"In the concept design stage, alternative designs are evaluated for technical and economic feasibility."

A Design Synthesis for Steel-Hulled Trawlers

by

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ABSTRACT

A computer-aided concept design synthesis for trawlers is developed. Hull resistance is estimated from a previously published statistical analysis of trawler resistance data. Construction costs are likewise approximated from published graphs, after updating where necessary. Extensive curve fitting was done to make these existing information suitable for a computerized procedure. A numerical example relevant to Philippine conditions is given.

INTRODUCTION

This paper brings together and organizes information from various sources within the framework of a ship design procedure to produce a computer-aided tool for the design of steel-hulled trawlers.

Figure 1 shows the major stages in a fishing vessel design process. This paper concerns itself with concept design — the determination of ship dimensions, draft, fullness and power and the

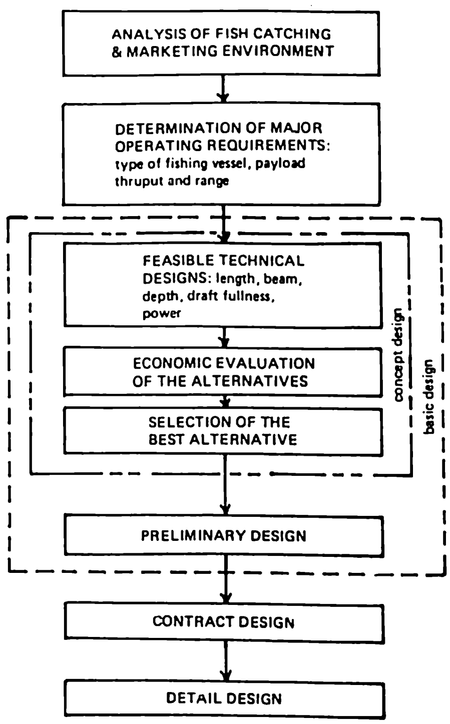

Figure 1. Major Steps in Fishing Vessel Design

initial estimates of construction and operating costs. It is assumed that a set of mission requirements has already been established. In the concept design stage, alternative designs are evaluated for technical and economic feasibility and the better designs are chosen for further development.

Table I, which is based on Reference 1, shows the various ship design variables. The secondary and tertiary variables will affect the selection of the final design, but their influence on the economic measure of merit is not nearly as strong as that of the primary variables [1] ; This underlines the importance of the concept design stage.

The procedure developed does not optimize but only allows for the evaluation of various designs one at a time. The designer can intervene at various points in the computerized procedure as he hunts for that combination of primary variables that define a good ship. With experience and judgment, a designer may be able to steer the design process efficiently towards increasingly better solutions.

Table I. Ship Design Variables

PRIMARY	SECONDARY	TERTIARY
Length	Number & arrangement of holds	Number & dimensions of hatches
Breadth	Number & height of decks	Number & type of propeller
Depth	Type & capacity of cargo handling gear	Crew number & accommodations
Draft	Machinery type & location	Auxiliary machinery
Speed	Structural configuration & materials	Location & arrangement of equipment
Block coefficient	Hull form characteristics	Maneuvering devices
	Superstructure arrangement	Extent of automation
	Tankage allocation & materials	Types of coatings

If desired, a parametric variation study may be conducted without intermittent manual input by simply imposing loops in the computer program.

The validity of the procedure is restricted to steel-hulled trawlers without a fish factory on board. Furthermore, the following constraints must be satisfied:

$$LBP \leqslant 67 \text{ m}$$

$$4.4 \leqslant LBP/B \leqslant 5.8$$

$$2.0 \leqslant B/d \leqslant 2.6$$

$$0.238 \leqslant Fn \leqslant 0.327$$

$$0.6 \leqslant C_p \leqslant 0.7$$

$$0.81 \leqslant C_m \leqslant 0.97$$

$$0\,\% \leqslant LCB \leqslant 6\,\% \text{ aft}$$

$$5^\circ \leqslant \tfrac{1}{2}\alpha_e \leqslant 30^\circ$$

The restriction on LBP comes from the use of the building cost data of Reference 2. The other restrictions are based on the regions of validity of the resistance data of Reference 3.

The program runs on a Hewlett-Packard HP-86 computer with 64 K RAM.

TECHNICAL FEASIBILITY

Figure 2 shows the algorithm used to determine the technical feasibility of a contemplated design. Essentially, it seeks to achieve consistency in the speed, power and displacement of the vessel. The solution is iterative because power depends on displacement and displacement in turn depends on power.

If desired, and if available data warrant it, an outer loop representing the satisfaction of GM requirement may be added. This is shown as dashed lines in Figure 2. The improvement of GM may be achieved with the addition of fixed ballast. Since such ballasting affects displacement, recalculation involves convergence in the inner loop.

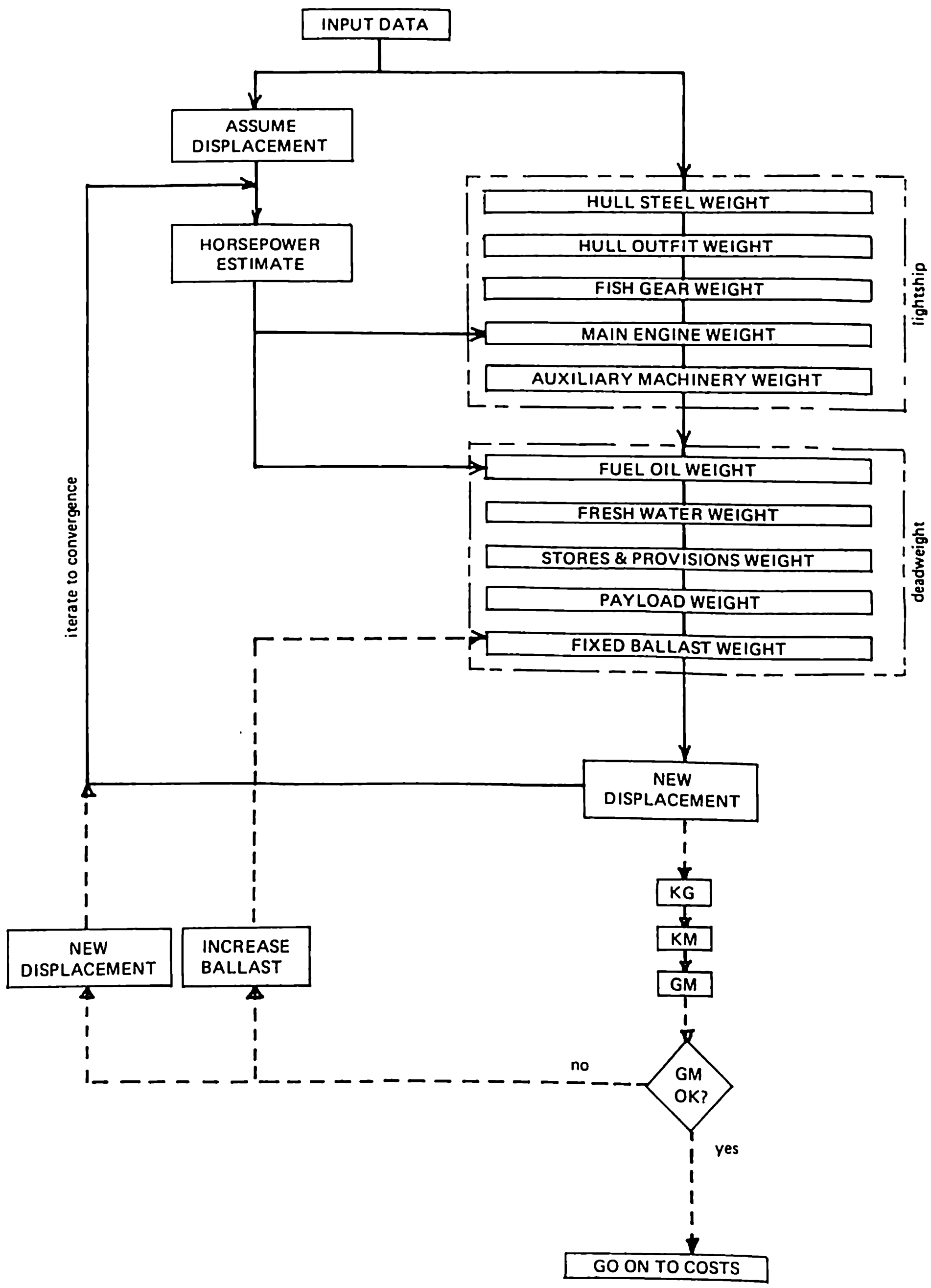

Figure 2. Algorithm to Determine Technical Feasibility

This paper leaves out the outer loop for lack of available data on the various centers of gravity of various ship components. This decision has been made easier by the observation in Reference 2 that most trawlers do not require any ballast.

The GM should be checked in latter design stages when the ship has been developed to a sufficient level of detail. Furthermore, satisfaction of the dynamic criteria of stability and survivability must be ascertained (See Reference 4 for these criteria). Reference 5 quotes certain studies on required GM for fishing vessels. Table II contains information on the GM of some trawlers.

The importance of stability considerations cannot be overstated. Reference 6 notes that when the fishing is good, it is almost certain that the crew will overload the vessel.

Ship Proportions

Table II shows, among other items, data on the major dimensions of trawlers built in different countries at different times. This table helps locate the ballpark of trawler proportions: LOA/LBP, LWL/LBP, LBP/D, LBP/B, B/D, d/D and B/d.

Reference 2 gives a plot of LBP vs. B, d vs. B, d vs. D and LBP vs. D of U.S. type trawlers. Second degree polynomials are fitted to the LBP vs. B and LBP vs. D curves. Thus:

$$B = 0.000962\,(LBP)^2 + 0.0298\,(LBP) + 4.705 \qquad (1)$$

$$D = 0.000214\,(LBP)^2 + 0.0333\,(LBP) + 5.529 \qquad (2)$$

with LBP, B and D in metres. For a given value of LBP, there is a range of good values of B and D. Equations 1 and 2 therefore serve only as guides.

The length to breadth ratio (LBP/B)

LBP/B is a measure of the fullness of the hull. As such, it is important in powering. Table II shows a maximum LBP/B of 6.14 for a 64.46 m ship and a minimum value of 4.06 for a 21.7 m vessel. The use of Eqn. 1 gives an LBP/B of 6.07 for a 64.46 m ship and 3.73 for a 21.7 m ship.

Reference 13 notes that there has been a steady decrease in LBP/B values over the years. This means that the trend is towards "fatter" ships, a reflection of the efforts to reduce building costs. Length, it must be noted, is the most expensive ship dimension. Furthermore, developments in model testing have led to more efficient hulls. Thus, for the same cargo carrying capacity, stubbier hulls can now be designed with the same resistance as the finer hulls of the past.

Reference 13 further states that recent practice shows a tendency to use an LBP/B value of 4.0 for small crafts, such as fishing boats, up to 30 m length. For vessels between 30 m and 130 m, the following formula is recommended:

$$LBP/B = 4 + 0.25\,(LBP - 30) \qquad (3)$$

When applied to the 64.46 m ship, this gives LBP/B = 4.86. This is lower than that of the sample ship of that length in Table II as well as that resulting from the use of Eqn. 1. Note that the data of Table II and the data upon which Eqn. 1 are based are less recent than those upon which Eqn. 3 is based.

The length to depth ratio (LBP/D)

LBP/D is important for the strength of the hull girder. For short crafts, this ratio is not critical since the bending load on the hull is not large. Table II gives a maximum LBP/D of 13.22 for a 64.8 m trawler and a minimum of 6.28 for a 23 m ship. Using Eqn. 2, the comparable values are 11.59 for the longer ship and 6.75 for the shorter ship.

Table II. Sample Ships

NAME	FLAG	YEAR	DIMENSIONS LOA m	LBP m	LWL m	B m	D m	d m	HULL PROPORTIONS LBP/D	LBP/B	B/D	d/D	B/d	HULL COEFFICIENTS ∇ m^3	Cb	Cp	Cm	POWERING V knots	Fn	HP	CAPACITIES FHV m^3	FHV/∇	FO m^3	FW m^3	RANGE days	CREW	GRT	STABILITY GM1 m	GM2 m	GM3 m	GM4 m	REF
	JAPAN			41.70		7.2	4	3.6	10.43	5.79	1.8	.9	2	602	.56			12.5	.31	510	166	.28	60	40			291			.4		7
	JAPAN			44.00		7.4	4.1	3.2	10.73	5.95	1.81	.78	2.31	608	.58			11.75	.28	700	350	.58	89	45		24	366			.61		7
	JAPAN			46.90		8.2	4.35	3.4	10.78	5.72	1.88	.78	2.41	776	.59			12.08	.28	850	386	.5	152	64		30	495			.8		7
	JAPAN			64.46		10.5	5.3	4.35	12.16	6.14	1.98	.82	2.41	1858	.63			13.82	.27	1200	953	.51	404	170		60	995			.81		7
	JAPAN			17.60		3.93	1.77	1.45	9.94	4.48	2.22	.82	2.71	52	.52			8.67	.33	90	24	.45	9	1		10	24			.45		7
	JAPAN			20.40		4.16	1.98	1.84	10.30	4.9	2.1	.93	2.26	85	.55			7.2	.25	80	46	.54	6	1		11	38			.59		7
	JAPAN			21.19		4.46	2.08	1.86	10.19	4.75	2.14	.89	2.4	93	.53			8.8	.3	160	39	.42	9	1		12	41			.44		7
	JAPAN			22.32		4.53	2.13	1.9	10.48	4.93	2.13	.89	2.38	106	.55			9.4	.32	200	46	.43	13	1		13	54			.01		7
	JAPAN			24.41		5.1	2.51	2.37	9.72	4.79	2.03	.94	2.15	172	.58			10.19	.33	270	88	.51	19	3		18	73			.42		7
RESOLUTE	USA	1891		25.90		6.7	2.93		8.84	3.87	2.29										71											8
SPRAY	USA	1905	41.60	38.60		6.71	3.92	3.34	9.85	5.75	1.71	.85	2.1								128											8
FABIA	USA	1919		40.00		7.62	4.8		8.33	5.25	1.59									360	170											8
NOTRE DAME	USA	1929	40.25	37.10		7.32	3.96	3.46	9.37	5.07	1.85	.87	2.12								172											8
GOLDEN EAGLE	USA	1941	30.40	30.20		6.71	3.35	2.44	9.02	4.5	2	.73	2.75								100											8
CALM	USA	1941	44.80	39.30		7.93	4.37	3.67	8.99	4.96	1.82	.84	2.16								249											8
BAY	USA	1945	32.45	30.50		7.1	3.97	2.95	7.68	4.3	1.79	.74	2.41								162											8
RUTH & MOSES	USA	1952	23.60	21.70		5.34	3.2	2.03	6.78	4.06	1.67	.63	2.63								60											8
RT-800	USSR	1956	57.80	52.35		9.75	5.03	4.25	10.41	5.37	1.94	.84	2.29	1251	.50			12.3	.27	1100	487	.39			30	44						9
RT-800	USSR	1951	59.30	53.50		9	5	4.5	10.70	5.94	1.8	.9	2	1254	.58			12	.26	820	387	.31			20	42	660					9
RT-800	USSR	1956	60.50	54.00		9.07	4.85	4.5	11.13	5.95	1.87	.93	2.02	1167	.53			12	.26	800	389	.33			18	41	650					9
RT-800	USSR	1956	63.00	55.00		9.3	4.85	4.46	11.34	5.91	1.92	.92	2.08	1233	.54			12	.26	800	414	.34			18	42	600					9
RT-800	USSR	1957	50.50	44.35		8.8	4.3	3.4	10.31	5.04	2.05	.79	2.59	706	.53			11	.26	650	344	.49			30	20						9
PRINCE CHARLES	UK	1950		54.30		9.3	4.9		11.08	5.84	1.9							13	.28		450					32	720					9
ANDANES	UK	1950	60.85	54.85		9.45	4.9		11.19	5.8	1.93							14	.3	1300	465					30	724					9
PRINCESS ELIZABETH	UK	1952	57.80	48.90		9.17	5.1		9.59	5.33	1.8							13	.3	1200	360					37	810					9
PORTIA	UK	1957	64.16	57.91		10.52	5.44	4.95	10.65	5.51	1.93	.91	2.12					14.5	.3	1500	490					30	883					9
NORDELITE	UK	1953		31.65		7.09	3.37		9.39	4.46	2.1							10.25	.29	450	170					20	219					9
BOSTON NEPTUNE	UK	1955		39.00		8.11	3.96		9.85	4.81	2.05							15	.38	750	192.6					16						9
WYRE WANGUARD	UK	1956	44.00	40.20		8.3	4.12		9.76	4.84	2.02									736	205					18						9
BOSTON SEAFOAM	UK	1956		42.00		8.56	4.27		9.84	4.91	2							12	.29	910	256					12						9
HEINRICH REIMS	UK	1956	69.20	64.8		10	4.9	4.15	13.22	6.48	2.04	.85	2.41					13		1500	455		283	90	40	38	825					9,10
CARL KAMPF	UK	1957	64.90	55.20	60.77	9.6	4.9	4.3	11.27	5.750	1.96	.88	2.23	1147	.5			14	.3	1490	570	.5	204	70	30	33	681					9,10
SAGITTA	UK	1958	67.30	57.60	63.17	9.6	4.9	4.3	11.76	6.000	1.96	.88	2.23	1336	.56			15	.31	2000	450	.34	253	85	35	38	720					9,10
PIERRE VIDAL	FRANCE	1950	73.00	69.35		11.75	6.3	5.45	11.01	5.9	1.86	.87	2.16	2439	.55			11.3	.22	1100	1400	.57				60	1400					9
CAP FAGNET III	FRANCE	1956	74.80	68.17		11.5	6	5.9	11.36	5.93	1.92	.98	1.95					12.5	.24	2100	1255											9
ZELANDE	FRANCE	1956	84.00	77.00		13	6.6	5.3	11.67	5.92	1.97	.8	2.45	2537	.48			11	.2	2050	1576	.62				65	1900					9
	FRANCE		31.45	29.50		6.5	3.65	2.95	8.08	4.54	1.78	.81	2.2	259	.46	.6	.76			375	100	.39			20							9,11
	FRANCE		35.85	33.50		6.85	3.9	3.25	8.59	4.89	1.76	.83	2.11	347	.46	.6	.77			450	120	.35			26							9,11
	FRANCE		41.90	39.35		7.5	4.25	3.5	9.26	5.25	1.76	.82	2.14	473	.46	.59	.78			600	241	.51			42							9,11
	FRANCE		46.45	44.00		8.25	4.7	3.85	9.36	5.33	1.76	.82	2.14	700	.5	.64	.78			750	320	.46			55							9,11
	FRANCE		73.00	69.35		11.75	6.3	5.25	11.01	5.9	1.86	.83	2.24	2647	.62	.67	.92			1100	1500	.57			100							9,11
BAHRENFELD	GERMANY	1950	50.35	43.80		8.2	4.75	4.31	9.22	5.34	1.73	.91	1.9					12	.29	970	356						454					9
WUPPERTAL	GERMANY	1953	59.60	53.50		8.8	5		10.70	6.08	1.76							13	.28	1000	470					25	620					9
BOREAS	GERMANY	1954	63.59	55.80		9.1	5.05	4.3	11.05	6.18	1.8	.85	2.12					13.5	.29	1500	510											9
HERMAN KRONE	GERMANY	1954	61.40	54.40		9	5.1	4.3	10.67	6.04	1.76	.84	2.09					13.5	.29	1440	505					38	602					9
BRAUNSCHWEIG	GERMANY	1956	62.00	56.00		9.15	5		11.20	6.12	1.83							13.5	.29	1000	470					24	653					9
GENEPESCA I & II	ITALY	1949	76.50	69.30		11.9	6.7	5.4	10.34	5.82	1.78	.81	2.2	2927	.66											70	1650					9
	PORTUGAL	1952	71.65	64.00		11	5.7	5.24	11.23	5.82	1.93	.92	2.1	2390	.65			11	.22	1100	1200	.5										9
	SPAIN		25.00	23.00	23.58	5.55	3.66	3.01	6.28	4.14	1.52	.82	1.84	231	.6	.68	.88	8.5	.28	120	77	.33		19	15	13	124	.38	.41	.45	.41	12
	SPAIN		30.33	27.86	28.30	6.6	4	3.37	6.97	4.22	1.65	.84	1.96	342	.55	.64	.86	9	.27	180	154	.45		20	22	13	107	.56	.53	.61	.54	12
	SPAIN		31.97	27.13	29.00	6.25	3.75	3.28	7.24	4.34	1.67	.87	1.9	302	.54	.64	.85	10.5	.32	430	152.3	.5		14	24	13	202	.46	.74	.57	.51	12
	SPAIN		30.80	27.13	29.00	6.25	3.45	3.13	7.86	4.34	1.81	.91	2	250	.47	.6	.79	10.5	.32	315	126	.5		4	26	13	154	.66	.65	.6	.56	12
	SPAIN		71.75	63.75	66.60	10.75	5.9	5.2	10.81	5.93	1.82	.88	2.07	2244	.63	.71	.89	10.5	.21	1200	1300	.58		89	120	53	1360	.82	.70	.7	.67	12
	SPAIN		35.49	30.00	32.80	6.85	3.9	3.25	7.69	4.38	1.76	.83	2.11	338	.51	.62	.81	10.5	.31	450	232.5	.69		20	36	18	224	.55	.52	.63	.6	12
HOLLWEIG FRODAN	ICELAND			52.00		9	4.5		11.56	5.78	2			1122				12	.26	1200	520	.46				35	621					9
	ICELAND			52.00		9	4.75	4.3	10.95	5.78	1.9	.91	2.09	1122	.56			12	.26	1200	560	.5			20	34	500					9
OLAFUR JOHANESSEN	ICELAND		60.40	55.90		9.1	5.2		10.75	6.14	1.75									1200						30						9
THORKEL MANI	ICELAND			56.60		9.3	4.88	4.33	11.60	6.08	1.91	.89	2.15	1171	.52			13.5	.29	1450	565	.48			20		700					9
JORUNDUR	ICELAND		50.90	45.72		8.53	4.56		10.03	5.36	1.87							13.5	.32	950	340					39	470					9

The breadth to depth ratio (B/D)

B/D governs stability since KG is mainly a function of ship depth and KM is largely a function of beam.

Reference 13 gives the usual value of B/D as 1.65. Among the vessels in Table II, the minimum B/D is 1.59. Equations 1 and 2, in their region of validity, give B/D from 1.71 to 1.84.

The draft to depth ratio (d/D)

The draft to depth ratio is important to the survivability of a vessel.

Reference 13 shows a design corridor for d/D between 0.7 and 0.8. The vessels upon which this corridor is located are cargo ships subject to the International Convention on Load Lines (ICLL) 1966 [14]. The d/D values are therefore an embodiment of the ICLL freeboard rules.

Fishing vessels are specifically exempt from ICLL 1966. It may therefore be expected that the d/D values of Table II, mostly between 0.8 and 0.9, may continue to be the practice. Note that the vessels of Table II are pre-1966.

The stability and survivability criteria of Reference 4 and the trawler's area of operation are the prime determinants of d/D. Reference 4 states that the maximum operating draft shall be determined such that in different operating conditions, all the stability criteria are satisfied. The sufficiency of the assumed value of d/D in the concept design stage must therefore be checked at a latter design stage.

The breadth to draft ratio (B/d)

B/d is important in hull resistance and powering. Table II shows that the B/d values of the sample ships are almost all within 2.0 and 2.6, the limits of validity of the procedure developed in this paper.

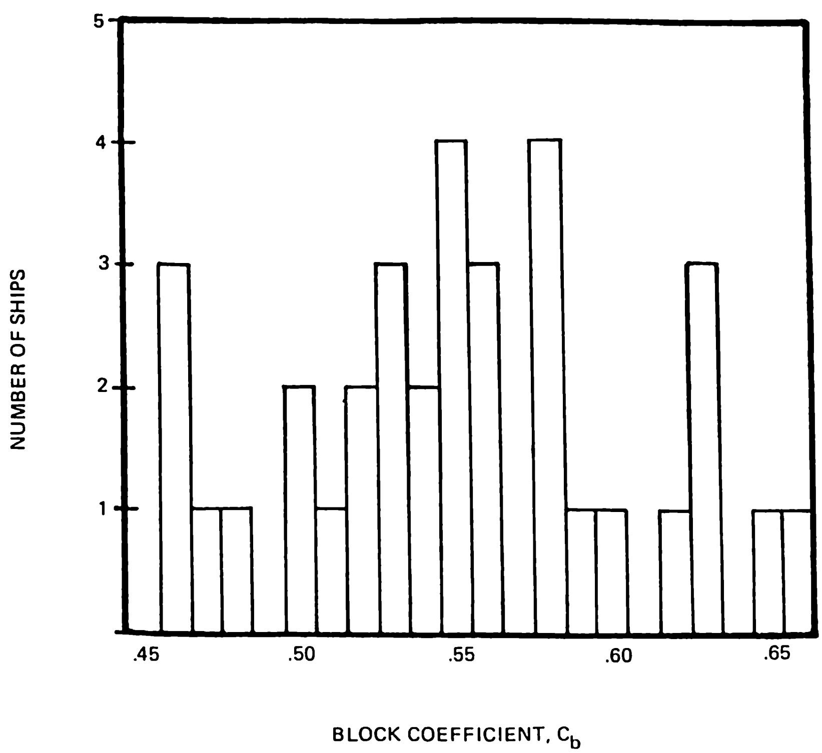

Figure 3. Frequency of C_b of the Sample Ships

LOA/LBP; LWL/LBP

The average LOA/LBP in Table II is 1.108. The average LWL/LBP is 1.064.

Hull Fineness and Speed

Figure 3 shows the frequency of C_b for the sample ships of Table II.

Reference 9 gives the usual values of C_b as follows:

classic trawlers	0.55 to 0.58
stern trawlers	0.58 to 0.62

Figure 4 shows a plot of C_b vs. Fn for the trawlers of Table II. Superposed is the recommended range from Ref. 13. Note that about half the sample ships fall outside the corridor. They have C_b values lower than what is recommended for the corresponding Fn's. Their hulls appear to be too fine for their speeds.

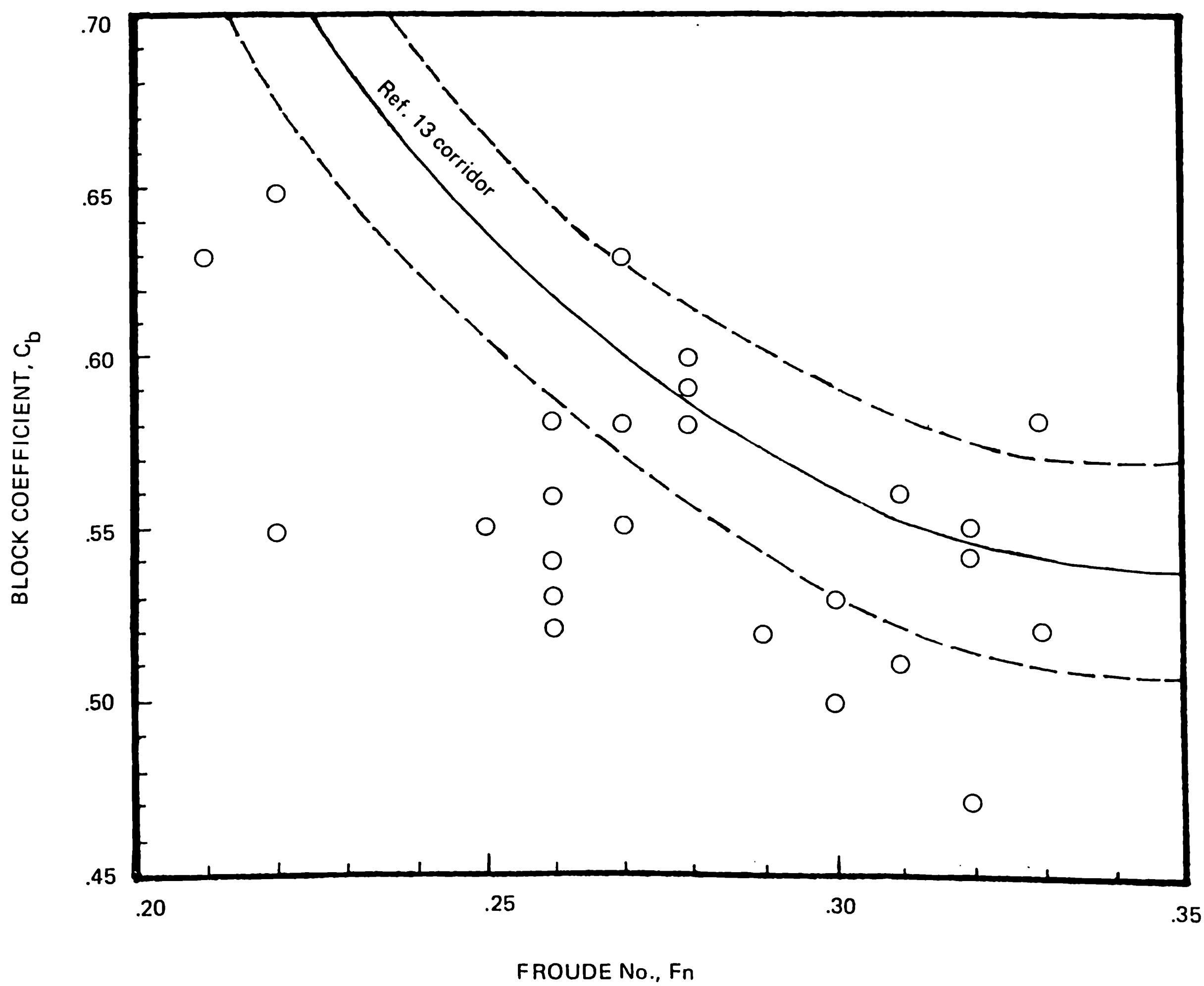

Figure 4. C_b vs. Fn for the Sample Ships

Along the mean line, values of C_b higher than 0.55 go with Fn lower than 0.31. C_b values lower than 0.55 are associated with Fn greater than 0.31.

Payload

Table II shows data on the ratio of fish hold volume to volume displacement. The spread of values is considerable, from 0.27 to 0.68.

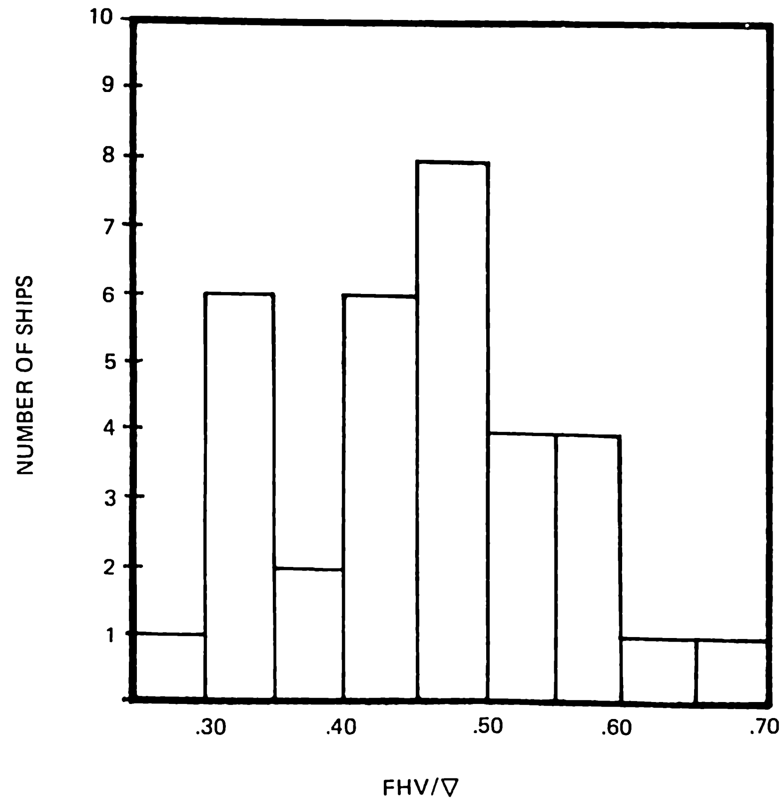

Figure 5. Frequency of FHV/∇ for the Sample Ships

Figure 5 shows the frequency of FHV/∇ for these sample trawlers. In the absence of more information about the sample ships, it is difficult to pinpoint the factors that cause the scatter.

It is clear that a high value of FHV/∇ is desirable. If the design is entirely new and data about similar vessels are lacking, the value of FHV/∇ assumed in the concept design has to be checked at a latter design stage.

The fish hold volume can be converted to payload by the application of the stowage factor. Reference 15 gives a stowage factor of 1.39 m^3/t for iced fish in barrels. Filipinos use tubs, called *bañeras,* as fish containers. Where stowage factor for these tubs are available, they should be used.

For the determination of vessel displacement, it is sufficient to know the combined weight of fish, ice and container. However, for the estimate of revenues, it is necessary to determine the weight of the fish alone.

Table III, which is based on Reference 12, gives some information on effective weight, the weight of fish and ice sans container. To get the weight of fish alone, it may be assumed that the weight ratio of fish to ice is 1:1, a figure given by some local fishing boat operators. The table shows that only about 40 percent of the cargo deadweight is fish.

Table III. Fish Weight vs. Fish Hold Volume

	ship 1	ship 2	ship 3	ship 4	ship 5	ship 6
fish hold volume (m^3)	77	154	152	126	1300	232
cargo deadweight (t)	65	114	117	99	1300	149
stowage factor (m^3/t) (FHV/cargo deadweight)	1.18	1.35	1.30	1.27	1.00	1.56
effective weight (fish + ice) (t)	40	90	90	75	1000	110
fish weight * (t)	20	45	45	38	500	55
$\frac{\text{fish weight}}{\text{cargo deadweight}}$	0.36	0.39	0.38	0.38	0.38	0.37

* A 1:1 fish to ice weight ratio is assumed.

For the estimate of annual revenue, the seasonal variation of fish catch must be considered. Reference 11 states a figure of 0.65 as the ratio of average landings to vessel capacity for the vessels studied therein.

Resistance and Powering

Cruising

The mathematical model for estimating EHP is based on Reference 3. Essentially, the method expresses ship resistance as a function of Fn and of six form parameters: L/B, B/d, C_p, C_m, LCB and $\frac{1}{2}\alpha_e$. Reference 3 does a regression analysis on resistance data from 130 trawler model experiments conducted over a 30-year period to come up with a single polynomial expression for the Froude resistance coefficient. Reference 3 gives the form of the equations but leaves out the coefficients. However, it gives 41 design diagrams, containing a total of 409 curves, for manual-graphical determination of the resistance coefficient. A minimum of five curves or a maximum of 17 curves have to be read depending upon the amount of interpolation necessary.

The author of this paper decided to fit equations to the given curves and electronically mimic the manual-graphical procedure. At worst, only second degree polynomials are involved, and all fit with good correlation. The coefficients of the 409 curves are stored in a random access file on a diskette to keep the number of program lines down.

The powering of trawlers is based on cruising requirements. To arrive at the required engine MCR, a sea margin, a propulsive coefficient and a cruising horsepower ratio are successively applied to the EHP.

Trawling

The power needed to trawl can only be very roughly estimated in the concept design stage. Still, its inclusion in the procedure is important in the determination of fuel oil consumption.

Reference 16 discusses loads imposed by trawling gear. Depending upon the trawling speed and kind of fish being caught (kind of net used), the fraction of engine MCR used for trawling will vary.

Two examples are given in Reference 16. A 55.93 m LBP, 12-knot ship with a 1,200 HP triple expansion engine and a fixed pitch propeller trawling at 3.2 k demands 23 percent of installed horsepower. Trawling at 4.7 k draws 49 percent. For a 22.4 m LOA ship with a 204 BHP diesel engine and a controllable pitch propeller, 36 percent of installed horsepower is required at a trawling speed of 3.5 k while 64 percent is used at 4.6 k.

The trend is towards higher trawling speeds. Modern trawlers have trawling speeds of 4.5 to 5 k [9].

Weight Estimates

Reference 2 serves as the basis for the weight estimate equations for the hull, hull outfit, main engine and auxiliary machinery. Reference 15 and Table II serve as the bases for the estimate of fresh water, stores and provisions weights.

The equations may be found in Appendix A. The variable names used are self-explanatory.

ECONOMIC EVALUATION

Figure 6, which is adopted from Reference 1, shows a decision chart for selecting a proper economic criterion to use depending upon the amount of information available. For cargo ships, the required freight rate is commonly used.

The author chooses to formulate a criterion similar to required freight rate. This is the required average fish price (RAFP). It is defined as the average fish price, after unloading from the vessel which produces equal present worth of income and expenditure, i.e., zero NPV. The design with the lower RAFP is naturally the better design. For variable cash flow:

$$\text{RAFP} = \sum_{1}^{N} \left[\frac{\text{PW (annual operating costs)} + \text{PW (ship acquisition cost)}}{\text{annual fish catch}} \right] \quad (4)$$

For uniform cash flows:

$$\text{RAFP} = \frac{\text{annual operating expenses}}{\text{annual fish catch}} \quad (5)$$

The RAFP offers the advantage of allowing an intuitive grasp of feasibility by a mere comparison of RAFP to the price of fish in the market. Since different kinds of fish command different prices, judgment will have to be exercised in the use of this criterion.

Figure 7 shows a block diagram for the determination of RAFP.

The cost estimate equations may be found in Appendix A. The variable names are self-explanatory. These equations are based on References 17, 18 and 19 with changes in coefficients to suit trawlers and Philippine conditions.

EXAMPLES

Appendix B shows the results of running the program for two sample ships. Both are assumed to be new buildings in a Philippine shipyard. Both are run on pure diesel oil, financed at 20 percent interest rate and operated at 65 percent of full-load capacity as a yearly average. Uniform cash flow is assumed. Each of the two ships is very similar to a sample ship in Table II. It is thus assured that the technical features, say $\frac{1}{2}\alpha_e$ and FHV/∇, are realizable in detail design.

The two ships have almost the same fish hold volume (126 vs. 120) and prismatic coefficient (0.600 vs. 0.605). Ship 1, however, is a smaller and slower ship. The results show how seemingly small differences in dimensions and speeds greatly affect the economic performance of the vessels. Ship 1 has an RAFP of ₱18.73/kg while ship 2 has ₱28.17/kg. The higher speed of ship 2 (11.5 vs.

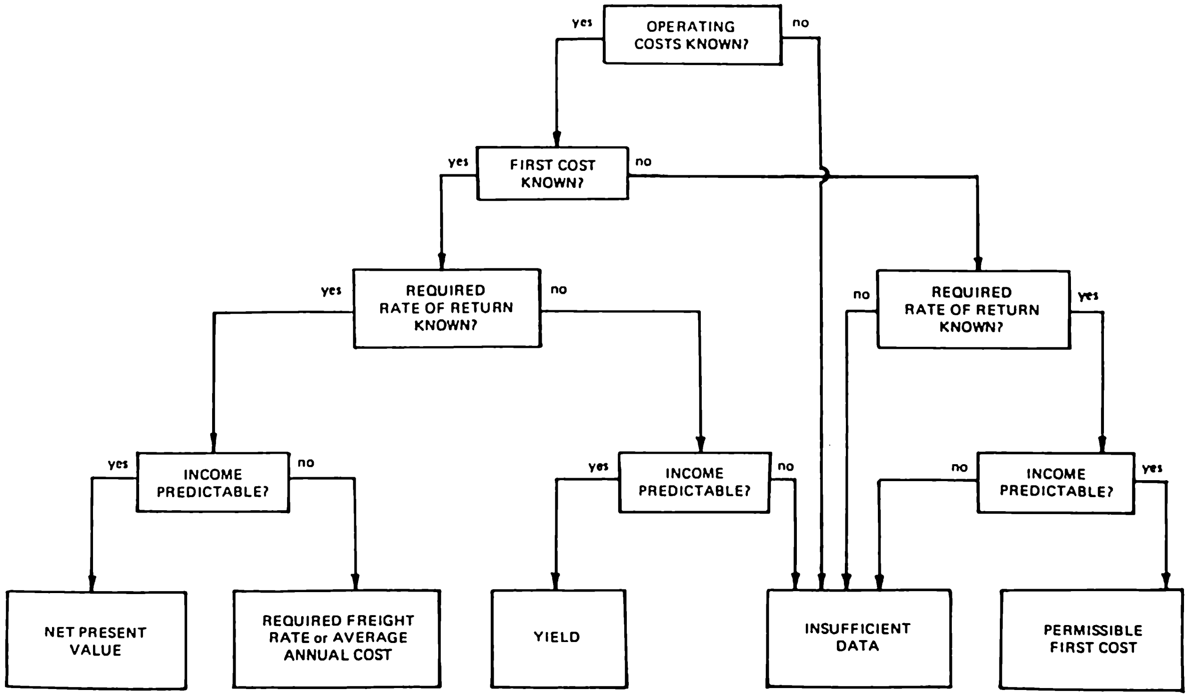

Figure 6. Decision Chart for Choice of Economic Criterion (1)

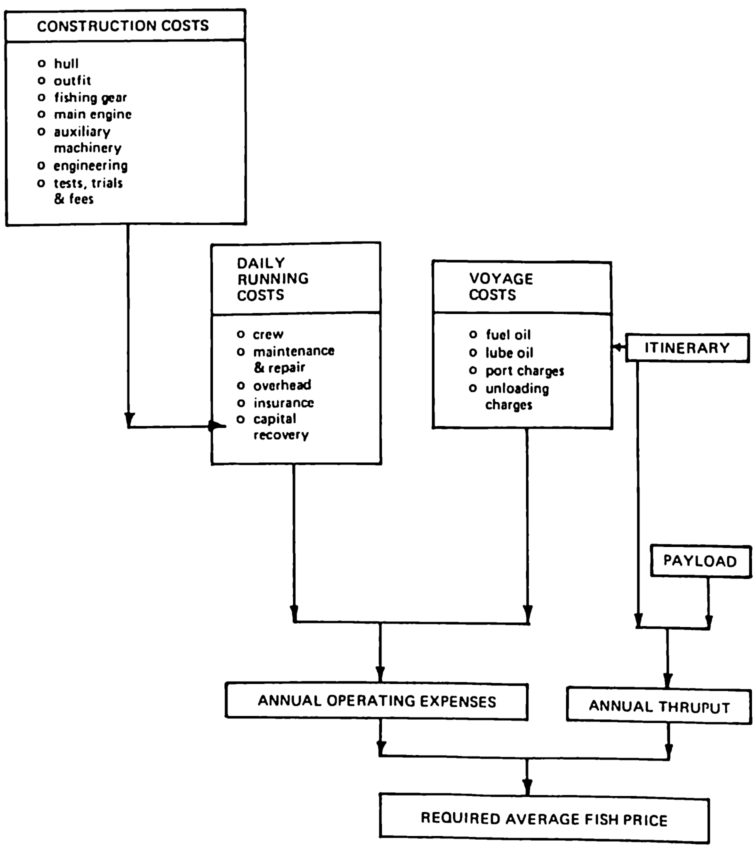

Figure 7. Determination of Required Average Fish Price

10.5k) and its bigger displacement resulted in a bigger main engine (510 PS vs. 348 PS). This ultimately led to a higher fuel consumption. The larger dimensions and engine of ship 2 drove the capital cost up to ₱11 M, versus ₱8.2 M for ship 1.

As of this writing (November 1985), the price of fish commonly found in market stalls in Metro Manila is about ₱30/kg. Ship 2 would thus be infeasible. To the RAFP must be added the markups of the boat operator, fish broker and other middlemen. It is conceivable that, starting with the RAFP of ship 1, the price may hit ₱30/kg when the fish reaches the final consumer.

If all the expenses are annualized for ship 1, it will be seen that the largest cost items are fuel oil and capital cost (See Figure 8). This makes it easier to understand the local practice of blending fuel oil even for small engines and the preference of shipowners for imported second-hand vessels.

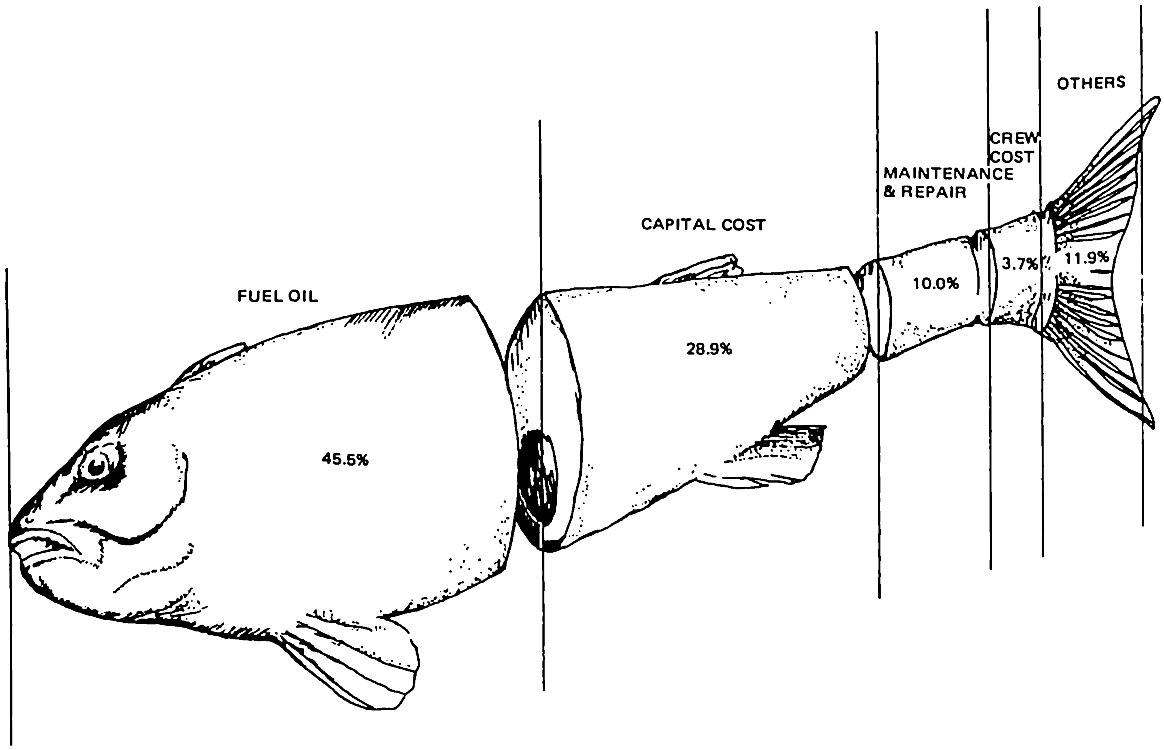

Figure 8. Cost Components of Fishing Vessel Operation

OTHER APPLICATIONS OF THE PROGRAM

Aside from concept design, the program may be used for other studies. The impact of changes in fuel oil price may be easily assessed. The financing terms that may spell the difference between feasibility and infeasibility may be studied. The effect of shipyard productivity may also be easily assessed. With slight modifications to the program, the economics of used vessel acquisition can be studied. With changes in the coefficients of the equations, the program may be made suitable for wooden trawlers or even for other types of fishing vessels.

FURTHER STUDIES

Refinements in the equations is possible with more data about Philippine yard productivity. Data about average fish price, considering seasonal variations and fish type, would be most useful. Also, information about average landings vs. vessel capacity would be most important.

NOMENCLATURE

B	=	breadth or beam of vessel, m
B/d	=	breadth to draft ratio
B/D	=	breadth to depth ratio
BHP	=	brake horsepower
C_b	=	block coefficient
C_m	=	midship coefficient
Cp	=	prismatic coefficient
D	=	depth of vessel, m
d	=	draft of vessel, m
d/D	=	draft to depth ratio
EHP	=	effective horsepower, PS
Fn	=	Froude number
FHV	=	fish hold volume, m^3
FO	=	fuel oil
FW	=	fresh water
GM_1	=	metacentric height, leaving port
GM_2	=	metacentric height, reaching fishing grounds
GM_3	=	metacentric height, beginning return journey
GM_4	=	metacentric height, reaching port
GRT	=	gross registered tonnage
HP	=	horsepower
KG	=	vertical distance from keel to ship's center of gravity, m
KM	=	vertical distance from keel to transverse metacenter, m
k	=	knot
LBP	=	length between perpendiculars, m
LCB	=	longitudinal center of buoyancy from midship, % of LBP
LOA	=	length overall, m
LWL	=	length on waterline, m
LBP/B	=	length to breadth ratio
LBP/D	=	length to depth ratio
LOA/LBP	=	ratio of length overall to length between perpendiculars
LWL/LBP	=	ratio of length on waterline to length between perpendiculars
m	=	metre
MCR	=	maximum continuous rating of engine, PS
N	=	useful life, years
NPV	=	net present value
PS	=	metric horsepower
PW	=	present worth
RAFP	=	required average fish price, ₱/kg
t	=	tonne
$\frac{1}{2}\alpha_e$	=	half entrance angle, degrees
Δ	=	vessel displacement, t
∇	=	vessel's volume displacement, m^3

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APPENDIX A

```
5000 ! ************************************** CALCULATE *************************
5010 Cubic_Number=LOA*B*D/100
5020 Cubic_Number_eng=Cubic_Number*3.2808^3
5030 ! ****************** DISPLACEMENT, SPEED & POWER *************************
5040 Cb=Displacement/(LBP*B*d*1.025)
5050 d=Displacement/(LBP*B*Cb*1.025)
5060 Cp=Cb/Cm
5070 Cm=Cb/Cp
5080 GRT=Grt_factor*Cubic_Number*Cb
5090 Displacement_eng=Displacement/1.01605
5100 L_B=LBP/B
5110 B_d=B/d
5120 Speed_length_ratio=Speed/SQR (3.28*LWL)
5130 ! ********************************** GET EHP ******************************
5140 Peso_to_dollar=18.73
5150 EHP=EHP*1.15
5160 BHP=EHP/PC
5170 MCR=BHP/HP_ratio_cruising
5180 Hull_steel_weight=Hull_stl_wt_factor*Cubic_Number_eng^.9764
5190 Hull_outfit_weight=Hull_outfit_wt_factor*Cubic_Number_eng^1.712
5200 Machinery_weight=Mchy_wt_factor*MCR^1.353
5210 Auxiliary_machinery_weight=-(.000000037741*Cubic_Number_eng^2)+.00011605*Cu
bic_Number_eng+1.0838
5220 Lightship=Hull_steel_weight+Hull_outfit_weight+Machinery_weight+Auxiliar_ma
chinery_weight
5230 Lightship=Lightship/.95
5240 Fish_gear_weight=.05*Lightship
5250 Lightship=Lightship/.95
5260 Margin=.05*Lightship
5270 Total_sea_days=Cruising_days+Trawling_days
5280 FO_weight_cruising=SFC_cruising*MCR*HP_ratio_cruising*Cruising_days*24/1000
000
5290 FOC_cruising=FO_weight_cruising/Cruising_days
5300 FO_weight_trawling=SFC_trawing*MCR*HP_ratio_trawling*Trawling_days*24/10000
00.
5310 FOC_trawling=FO_weight_trawling/Trawling_days
5320 FO_weight=1.1*(FO_weight_cruising+FO_weight_trawling)
5330 Fresh_Water_weight=.05*Total_sea_days*Crew
5340 Stores_provisions_weight=.0095*Total_sea_days*Crew
5350 Fish_weight=FHV/Stowage_factor*.4 @ Payload_weight=Fish_weight/.4
5360 Displacement=Lightship+Payload_weight+FO_weight+Fresh_Water_weight+Stores_p
rovisions_weight+Ballast
5370 ! ********************* CONSTRUCTION COSTS ******************************
5380 Man_days_hull=Manhours_hull_factor*Hull_steel_weight^.92812
5390 Labor_hull=Man_days_hull*Labor_cost
5400 Material_hull=Hull_steel_weight*Steel_cost*1.05
5410 Hull_cost=Labor_hull+Material_hull
5420 Man_days_outfit=Manhours_outfit_factor*Hull_outfit_wt^.8673
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```
5430 Labor_outfit=Man_days_outfit*Labor_cost
5440 Material_outfit=Hull_outfit_weight*Steel_cost*95/89
5450 Outfit_cost=Labor_outfit+Material_outfit
5460 Man_days_Fish_Gear=Manhours_outfit_factor*Fish_gear_wt^.8673
5470 Labor_Fish_Gear=Man_days_Fish_Gear*Labor_cost
5480 Material_Fish_Gear=Fish_gear_weight*Steel_cost*95/89
5490 Fish_Gear_cost=Labor_Fish_Gear+Material_Fish_Gear
5500 Machinery_cost=Machinery_cost_factor*MCR^.685*Peso_to_dollar
5510 Mandays_auxiliary_machinery=Man_days_aux-mchy_factor*Auxiliary_machinery_we
ight
5520 Labor_auxiliary_machinery=Mandays_auxiliary_machinery*Labor_cost
5530 Material_auxiliary_machinery=Auxiliary_machinery_weight*Steel_cost*6
5540 Auxiliary_machinery_cost=Labor_auxiliary_machinery+Material_auxiliary_machi
nery
5550 Yard_overhead=(Labor_hull+Labor_outfit+Labor_Fish_Gear+Labor_auxiliary_mach
inery)*1
5560 First_cost=Hull_cost+Outfit_cost+Fish_Gear_cost+Machinery_cost+Auxiliary_ma
chinery_cost+Yard_overhead
5570 Shipyard_engg=Shipyard_engg_factor*First_cost
5580 Test_Trial_Fees=Test_Trial_factor*First_cost
5590 First_cost=First_cost+Shipyard_engg+Test_Trial_Fees
5600 Average_cost=Multiple_ship_factor*First_cost
5610 Owners_engg=Owner_engg-factor*Average_cost
5620 Owners_inspection=Owner_insp_factor*Average_cost
5630 Owners_outfit=8000*Cubic_Number*Peso_to_dollar
5640 Total_cost=Price_adjustment_factor*(Average_cost+Owners_engg+Owners_inspect
ion+Owners_outfit)
5650 ! ******************************************** ITINERARY ******************

5660 Operating_days=365-Yard_days
5670 Voyage_days=Total_sea_days+Port_days
5680 Voyages_per_yr=Operating_days/Voyage_days
5690 Operating_hrs=Total_sea_days*Voyages_per_yr*24
5700 ! ******************************************** DAILY COSTS *************
5710 Crew_daily_cost=Crew_cost*No_Crew
5720 Crew_daily_subsistence=Crew_subsistence*No_Crew
5730 Hull_steel_Maintenance_Repair=Hull_MR_factor*Hull_steel_weight
5740 Hull_outfit_Maintenance_Repair=Outfit_MR_factor*Hull_outfit_weight
5750 Fish_Gear_Maintenance_Repair=Fish_gear_MR_factor*Fish_gear_weight
5760 Machinery_MR_factor=Peso_to_dollar*factor*(MCR/1000)^.42
5770 Machinery_Maintenance_Repair=Machinery_MR_factor*Operating_hrs
5780 DDS=Drydocks_surveys*DWT
5790 Total_Maintenance_Repair=(Hull_steel_Maintenance_Repair+Hull_outfit_Mainten
ance_Repair+Fish_Gear_Maintenance_Repair+Machinery_Maintenance_Repair+DDS)/365
5800 Overhead_daily=Overhead_factor*(Crew_daily_cost+Crew_daily_subsist+Total_MR
)
5810 Hull_Machinery_insurance=HM_ins_factor*Total_cost
5820 War_risk_insurance=War_risk_ins_factor*Total_cost
5830 Increased_value_insurance=Inc_val_ins_factor*Total_cost
5840 Protection_Indemnity_insurance=PI_ins_factor*GRT
5850 Total_insurance=(Hull_Machinery_insurance+War_risk_insurance+Increased_valu
e_insurance+Protection_Indemnity_insurance)/365
5860 CRF=Discount_rate/(1-((1+Discount_rate)^((-1)*Useful_life)))
5870 Capital_recovery=CRF*Total_cost/365
5880 Daily_running_cost=Crew_daily_cost+Crew_daily_subsistence+Total_Maintenance
_Repair+Overhead_daily+Total_insurance+Capital_recovery
5890 ! ******************************************** VOYAGE COSTS ***************
5900 FO_cost=Fuel_oil_price*(FO_weight_cruising+FO_weight_trawling)
5910 LO_cost=Lube_oil_price*Lube_oil_sfc*HP_ratio_cruising*MCR*Cruising_days*24/
923
5920 LO_cost=LO_cost+Lube_oil_price*Lube_oil_sfc*HP_ratio_trawling*MCR*Trawling_
days*24/923
5930 Port_cost=Port_charges*GRT
5940 Unloading_cost=Unloading_charges*Payload_weight
5950 Voyage_cost=FO_cost+LO_cost+Port_cost+Unloading_cost
5960 ! ****************************************************** RAFP **************

5970 Annual_operating_cost=Daily_running_cost*365+Voyage_cost*Voyages_per_yr
5980 Annual_thruput=Fish_weight*Load_density*Voyages_per_yr
5990 RAFP=Annual_operating_cost/Annual_thruput/1000
6000 ! ********************************************************************
```

APPENDIX B

SAMPLE SHIP 1

PRELIMINARY PARTICULARS

DIMENSIONS

LOA	(m)	30.80
LBP	(m)	27.50
LWL	(m)	29.00
B, mld	(m)	6.25
D, mld	(m)	3.45
d, design, mld	(m)	3.12

HULL COEFFICIENTS

Cb	.505
Cp	.600
Cm	.842

HULL PROPORTIONS

LBP/B	4.40
LBP/D	7.97
B/D	1.81
B/d	2.00
d/D	.90

OTHER PARTICULARS

Fish hold volume	(m^3)	126
Stowage factor	(m^3/tonne)	1.393
Range	(days)	26
No. of crew		13
Cubic number	(English)	235
GRT	(estimated)	161

RESISTANCE & POWERING

LCB	(% Aft)	1.52
1/2 entrance angle	(degrees)	23.0
Cruising speed	(knots)	10.5
Froude No.		.32
EHP	(with 15% sea margin)	181
BHP		279
MCR		348
Propulsive coefficient	(%)	65
% MCR cruising		80
% MCR trawling		60
FUEL CONSUMPTION		(tonne/day)
Cruising		1.14
Trawling		.85

WEIGHTS & DISPLACEMENT (tonne)

		(tonne)
Hull	91	
Hull outfit	27	
Machinery	5	
Auxiliary machinery	1	
Fishing gear	7	
Margin	7	
LIGHTSHIP		137
Fuel oil	30	
Fresh water	17	
Ballast	0	
Stores & provisions	3	
Payload	90	
DEADWEIGHT		141
DISPLACEMENT		278

ECONOMIC ANALYSIS

FINANCIAL CONDITIONS

Discount rate		.20
Useful life	(years)	25
Capital recovery factor		.20

ANNUAL THRUPUT

Fish Catch	(tonne)	36
Average landings/capacity		.65
Annual thruput	(tonne)	305

CONSTRUCTION COSTS

Cost of labor	(₱/man-day)		45
Cost of steel	(₱/tonne)		8,700
No. of ships to be ordered			1
Hull steel		₱	938,624
Hull outfit			306,155
Fishing gear			77,736
Machinery			5,234,493
Auxiliary Machinery			59,944
Shipyard engg			203,954
Test, trials & fees			101,977
Yard overhead			181,529
Owner's engg & inspection			71,044
Owner's outfit			995,125
Total price per ship		₱	8,170,581

ITINERARY

Yard days/yr	15.0
Cruising days/voyage	18.0
Trawling days/voyage	8.0
Total days at sea/voyage	26.0
Port days/voyage	1.0
Total days/voyage	27.0
Voyages per year	13.0

DAILY RUNNING COSTS

Crew cost	₱	585
Crew subsistence		195
Maintenance & repair		1,559
Overhead		234
Total insurance		560
Capital recovery		4,524
Total daily running costs	₱	7,657

VOYAGE COSTS

Fuel oil	₱	200,189
Lube oil		7,608
Port charges		33
Unloading charges		2,714
Ice		14,246
Total voyage cost	₱	224,789

ANNUAL OPERATING EXPENSES: ₱ 5,708,636

REQUIRED AVERAGE FISH PRICE: ₱ 18.73/kg

SAMPLE SHIP 2

PRELIMINARY PARTICULARS

DIMENSIONS

LOA	(m)	35.85
LBP	(m)	32.00
LWL	(m)	33.50
B, mld	(m)	6.85
D, mld	(m)	3.90
d, design, mld	(m)	3.25

HULL COEFFICIENTS

Cb	.499
Cp	.605
Cm	.825

HULL PROPORTIONS

LBP/B	4.67
LBP/D	8.21
B/D	1.76
B/d	2.11
d/D	.83

OTHER PARTICULARS

Fish hold volume	(m^3)	120
Stowage factor	(m^3/tonne)	1.393
Range	(days)	26
No. of crew		13
Cubic number	(English)	338
GRT	(estimated)	229

RESISTANCE & POWERING

LCB	(% Aft)	1.52
1/2 entrance angle	(degrees)	23.0
Cruising speed	(knots)	11.5
Froude No.		.33
EHP	(with 15% sea margin)	298
BHP		459
MCR		510
Propulsive coefficient	(%)	65
% MCR cruising		90
% MCR trawling		60
FUEL CONSUMPTION		(tonne/day)
Cruising		1.87
Trawling		1.25

WEIGHTS & DISPLACEMENT (tonne)

		(tonne)
Hull	131	
Hull outfit	50	
Machinery	8	
Auxiliary machinery	1	
Fishing gear	10	
Margin	11	
LIGHTSHIP		210
Fuel oil	48	
Fresh water	17	
Ballast	0	
Stores & provisions	3	
Payload	86	
DEADWEIGHT		154
DISPLACEMENT		364

ECONOMIC ANALYSIS

FINANCIAL CONDITIONS

Discount rate		.20
Useful life	(years)	25
Capital recovery factor		.20

CONSTRUCTION COSTS

Cost of labor	(₱/man-day)	45
Cost of steel	(₱/tonne)	8,700
No. of ships to be ordered		1
Hull steel	₱	1,338,169
Hull outfit		564,280
Fishing gear		117,536
Machinery		6,796,415
Auxiliary Machinery		60,473
Shipyard engg		274,473
Test, trials & fees		137,236
Yard overhead		272,218
Owner's engg & inspection		95,608
Owner's outfit		1,435,067
Total price per ship	₱	11,091,475

VOYAGE COSTS

Fuel oil	₱	320,563
Lube oil		12,182
Port charges		45
Unloading charges		2,584
Ice		13,574
Total voyage cost	₱	348,949

ANNUAL THRUPUT

Fish catch	(tonne)	34
Average landings/capacity		.65
Annual thruput	(tonne)	290

ITINERARY

Yard days/yr	15.0
Cruising days/voyage	18.0
Trawling days/voyage	8.0
Total days at sea/voyage	26.0
Port days/voyage	1.0
Total days/voyage	27.0
Voyages per year	13.0

DAILY RUNNING COSTS

Crew cost	₱	585
Crew subsistence		195
Maintenance & repair		2,048
Overhead		283
Total Insurance		760
Capital recovery		6,142
Total daily running costs	₱	10,012

ANNUAL OPERATING EXPENSES: ₱ 8,177,829

REQUIRED AVERAGE FISH PRICE: ₱ 28.17/kg