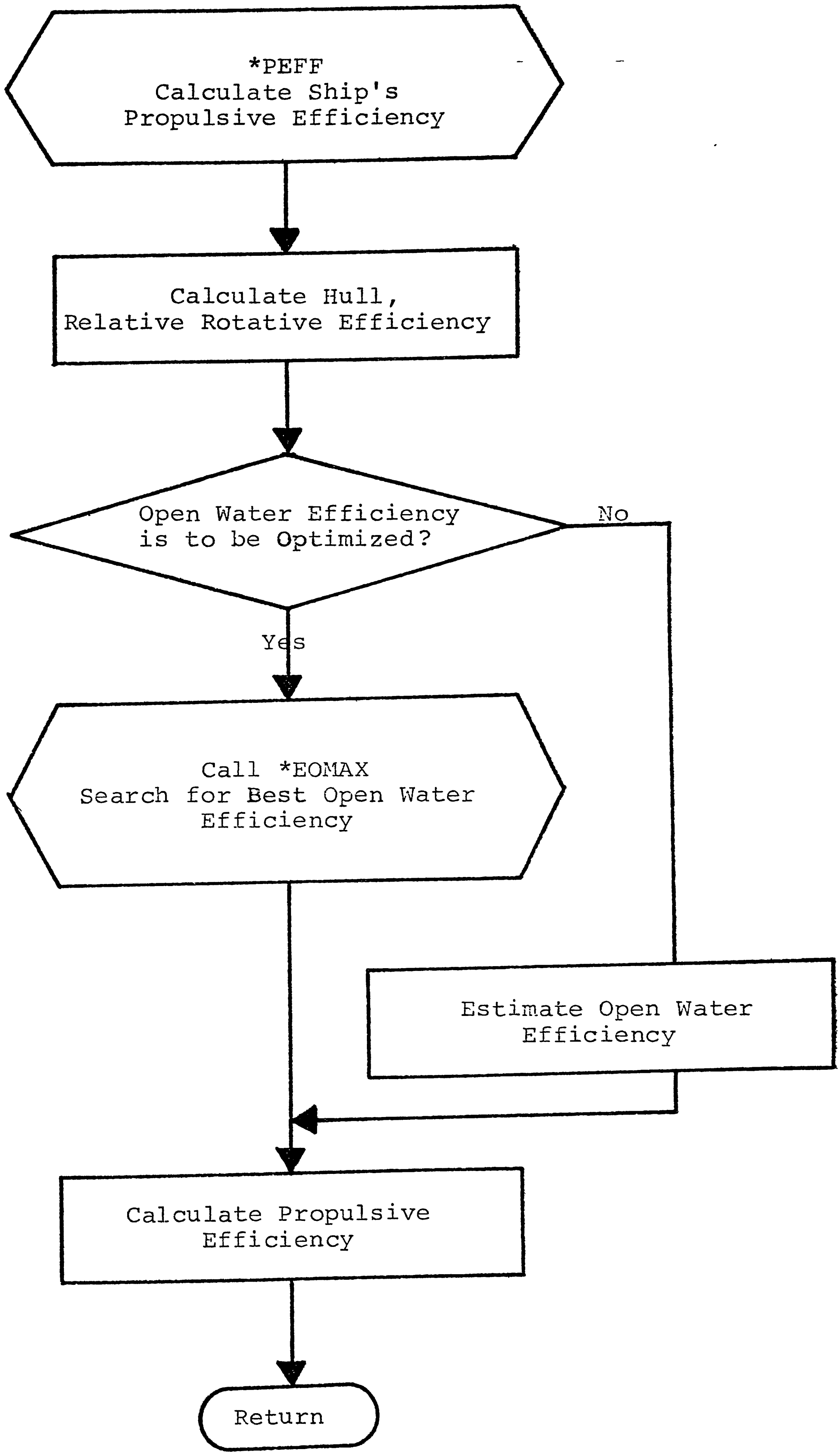
APPENDIX IV: FLOW CHART



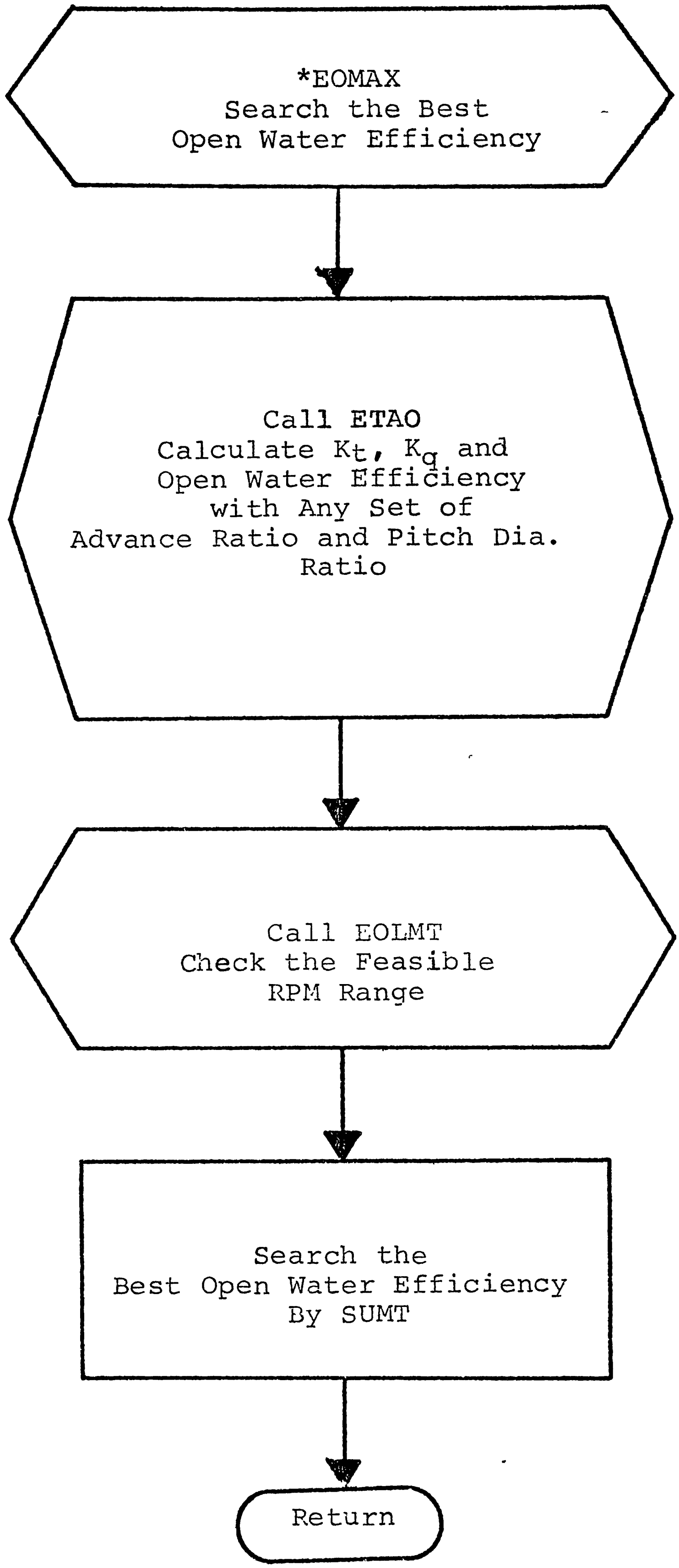

K
Calculate RFR During Regular Season and Each Extension Season
New Construction
Conversion
Calculate the Net Present Value and Capital Recovery Factor During Regular and Each Extension Season
Calculate the Differential Net Present Value and Capital Recovery Factor During Each Extension Season
C
Return to Main Program

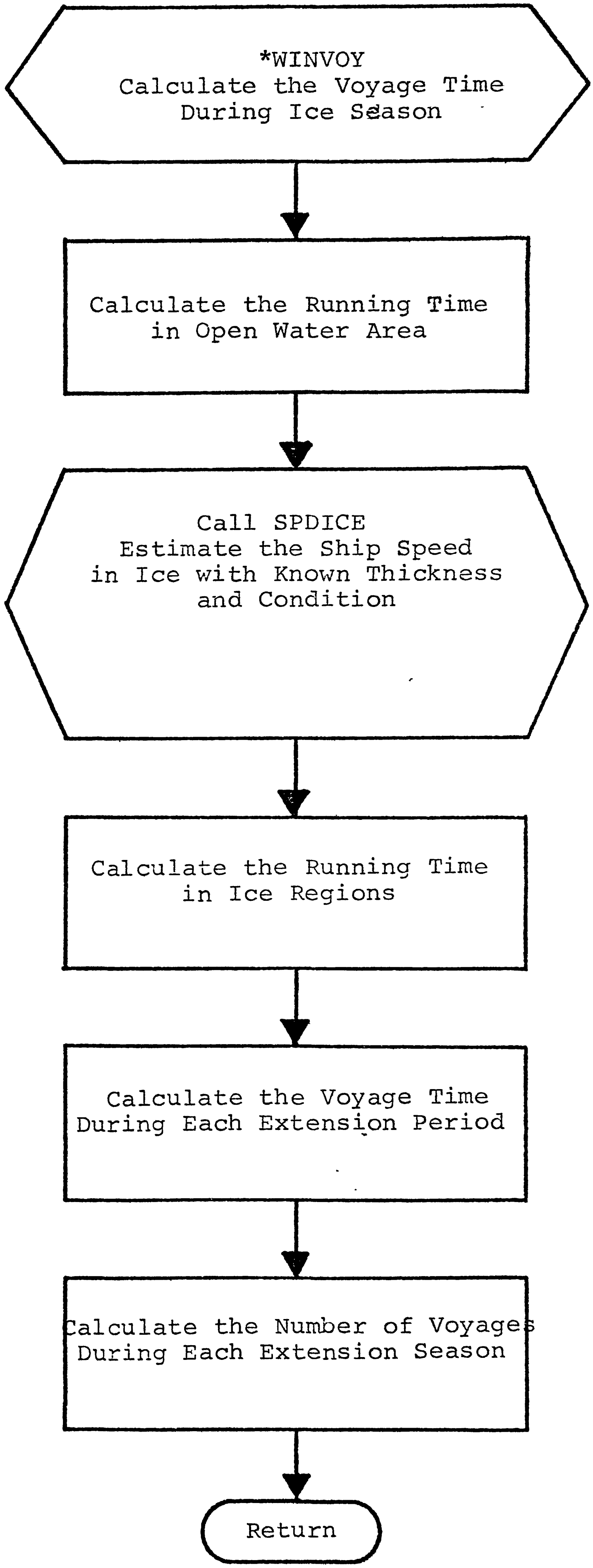
APPENDIX IV: FLOW CHART




*PEFF
Calculate Ship's
Propulsive Efficiency
Calculate Hull,
Relative Rotative Efficiency
Open Water Efficiency
is to be Optimized?
No
Yes
Call *EOMAX
Search for Best Open Water
Efficiency
Estimate Open Water
Efficiency
Calculate Propulsive
Efficiency
Return

APPENDIX IV: FLOW CHART




*WINVOY
Calculate the Voyage Time
During Ice Season
Calculate the Running Time
in Open Water Area
Call SPDICE
Estimate the Ship Speed
in Ice with Known Thickness
and Condition
Calculate the Running Time
in Ice Regions
Calculate the Voyage Time
During Each Extension Period
Calculate the Number of Voyages
During Each Extension Season
Return

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