社会開発調査部報告書

Commission for the study of alternativeces to the Panama canal : the study of alternatives

COMMISSION FOR THE STUDY OF ALTERNATIVES
TO THE PANAMA CANAL

THE STUDY OF ALTERNATIVES TO THE PANAMA CANAL
(COMPONENT STUDY : ENGINEERING AND COST ESTIMATES)

PHASE 1 : PRELIMINARY ENGINEERING AND COST ESTIMATES

ANNEX

Feb. 1992

YACHIYO ENGINEERING CO., LTD.
under the contract with
JAPAN INTERNATIONAL COOPERATION AGENCY

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ANNEX 1 : ALTERNATIVES FOR UPGRADING TRANSIT CAPACITY ACROSS THE PANAMANIAN ISTHMUS

1.1 Historical Development of Alternatives

The most exhaustive study undertaken to evaluate alternative routes for a sea-level canal across the American Isthmus was executed during the period of 1965 to 1970 under the title of "Atlantic-Pacific Interoceanic Canal Study Commission" and also often referred to as the Anderson Report or IOCS Study.

The studies that preceded the IOCS study and as described in the report of that study, are briefly as follows:

- 1929-1931: US Army Interoceanic Canal Board
  Purpose: Determine the practicability of providing additional locks and other facilities at the Panama Canal and practicability of constructing a ship canal elsewhere on the American Isthmus.
  Results: Recommended that; (1) Madden Dam be constructed; (2) consideration of a canal across Nicaragua be continued; and (3) no immediate steps be taken to provide more facilities to increase traffic capacity.

- 1936-1939: Third Locks Project Study
  Purpose: Increase the canal capacity, and propose designs and cost estimates of facilities needed.
  Results: Recommended construction of a third set of locks, excavation for which began in 1940 but was suspended in 1942.

- 1945-1947: Isthmian Canal Studies
  Purpose: Investigate the means of increasing capacity and security of the Canal to meet future needs of interoceanic commerce.
  Results: Recommended that the Canal be converted to a sea-level canal.

- 1949: Special Canal Study - Atrato-Truando Route
  Purpose: Check reliability of surveys of this route.
  Results: Confirmed the validity of conclusions of the 1947 study regarding this route, ie. that conversion of the Canal to sea-level could be accomplished for less cost.

- 1957-1960: Ad Hoc Committee for Isthmian Canal Plans
  Purpose: Determine adequacy of the Canal to meet needs of commerce to 1999, and recommend plans for improvement if required.
  Recommended; (1) completion of an improvement program costing US$ 90 million; (2) initiation of planning for construction of a sea-level canal outside the Canal Zone by nuclear methods; (3) development of nuclear excavation technology; and, (4) planning to construct a sea-level canal in the Canal Zone if plans are not made to construct a sea-level canal by nuclear methods by the early 1970's.

- 1957-1960: Board of Consultants, Isthmian Canal Studies
  Purpose: Investigate short- and long-range plans for operation, improvement, and other matters relating to the adequacy of the Canal.
  Recommended: (1) continued studies of new methods of conventional construction; (2) further development of nuclear excavation; (3) no sea-level canal construction in the near future; and (4) another review of the situation by 1970.

- 1963-1964: Isthmian Canal Studies, 1964
  Purposes: Update traffic projections and plans to meet them and to summarize information on a sea-level canal construction by nuclear methods.
  Results: Updated previous studies for a sea-level canal, particularly one to be constructed by nuclear means, and presented detailed analyses of plans to improve the existing lock canal, including a third locks plan.

- 1967-1969: Improvement Program for the Panama Canal-1969
  Purposes: Develop and test improvement plans to increase capacity of the present canal.
  Results: Development of a plan which could increase yearly traffic to 26,800 transits.

The IOCS study was undertaken "for the purpose of determining the feasibility of, and the most suitable site for, the construction of a sea-level canal connecting the Atlantic and Pacific Oceans; the best means of constructing such a canal, whether by conventional or nuclear excavation, and the estimated cost thereof." The IOCS study examined the routes described in Table 1.2.1, through data collection and analysis, conceptual designs and construction cost estimates of the various alternatives, and comparison of the alternatives.

Among the IOCS study's many recommendations the main ones were as follows;

- Creation of an Isthmian canal system including both existing Canal and a sea-level canal on Route 10.

- Acquisition of the Route 10 right of way as soon as possible.

- That construction of a sea-level canal be initiated on Route 10 no later than 15 years in advance of the estimated saturation date of the present canal, projected by the study to occur during the last decade of this century.

- Modernization of existing canal so that its maximum potential transit capacity be accomplished, but no additional locks be constructed.

- That the US pursue development of the nuclear excavation technology, but not postpone Isthmian canal policy decisions because of the possible establishment of feasibility of nuclear excavations at some later date.

An analysis of the above events would indicate the IOCS study ended the debates on the improvement of the existing canal by adding new locks or the construction of a new sea-level canal by clearly supporting the sea-level canal option. The study shelved the idea of use of nuclear excavation. The study however, was not conclusive on the important issue of the environmental impacts the sea-level canal would generate, and may have over-estimated the traffic demand forecasts as can be seen from the actual decline in traffic during the past two years (PCC Annual Reports). Elimination of the alternative calling for the construction of new locks, recommended by the study, may therefore be premature under the present conditions.

Table 1.1.1 Alternative Sea-Level Canal Routes Studied by IOCS

Route No.	Route Name	Country	Length (statute miles)	Divide Elevation (feet)	Reasons for selection/rejection by IOCS
5	San Juan del Norte-Brito	Nicaragua and Costa Rica	177	153	Rejected as sea level canal because it requires draining of Lake Nicaragua. Studied as a lock canal for comparative purposes, but rejected because construction cost found to be too high.
8	San Juan del Norte-Salinas Bay	Nicaragua and Costa Rica	176	760	Selected for further study as the most favourable sea-level canal option in the Nicaragua-Costa Rica area. Eliminated due high construction costs.
10	Chorrera-Lagarto	Panama	53	430	Selected for further study as sea-level canal for comparision with Route 14. Was identified as the most advantageous sea-level route by the study.
14	Panama Canal Sea-Level Conversion	Panama	54	390	Selected for further study as sea-level canal. Route 10, being separated from the existing Canal was found to far outweigh potential difficulties of this route. Two alternatives were studied, 14S (separate from existing canal) and 14C (combined). 14S was more favourable.
15	Panama Canal (Lock Canal only)	Panama	61	Existing Channel	Studied as a lock canal for comparative purposes. Will increase capacity and number of transports possible, but limitation of future expansion and possible need to pump salt water in Gatun Lake were disadvantages.
17	Sasardi-Morti	Panama	77	1000	Studied as sea-level canal to be constructed by nuclear excavation. Nuclear excavation technology deemed unapplicable. Most favourable of nuclear excavation routes studied.
23	Atrato-Cacarica-Tuira	Panama and Colombia	146	450	Studied as sea-level canal at request of Colombia. Eliminated due to great length, technical disadvantages and economic disadvantages for Panama.
25	Atrato-Truando	Colombia	103	932	Studied as sea-level canal, nuclear excavation method. Although cheaper than R17, C&M costs much higher, and also political disadvantages.

Source : by P.C.C. Report

The pace of studies fell during the 1970 decade, picking up again in 1981 with the release of the results of the Nagano Plan prepared by a Japanese consortium calling for the construction of a sea-level canal along Route 10 of the IOCS study, but with the addition of various facilities. The Vergara Plan followed in 1982, again proposing the adoption of Route 10 with some modifications.

"The Panamanian Alternative" was introduced in a report published in 1982 by a group of Panamanian firms. This alternative advocated the improvement of the existing canal by the construction of new locks and was opposed to the construction of a sea-level canal.

The major alternatives studied so far are described in the following sections.

1.2 Culebra Cut Widening Project

The Cut is described in a Panama Canal Commission 1985 Report as a 14.5km long section of the waterway carved mostly through rock and shale. Coming from the Atlantic Ocean, ships enter the Cut at Gamboa where the Chagres River flows into the Canal channel. A short distance before reaching Pedro Miguel Locks, the ships pass Gold Hill on the left, which rises 202m above sea level. The original excavated channel width at Culebra Cut was 92m. During the 1930's and 1940's, the straight section immediately north of Gold Hill was widened to 153m to provide a passing section for large ships, and during the period 1957-1971, the remaining portions of the Cut were also widened to 153m.

In July 1991, the Panama Canal Commission announced that a US$200 million project to widen the Culebra Cut will commence in 1992 using the resources available at PCC for the dredging excavation work while employing outside contractors to implement the dry land work.
The project calls for the excavation of 26 million m3 of earth and rock to widen the Cut section from 153m to 192m along tangents and 223m with transitions from and to 192m, in curve sections. The widening objective is to permit two-way traffic through the divide, and thereby the entire Canal.

1.3 Lock Improvement Plans

(1) The Third Locks Plan

This plan was reviewed in the IOCS report and updated in the Transisthmian Alternatives report. In 1936 a study was launched with the objective of increasing the capacity of the existing Panama Canal. The study recommended a third lane of locks, construction of which commenced in 1939. Excavation for the third locks at Gatun and Miraflores and design of structures and appurtenances were almost complete when the project was suspended in 1942, due to the war. The work did not resume after the war ended.

This plan, subsequently modified, calls for deepening the ocean approaches and the Culebra Cut and construction of one additional lane of locks 43m by 370m by 15m adjacent to each existing set. The new locks could pass 105,000 DWT ships. In conjunction with the existing locks, the Canal's annual transit capacity would be increased. The IOCS report quotes this capacity as 35,000 ships annually, however in a recently published report (Transisthmian Alternatives, 1988, by D. Bastian) this figure was downgraded to 20,600 or an average of 56 ships per day. Cost estimates for this .pm7

(2) Terminal Lake Plan

The IOCS report states that this plan was first considered in the design of the existing canal, and was proposed again in 1943. Two new one-lane sets of locks, of dimensions 61m by 457m by 15m, would be added adjacent to the existing Gatun and Miraflores locks. Such larger locks could accommodate 110,000 DWT ships. Raising Miraflores Lake level to that of Gatun Lake would provide an anchorage area above the Miraflores locks, reducing navigation hazards at the Pacific end of the Cut. Pedro Miguel Locks would be abandoned, while the existing two locks at Gatun and Miraflores would continue in operation. IOCS report quotes the annual transit capacity as 35,000 ships, however the transisthmian alternatives report downgraded this figure to 20,600. Cost estimates for this plan were calculated as $946 million in 1970, and

revised to $4.3 billion by 1988 prices.
Variations of this plan call for replacing the locks at Gatun and Miraflores with two lanes of locks 43m wide and 366m long, having minimum depth of 14m. Ships of 80,000 to 110,000 DWT would be accommodated, depending on the Gatun Lake level. Modifications of the dam and spillway at Gatun would be required to regulate the lake at 25m and 27m. A terminal lake at Gatun Lake level would be formed above the new Miraflores Locks improving conditions for navigation. Raising the lake level would offset the need for major excavation, however environmental changes will result. This variation was described in a Congressional Bill and was not detailed.

(3) Deep Draft Lock Plan

This plan was developed by the IOCS study as Route 15, to incorporate the most desirable features of the previously proposed lock canal plans in order to accommodate ships up to 150,000 DWT. The plan calls for adding a lane of triple-lift locks measuring 442m by 49m by 20m to the existing two lanes at Gatun and constructing a separate lane of triple-lift locks of similar dimensions at Miraflores bypassing the Pedro Miguel Locks and Dams.

The ocean approaches would be widened to 396 m and deepened to 23m. The Culebra Cut would be deepened to 20m. The total excavation was estimated to be about 428.4 million m3 and require a construction period of 10 years.

This plan was considered to have the advantage of permitting continued operation of all existing locks throughout their useful lives. The IOCS report states that an annual transit capacity of 35,000 ships would be accommodated, however the Transisthmian Alternatives report downgraded this figure to 20,600. Cost estimates were calculated as $1.5 billion in 1970, and revised to $4.8 billion by 1988 prices.

(4) Lopez Moreno Plan

This plan was presented in the 1982 report titled "Interoceanic Canal: The Panamanian Alternative" and further discussed in the Transisthmian Alternatives report of 1990. The plan calls for increasing the ship size capacity to 250,000 DWT through major channel excavation, the building of two new sets of locks, constructing a storage reservoir and the lowering of the water level of the existing Canal.

Substantial structural and other configuration changes are required under the plan. Gatun Lake would be lowered; Pedro Miguel Locks and Dam and the upper chamber of Gatun Locks would be eliminated; the existing two lower chambers of the original two lanes of Gatun Locks would remain in place. Two more lanes of new locks would be constructed utilizing the excavation completed for the Third Locks Plan.

The larger set of the new locks would consist of two lifts measuring 427m by 58m with a minimum of 23m of water over the sills. The second set of new locks would be built to accommodate smaller ships. They would be triple-lift structures measuring 213m in length and 23m in width. The combination of smaller chamber size and triple lift was chosen to conserve water.

Culebra Cut would have to be widened to 244m and the Gatun lake channels to 427m. The ocean approaches would also need to be deepened to provide a 26m channel depth.

Under this plan a new storage reservoir was proposed to eliminate the water management problems posed by other schemes. This plan would require an excavation of approximately 612 million m3. The cost quoted in the Panamanian Alternative report was $3.9 billion, which the 1990 report revised to $4.4 billion in 1988 prices. The 1990 report considered this cost to be under-estimated when compared to the conditions and costs of the Route 15 alternative.

The Panamanian Alternative report presented a comparative study of the plan and the sea-level Route 10 alternative. The study was basically opposed to the construction of a sea-level canal citing the associated huge costs, resulting social upheavals, and insufficient hydrological studies.

1.4 Sea-Level Canal Alternatives

(1) IOCS Route 10

This route was studied in great depth by the IOCS study and was recommended as the best sea-level canal route. The findings of that study will be described hereafter.

Data

The adequate climatic and hydrologic records available for the Canal Zone area were extrapolated to Route 10, and on site geologic investigations were conducted.

Route Location

The Pacific terminus of the route is at the town of Puerto Caimito at the mouth of Caimito River. The trace follows the river northwestward for 8km, crossing the Pan American Highway about 4.8km northeast of La Chorrera. It continues to the north through generally open, rolling terrain; crosses the Continental Divide through the Chorrera Gap; and parallels the Pescado River until it reaches an arm of Gatun Lake at La Laguna. Turning in a more westerly direction, the trace continues over relatively flat terrain and crosses the Trinidad Arm of Gatun Lake, to a point about 4.8km southwest of the town of Escobal. From there it runs northwesterly through low ridges which become more open toward the coast. It enters the Atlantic at the town of Lagarto. The Atlantic approach channel would be only 3.2km long; however, that on the Pacific would require 24.1km of underwater excavation, extending past Taboga Island. The total length of the alignment, including approaches, is 85.3km; its peak elevation is about 122m. The route plan is shown in Fig. 1.4.1.

Construction

The IOCS study proposed that most of the excavation along the route be done by open-pit mining techniques. Dredges would be employed for the approach channels excavation and the layer of muck at the bottom of Gatun Lake. Barrier dams would maintain Gatun Lake at levels needed for the uninterrupted operation of the Panama Canal during construction, and at the same time allow for excavation at controlled water levels or in the dry.

Most of the streams on Route 10 would be relatively easily diverted into the Caribbean Sea, and the Caimito River would be the only major river to discharge into the canal. Construction requirements would include a transisthmian highway crossing Gatun Lake over the barrier dams; breakwaters on the Caribbean coast; a jetty on the Pacific; and a high-level bridge over the canal.

Reduction of tidal currents would require the use of tidal checks. Under a 2-knot current limitation, expansion beyond the minimum design capacity would require construction of a bypass. The alignment was considered well suited for a centrally-located bypass, excavated through the Gatun Lake reach.

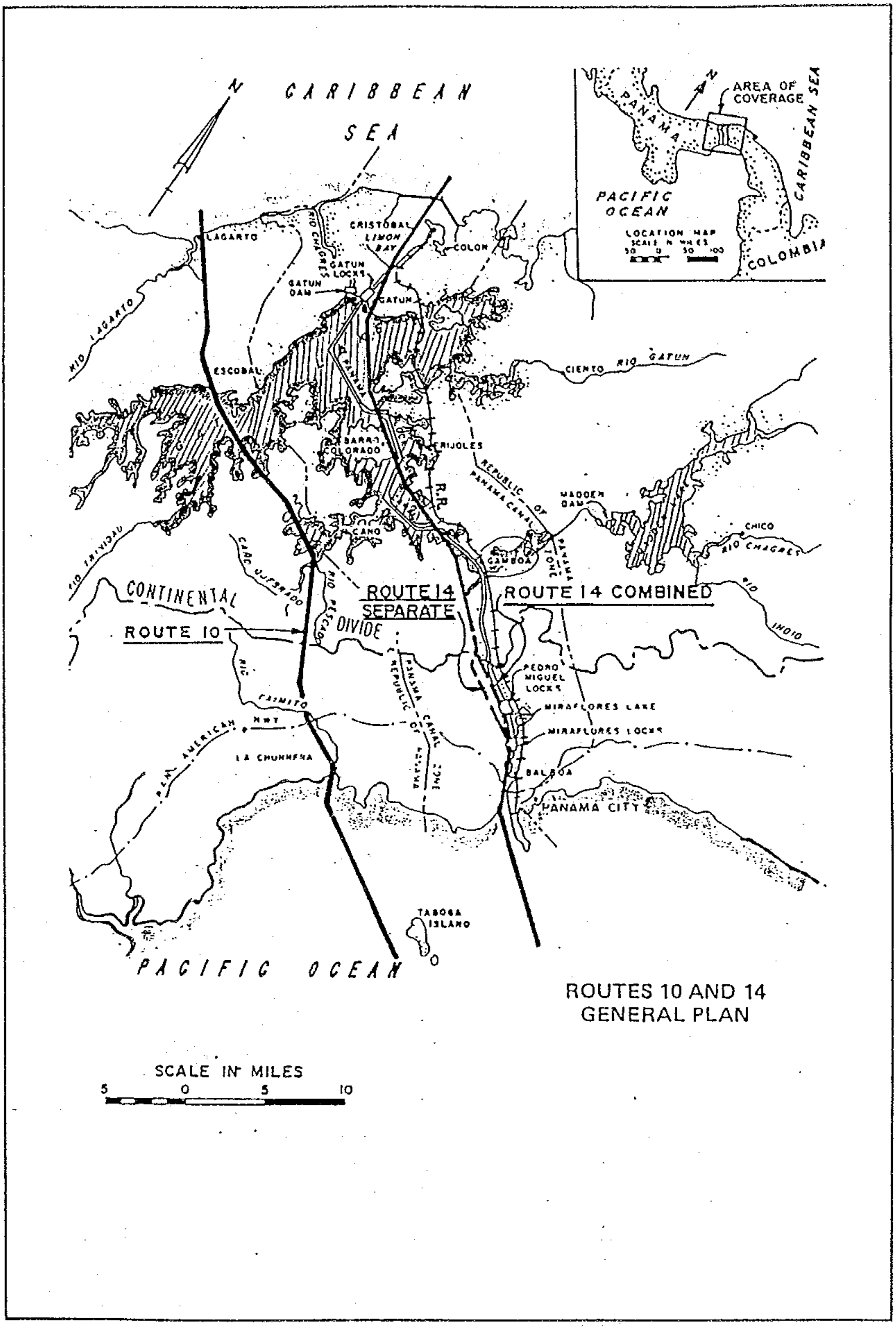


Fig. 1.4.1 Routes 10 and 14 Sea-Level Canal Alternatives

Source : by P.C.C. Report

The IOCS summed up the main characteristics of Route 210 as follows (based on a 58km design channel and 427m by 26m ocean approaches);

Canal dimensions	168mx23m (26m max. depth)
Length of land cut	58km
Length of approaches	27.4km
Design ship	150,000 DWT (250,000 DWT in favorable conditions)
Construction time	14 years
Capacity	38,000 transits/year
Excavation volume	1.43 billion m3
Total construction cost	US$2.88 billion

The total construction cost was revised to $8.9 billion in 1988 prices by the Transisthmian Alternatives study. The annual transit capacity was also recalculated by the same study to be 22,000 annually.

Problem Areas

The IOCS study considered that the most critical engineering problems involved the geology of the divide area, which mostly consists of a hard basalt cap overlying much weaker materials. Softrocks, similar in strength to those along the Panama Canal, were found at the depth of the navigation channel. These highly altered volcanic rocks have the undesirable properties of clay shales. The study recommended detailed investigations to verify slope angles required for stability in the divide area, or modifications of such angles during construction.

In the design of the barrier dams, particular attention to the poor foundation material in Gatun Lake and the stability of fill material in embankments was considered necessary. Throughout the construction period, the lake would have to be maintained at present levels, thus creating hydraulic heads of over 46m when dry excavation reaches the bottom of the cut. Although failure of those dams was highly unlikely, the study pointed out that its occurrence would have disastrous effects on the new canal construction as well as the existing canal operation and safety.

The relatively short length of the alignment and high Pacific tides would cause currents greater than 2 knots in an unrestricted channel for short periods of almost every tidal cycle. Should ships be unable to transit safely in currents faster than 2 knots, continuous use of tidal checks would be required, limiting capacity to 38,000 transits yearly, as then estimated.

The physical conditions at either end were concluded to be unfavorable to shipping. On the Atlantic coast, breakwaters would be necessary to overcome the lack of natural protection. The Pacific coast was found to offer more protection but the approach channel would have to be dredged about 24.2km into the Gulf of Panama.

(2) IOCS Route 14S

This route was studied in great depth by the IOCS study. The findings of that study will be described hereafter.

The IOCS study considered two different alignments along this route; Route 14C Combined and Route 14S Separate (Fig. 1.2.1). Route 14C involves deepening and widening of the present Culebra Cut, while Route 14S requires a new cut through the divide about 1.6km southwest of the present cut.

While the combined cut in the case of Route 14C was estimated to offer considerable savings in the volume of excavations because of the lower elevation of the divide, the separate cut, Route 14S, permitted excavation in the dry to project depth in the Divide area. A major disadvantage of the Route 14C alignment was its interference with the operation of the existing canal during the construction period due to widening works in the Culebra Cut area. Furthermore excavation to 26m below sea level in the Cut could induce slides that would block the existing canal for long periods. These and other disadvantages led the IOCS study to conclude that Route 14S would be the preferable sea-level canal alignment within the existing Canal Zone, regardless of its slightly greater costs.

Route Location

On the Pacific side Route 14S coincides with the approaches to the present lock canal until it reaches the Pacific Third Locks cut where it passes through an 12.9km separate cut through the divide. The route then generally follows the alignment of the Panama Canal northeast of Cerro Gordo, continuing toward Gatun Lake, keeping southwest of the present canal until it reaches the Darien peninsula. Turning slightly northward then, it passes Barro Colorado on the east, touching the end of Bohio Peninsula. The route then turns north across Gatun Lake and enters the Atlantic Third Locks cut. It then follows the present canal into the Caribbean. The pacific approach channel is 20.9km long; that on the Atlantic is 12.9km. The total length of this alignment, including approaches, is 86.9km; the highest elevation is about 121.9km.

Construction

This route would require two principal excavation efforts; dredging across Gatun Lake and cutting through the divide. Across Gatun Lake deep dredging techniques would be employed, using hydraulic dredges for soft muck, dipper dredges for rock at shallow depths and barge mounted draglines for rock at deeper depths. Construction plugs would maintain the present level of the Panama Canal to maintain operations while the construction work is in progress. Much of the excavated material would be used as fill materials in the permanent flood control dams on either side of the alignment. As the final step of the construction phase, Gatun Lake would be drawn down and the sea-level canal placed in operation. Pools behind the flood control dams would be maintained at an elevation of 17m.

Costs of facilities to support route construction and operation were considered to be affected by existing development within the Canal Zone. The necessary harbors, communications, and utilities already exist and could be used as they are. Other facilities, as channels and anchorages, might have to be modified. Mobilization for construction on this route was considered to be easier than other routes.

The minimum project was considered to have two-lane

(427m) approaches and a 53km single lane section cut to the design channel dimensions. Tidal checks would be installed to maintain current velocities at 2 knots or less.

The IOCS summed up the main characteristics of the route as follows (based on a 53 km design channel and 427m by 26m ocean approaches);

Canal dimensions	168mx23m (26m max. depth)
Length of land cut	53km
Length of approaches	34km (21 miles)
Design ship	150,000 DWT (250,000 under favorable conditions)
Construction time	16 years
Capacity	39,000 transits/year
Excavation volume	1.49 billion m3
Total construction cost	US$3.04 billion

The annual transit capacity was also reviewed by the Transisthmian Alternatives Study and was estimated at 22,200 annually.

Problem Areas

The IOCS study considered the geology of the divide to be poorly suited for deep cuts. Route 14S was proposed to lessen the possibility of slides blocking the Panama Canal for long periods during construction of a sea-level canal, however the risk of major slides into the present canal remains.

Conversion of the canal's operations from locks to sea level would take between 1 and 3 months, during which time all canal traffic would be suspended. The conversion operation itself would be complex.

The poor foundation material underlying the flood control dams and the possible instability of their fill material would be countered by making them massive and by building them on a blanket of select material. Construction of these dams in water depths of up to 24m would demand special care. Because the Gatun Lake reach would be excavated by dredging, the hydraulic head on these dams would not be as great as that developed on the Route 10 barrier dams.

The route topography does not lend itself to a bypass. Increased capacity could be achieved by widening the channel in from the Atlantic Coast and across Gatun Lake to two lanes and reducing the length of the single-lane section.

(3) Vergara Plan

This plan was presented in the 1982 report titled "El Canal A Nivel" and was further described in the 1990 Transisthmian Alternatives report. Both reports were used to prepare this description.

The plan follows Route 10 proposed in the IOCS and described above. The plan calls for a channel of 300m in width with a 30m centerline depth, to be achieved through 2 billion m3 of excavation. The entire length, including ocean approach channels, is 93.4km. The construction cost was estimated in the 1982 report to be $15 billion dollars. This figure was revised to $17.5 billion in the 1990 report.

The plan calls for developing harbors at either end by constructing breakwaters from dredged material, to neutralize the effects of the tides as well as to provide safe anchorage. The huge embankment at the Pacific side, which would extend about 19.3km offshore, was calculated to eliminate the need for tidal gates.

Although transit capacity was not addressed in the plan, it was considered by the 1990 study to be greater than that of the IOCS sea-level proposals. The description of the geological conditions and route are presented in the Route 10 alternative description.

The El Canal A Nivel report makes a comparison between this route and the two alternatives of Route 10 and the Lopez-Moreno Plan. The comparison favored the Vergara plan for various reasons, some of which are mentioned below;

- Equipment and personnel required for this alternative are less than those required in the lock canal.
- Superiority in ease, safety and speed of transit.

- Potential for future expansion.
- Security of the waterway.

(4) Nagano Plan

In 1981 the Nagano Plan was launched by a Japanese consortium. A description of this plan is described in a number of documents produced by the consortium during the period of 1981 to 1983 in English and Japanese, and the Transisthmian Alternatives study carries a review of the plan. These reports have been used to describe this alternative as follows.

At the urging of Mr. Nagano, President of the Japanese Chamber of Commerce, a Japanese group of construction companies set up a consortium, the KPTM Group, and prepared a study solely focused on the engineering aspects of this alternative.

Route Location

The route adopted by this plan is that of Route 10, and therefore the route description presented for Route 10 is applicable for this plan.

Construction

To insure that there are only minimal affects to Gatun Lake's water level by the construction of this plan, and that water supply continues to be available for the existing canal, barrier dams are planned to be built prior to the commencement of excavation works for the new canal. A part of the coffer of these dams will be built in the water and will be cutoff structures.

Diversion channels will be built in order to regulate the water level of the lake, which will be isolated by the barrier dams. The volume of water that flows into the lake from rivers and streams was estimated to be 3 million ton/day.

The particulars of the plan are as follows;

Total Length	98 km	
Pacific Ocean Approach	35 km	
Inland Canal	58 km	
Atlantic Ocean Approach	5 km	
Dimensions;	Width	Depth
Pacific	400 m	-35.3 m
Inland	200 m	-33.0 m
Atlantic	400 m	-33.1 m

Transiting Ships;	
Normal	300,000 DWT
Occasional	500,000 DWT
Construction Period	10 years
Excavation Volume	1.8 billion m3

The proposed route was divided into four zones for which construction methods and quantity calculations were estimated. Most of the excavated material is planned to be dumped at available valleys nearest to the borrow area or in offshore areas in both oceans. Part of the excavated material would be utilized for land reclamation for port facilities and construction of barrier dam and breakwaters.

No mention was made of the construction cost in the KPTM reports, however the 1990 report put the total construction cost at US$16.2 billion. The 1990 study commented that this plan would compound the environmental issue of connecting the oceans, and also disrupt circulation in the metropolitan portion of the Gulf of Panama with the construction of a breakwater from the mainland to Taboga Island.

The same study added that neither capacities nor tidal velocities were addressed in the plan, but that concerning traffic, the ungated free-flowing sea-level canal would be unrestricted except if tidal velocities exceeded safe navigation requirements.

(5) Centerport Plan

This plan has been described in the draft final report of the "Strategic Master Plan for the Development of Panama Centerport" (1988) and the Transisthmian Alternatives study (1990). The following description has been prepared based on these documents.

Concept of Plan

The concept of the Centerport plan is to improve the ports of Cristobal and Balboa and their connecting railroad to facilitate container cargo transshipment operations. The ports would be used as major load centers for interlinking and feeder services and an improved railway would supplement the canal's transshipment operations.

The market for transshipment services would be the worldwide containerized cargo traffic, specifically the segment of traffic transiting the Panama Canal, as well as the commercial movements of Latin American and Caribbean countries. In addition, local containerized cargo (import-export, Colon Free Zone) would also be handled by Centerport.

Plan Execution

At present the volume of cargo handled by the two ports of Cristobal and Balboa are roughly the same, at 300,000 to 350,000 tons/year each. Each of the ports has an installed capacity of 1.5 to 2 million tons.

The plan calls for upgrading and expanding the container ports at Balboa and Cristobal. Construction of new terminals are also proposed at the islands of Telfers on the Atlantic side and at Diablo Heights on the Pacific. The project would be implemented by phases during a 10-year period, and the costs were estimated in the 1988 report to be $323 million. In the final stage of the project shipping services would be available for a total container handling capacity of 1.3 million TEU annually (approximately 12.7 million tons).

The report describing the plan does not offer any discussions for improving the railroad connecting the two ports or the associated costs.

ANNEX 2 : PRINCIPAL CONCEPTS OF OPERATION AND CAPACITY

2.1 General

The operational capacity of a canal is dependent upon transit times through its various elements. Those times will vary with the size of ship so that capacity, measured as the number of transits, will vary with the make-up of the fleet expected to use the canal.

Capacity will also depend directly upon the speed and spacing of the ships as they pass through the canal which, in turn, depend upon the cross-sectional area of the canal and the safe stopping distances for the different classes of ship.

Currents will be low in a locked design and may be ignored but for a sea level canal without tidal check gates they would be a significant factor in the safety of transit. They would affect stopping distances and consequently the separation distances which could safely be adopted. They would also increase the difficulties in mooring ships which have stopped because of an emergency.

Once details of the expected fleet are known and a potential market established, the number of ships using the canal would be estimated by simulating traffic through the canal assuming random arrivals both in time and size of ship. At this stage insufficient data are available to set up a suitable simulation model. For the purposes of report capacity has been estimated by using and "average" ship. The properties of the average ship are the result of a review of the lockage times in the existing canal and a prediction of the fleet composition in 2010 made by Manalytics Inc.

2.2 Ship Speed

The increase in ship size envisioned for the improved canal introduces new factors in the choice of ship speed through the canal. Very large ships, which are all bulk carriers of oil (VLCC's), ore and possibly grain are under-powered when compared with smaller ships. In consequence, their speed in restricted waters is much reduced. Extensive model studies for the Suez Canal Development in 1976-77 showed that, without adopting uneconomically large area ratios, a 250,000 DWT ship would be unlikely to be able to attain a speed of 15km/hr and that a speed of 13km/hr should be assumed for those ships.

2.3 Stopping Distances

Hulls of very large ships are more liable to damage from stranding than those of smaller ships and must not be allowed to go around. Most large bulk carriers have only one propeller and stopping such a vessel in an emergency requires tug assistance because the ship becomes very hard to control at speeds below about 6km/hr. Tugs also reduce the stopping distance to a practicable value of about 2,100 m which, with a following current of 1m/sec, increases to about 2,500 m. Where stoppage is due to combined engine and rudder failure these distances would be increased by 80%. A "Crash" stop in which the engine is put full astern should never be adopted with a large ship in restricted waters. It can be a very dangerous maneuver as control of direction is lost completely.

2.4 Separation Distances

In addition to the greatest stopping distance, separation distances must include allowances for reaction time and clearance from the ship ahead after the maneuver has been completed. Reaction time includes both the human reaction and that of engines. Observation of full size trials held in the Suez Canal led to a figure of 750m for reaction time, at a convoy speed of 13 km/hr. Separation distance being measured from bow to bow, a reasonable clearance allowance of twice the ship's length would result in a final clearance between ships of one length.

Small ships are more maneuverable and have more room in a canal designed for larger ships and can sail safely at a closer spacing than would be possible for large bulk carriers. Suez Canal experience has been included in their regulations, which specify a minimum interval of 6 minutes between ships of less than 30,000 DWT at a convoy speed of 14 km/hr with progressively larger separations as ship size increases. Based on those established intervals together with the results of the studies of

VLCC's recommended separation distances, converted to time at a convoy speed of 13 km/hr, for ship sizes in the following ranges are:

Greater than 150,000 DWT	27 minutes
Between 100,000 and 150,000 DWT	25
Between 60,000 and 100,000 DWT	15
Between 30,000 and 60,000 DWT	10
Less than 30,000 DWT	6

Observed separation distances are greater and an average 50% greater than the above figures has been assumed when calculating canal capacity.

2.5 Canal Cross-Section Design

Canal cross-section design must allow for:

An area ratio increasing from 4.5 to 5.0 with increasing size of design ship to enable large ships to maintain a speed of 13 km/hr.

A minimum lane width at keel level of 2.8B where B is the design vessel beam. This is based upon experimental measurement of lane width for a 250,000 DWT ship in a canal with area ratio 4.8.

Allowances for clearance under the keel, squat, dynamic trim and siltation.

The area ratio is the cross-sectional area of the water, including the area over the sideslopes, divided by the nominal cross-sectional area of the design ship (Beam x draught; ignoring squat). It should not be less than:

4.5 for	100,000 DWT
4.8	250,000
5.0	300,000

No widening of lane width at bends is required if the lane width is at least 3B. Where widening is necessary, it affects ships least if the transition is on the inside of the bend.

Lane width was determined for the Suez Canal after considering the influence of bank suction and course keeping errors and making allowances for the desirability of limiting the rudder movement needed to keep within the specified lane width. Previous work by the Suez Canal Authority showed it to be desirable that the rudder angle should not exceed 15° for more than 10% of the navigation time. Course error was found to be ±0.2B, the error associated with basic controllability and wind was ±0.25B and to keep bank effects under reasonable control these combined errors should not exceed 0.16 times the width of canal at keel depth. From this it follows that the width of canal should not be less than 2.8B. (See T.F.D. Sewell in PIANC Bulletin 1978 No 28).

Side slopes proposed for the Panama Canal are generally steeper than those of the Suez Canal and a paper by M Fuehrer shows that the bank effects are greatly influenced by the steepness of the side slopes. For complete confidence that lane width assumptions are justified, similar work to that carried out for the Suez Canal Authority needs to be undertaken using the side slopes applicable to the Panama Canal.

A minimum clearance of 5% of the draught should be provided between keel and canal bottom after allowance for squat and dynamic trim has been made. There is little difference in the sum of squat and dynamic trim between ships in the 100,000 to 250,000 DWT range when sailing in a canal with an area ratio for the largest vessel of 4.8. In such a cross section and for a ship trimmed to be level when sailing in deep water, squat plus dynamic trim would be about 1.1m.

A siltation allowance must be added to the clearance and will depend upon the material of the canal bank and any silt deposited by rivers. In readily eroding soils, the rate of erosion is very sensitive to ship speed and area-ratio.

Power demands at a given speed are dependent upon the depth to draught ratio as well as the area ratio. The values given for area ratio assume that the depth to draught ratio will not be less than 1.15. This requirement will, in general, be met by the proposed depths of water except for some deep draught ships in the 150,000 DWT class.

2.6 Currents

Handling lare bulk carriers in a canal appears to be a little easier with a following current and worse in a head current. Neither requires modification of a cross-section designed for still water. Stopping a large ship in an emergency, however, becomes impossible without tug assistance with a following current and is another reason for all large ships to be attended by tugs throughout a transit of the canal.

Cross currents of as little as 0.5 m/sec could cause serious difficulty in handling a large bulk carrier, chiefly because of the inability of a pilot to sense that his ship is being affected until a shear has already started. There is then too little room in which to regain control and a stranding becomes likely. The PIANC supplement to Bulletin No. 35 "The optimal layout and dimensions of fairways for large ships" refers to the handling of large ships in these circumstances.

If a pilot can be informed of the intensity of the current immediately before the ship enters it, some anticipation of the resulting ship behaviors is possible which might alleviate the problems. Without such an information system the velocity of the cross current should be reduced by a suitable diffuser to a value low enough not to produce a noticeable deviation of the ship's course.

2.7 Tugs

Tugs will be required to attend all large ships which may experience difficulty and risk damage should an emergency stop be required. This would include all bulk carriers of 100,000 DWT and larger. Container ships and car carriers also become difficult to steer at speeds much below 14 km/hr when there is a strong cross wind. However, simulator trials showed that twin-screwed ships of that type could be stopped safely in adverse conditions without tug assistance and tug escort for these ships is unlikely to be necessary.

Tug numbers per ship depend upon the intensity of following current and cross-wind. For ships of 250,000 DWT and above, two tugs would be sufficient in currents of up to 0.5 m/sec. Three tugs would be required for currents of 1 m/sec. Transit of large bulk carriers should not be attempted in current velocities greater than 1.0 m/sec.

Tugs would require to have a bollard pull of from 50 to 60 tonnes to be effective in escorting ships of more than 150,000 DWT and the stern tug should make the transit attached by a bridle to the escorted vessel. In trials in the Suez Canal it was found best to allow the bow tug to run free ahead of the ship it was escorting. For smaller ships, 40 tonne tugs would be adequate and would run free during the transit. Particular attention will be necessary in tug design to ensure that the tugs will be directionally stable when being towed. Tank testing has shown that vectored thrust units should be aft and that large skegs may promote instability under tow.

2.8 Ship Size Distribution

The following size distribution of ships using the existing canal was predicted by Manalytic Inc for 2010 in terms of Panama net tonnage and is shown in the table below. Estimates of equivalent gross and deadweight tonnage have been added. These are approximate as no authoritative comparison between net and deadweight tonnage is available.

Table 2.8.1 Ship Size Distribution

NT	GRT	DWT	Percentage of transits 1985	2010
5,000	8,300	12,500	20.0	0.31
10,000	16,600	25,000	60.0	2.35
15,000	25,000	38,000	10.0	7.56
20,000	33,000	50,000	8.0	14.59
25,000	42,000	63,000	2.0	75.19

For the purposes of estimating the canal capacity it has been assumed that 75% of the fleet will be equal to or larger than 63,000 DWT with smaller ships being distributed as above.

2.9 The Average Ship

Relay locking times (ie. time interval between successive ships passing the same point) and lock transit times or lock passage times (ie. time taken by one ship to pass through the locks) are critical for determining the capacity of a lock canal. Since details the mix of ship sizes in the likely fleet are not yet known it is not possible to set up a model to simulate and examine the effects of the random arrival of ships. It has therefore been necessary to estimate capacity using the concept of an "average" ship.

Using the distribution of ship size given for 2010 in section 2.8, together with the relay locking times given by Marine Traffic Control for Gatun, the total relay time for 100 ships has been calculated. From this total the average relay time per ship has been obtained by dividing by 100. The results are given in Table 9.1. Note that the relay time for the largest size is estimated as no figure is given in the pilot's manual.

Table 2.9.1 Estimation of Average Relay Time for Gatun

Ship (DWT)	Relay time (Hours)	No. of ships	Total time (Hours)
63,000	1.42	75.19	106.7
50,000	1.25	14.59	18.2
38,000	0.75	7.56	5.7
25,000	0.58	2.35	1.4
12,500	0.58	0.31	0.2
		Total	132.2
Average relay time for 1 ship			1.32 hours

Similar calculations may be made for Miraflores and Pedro Miguele. Both relay and transit times are given below but it should be noted that relay is not possible at Pedro Miguele, there being only one lock. For that case the relay figure is equal to the transit time.

	Relay	Transit
Gatun	1.32 hours	2.05
Pedro Miguele	1.10	1.10
Miraflores	1.10	1.50

2.10 New Lock Transit Times

New locks at Gatun for large ships are to be two lift rather than three. Lock basins will be larger but the overall length will be smaller. Time savings will arise form the omission of one cycle of movement and lock filling but filling times of the larger basins will probably be longer offsetting some of the savings. Further savings should be possible by providing a sufficient number of mules to avoid the need for relay while not delaying the start of the next locking. Escape tracks which allow mules to pass one another will be necessary for this method of working to be possible.

As estimate of transit times through the new locks, using durations observed for the larger ships using the existing canal, is as follows:

Secure mules	3.0 minutes
Move to 1st level	27.7
Fill 1st level	15.0
Move into 2nd level	19.0
Fill 2nd level	15.0
Retain mules	11.1
Clear 2nd level	18.0
Total	108.8

Relay times would comprise the 2nd, 3rd and 4th items plus the time to spill water from the first level, assumed to be 15 minutes. Thus the relay time or the frequency of passage would be about 76 minutes. A figure of 80 minutes has been assumed for capacity calculations.

For the new locks at Miraflores transit and relay times will be the same as those for Gatun. Assumed transit and relay times for new locks are:

	Transit	Relay
Gatun	1.82 hours	1.33 hours
Miraflores	1.82	1.33

2.11 Canal Transit Capacity Restraints

For the purpose of reviewing the likely order of capacity in the improved canal two cases are considered. The first is a high rise locked system on Route I while the second is a sea level canal on Route 10. The limited data on ship mix is not likely to be representative of traffic for any of the cases considered in the Engineering Feasibility Report because it makes no allowance for the larger ships which could transit any of the schemes under consideration. Their presence would reduce the number of transits possible but would increase the total cargo passing through the canal. Nevertheless, the following illustrates the likely order of canal capacities.

2.11.1 Locked Canal

Restraints to the number of transits will exist at the three sets of existing locks, two new sets of locks and at Culebra Cut. Although it has been decided that the Cut will be widened, the proposed section does not appear adequate for VLCC's to pass each other safely. Some single-way working may still be necessary.

Throughput at each of the lock groups may be estimated from the figures given above. Assuming no restraint, that is each lane of locks operates continuously in one direction, the capacities per day for 4 lanes (2 existing and 2 new) would be:

	Existing	New(transits/day)
Gatun	36.4	36.0
Pedro Miguel	43.6	-
Miraflores	43.6	36.0

Thus the canal capacity would be constrained by that of Gatun to an average of 72 standard ships per day, equally divided between north and southbound directions. By comparison a two lane channel could accommodate 128 average ships per day, based on a separation time between ships of 22.5 minutes. In 24 hours 24 x 60/22.5 = 64 ships would pass in each lane.

Alterations of direction through a lane of locks would result in loss of capacity in that the lane must be cleared before the first ship from the new direction could enter. At Gatun, the loss would amount to about 30 minutes per change of direction.

In general, no reduction of capacity will be caused by a narrow section provided the daily throughput of the locks in one direction can pass the narrow section in half a day and sufficient mooring space is available at both ends of the narrow section to accommodate those ships which have to wait their turn.

No waiting space has been provided between Pedro Miguel locks and the Gaillard Cut and this would act to reduce the number of possible transits. The effect is illustrated on the transit diagram which is Fig. 2.11.1. No stoppage arises at the locks when a southbound convoy is followed by one going north but the first ship of the southbound convoy must wait until the last northbound ship clears the Cut before it can proceed. No ship can pass through the locks for about 2.5 hours. This would reduce the capacity through Pedro Miguel to about 32 transits per day; a penalty of about 4 ships.

A similar delay would occur at new locks at Miraflores if large ships were to be unable to pass each other in the Gaillard Cut (see Fig. 2.11.2) with a similar penalty of 4 ships/day.

It would appear to be practicable to provide berthing space for, say, 8 ships above the locks at Pedro Miguel and at Miraflores, thus avoiding the penalty at rather less cost than the widening of 12km of canal through the central divide.

2.11.2 Sea Level Canal

Considerations of safety in the event of an emergency in the canal precludes operating VLCC's and other large vessels in currents stronger than 2 knots (1 m/s). Thus from previous work it would be essential to provide tidal check gates in a sea level canal. It would also be advisable to open or shut those gates at times when tidal currents are at a minimum. This occurs at half tide intervals of about 6.25 hours. The terms of reference specify that 50% of the canal's length shall be single lane with the remainder dual lane and equally divided between the Pacific and Atlantic ends. It is of interest to examine the capacities for various layouts assuming that gates will be moved either every half tide. The results confirm that the configuration given in the terms of reference will achieve a reasonable capacity but shows that an increase of 60% in capacity would be achieved by using a 12.5 hours cycle with the longest possible single lane section.

In the general case of a single lane canal with two gates separated by a distance 'a' and distant from unrestricted water by distances 'b' and 'c' respectively (see Fig. 2.11.3) two equations can shown to hold. These link the length of the convoy (a x r) to the distances 'a', 'b' and 'c' and to the velocities of the convoys. A clearance between the first ship of a convoy and a closed gate of 10 minutes (0.167 hours) has been assumed together with a clearance of 15 minutes (0.25 hours) between the last ship of one convoy clearing the canal and the first ship of the next to enter in the reverse direction.

Reference to Fig. 2.11.3 will show that the total elapsed time for the first half of the cycle, which is shown in the first four diagrams, is:

$$0.25+(a(1+r)+2b)/v1.$$

This equals one half tide of 6.25 hours giving the equation:

$$(a(1+r)+2b)/v1 = 6.0.$$

Similarly the time to complete the cycle of events is:

$$0.25+(a(1+r)+2c)/v2.$$

This is also equal to 6.25 hours and leads to a second equation:

$$(a(1+r)+2c)/v2 = 6.0,$$

where v1 is the speed with which the convoys enter and leave one end of the canal and v2 is the comparable speed at the other end.

For gate movements every tide the half cycle time is 12.5 hours leading to similar equations but with the right hand side becoming 12.25.

The effects of varying the five parameter can best be seen by tabulating r, v1 and v2 for different combinations of 'a', 'b' and 'c' (see Table 2.11.1).

Cases 1 to 10 assume that the gates would be operated at half-tide intervals and that the separation of average ships is 22.5 minutes at 13 km/hr. It will be noted that, only as the distance between the gates is reduced to about 24 km will the space between the gates be fully occupied by a convoy, unless the operating speed is increased to more than 13 km/hr. Maximum cpapcity would be about 7,000 transits a year and would be attained if the gates are symmetrically placed and at least 20 km apart. This follows because the total length of channel governs the length of convoy which can evacuate the canal and be replaced by a convoy of similar length within the time one gate remains open. Given the assumed speed of the convoys (13 km.hr) and the total length of canal (58 km) the maximum length of convoy is about one third of the canal length. The minimum distance between gates must therefore be long enough to accommodate the maximum length of convoy. A shorter distance between gates would truncate the convoy length without altering the frequency of apssage and would reduce the total capacity of the canal.

The maximum length of convoy can most readily be calculated by assuming the gates to be at the ends of the canal so that b and c in the equations become zero and V1 becomes equal to v2 as the convoy speeds in both directions are constant. Then:

$a(1+r) = 6.0v$,

If $v = 13$ km/hr and $a = 58$ km, we have:-

$1+r = 6.0 \times 13/58 = 1.345$ thus:-

$r = 0.345$.

Maximum convoy length then becomes 0.345 x 58 = 20 km.

If the gates were to be operated every 12.5 hours but all other conditions were to remain unchanged, there would be more than sufficient time to fill the space between the gates whatever the distance separating them. For convoys to operate without stopping to await the next gate opening, speeds would be less than 13 km/hr. Under these conditions maximum capacity would be achieved by placing the gates as far apart as possible (ie at the canal entrances, 58 km apart) and would amount to about 11,200 transits a year (see Table 2.11.1).

Table 2.11.1 Capacity of single Lane Canal: Varying Gate Positions

Case	Sector length (km) a	b	c	r	Speed km/hr v_1	v_2	Convoy length	No of ships	Transits/ 25hrs	Transits/ years	Comments
a) Gates operating every 6.25 hours											
1	58	0	0	0.138	11	11	8.0	2.6	8	2,800	
2	58	0	0	0.345	13	13	20.0	5.1	20	7,000	Max convoy length
3	58	0	0	0.5	14.5	14.5	29.0	6.4	24	8,400	Max speed exceeded
4	48	10	0	0.208	13	9.7	10.0	3.0	12	4,200	
5	40	18	0	0.05	13	7.0	2.0	1	4	1,400	Single ship in convoy
6	38	20	0	0	13	6.33	0	1	4	1,400	ditto
7	48	5	5	0.417	13	13	20.0	5.1	20	7,000	
8	40	9	9	0.5	13	13	20.0	5.1	20	7,000	
9	30	14	14	0.667	13	13	20.0	5.1	20	7,000	
10	20	19	19	1.0	13	13	20.0	—	—	—	Convoy fills space between gates without cleanrance
11	24	17	17	0.83	13	13	20.0	5.1	20	7,000	Total clearance 18.5 minutes between gates
b) Gates operating every 12.5 hours											
12	58	0	0	1.746	13	13	101.3	—	—	—	Convoy too long
13	58	0	0	0.94	9.2	9.2	54.5	16.8	32	11,200	Maximum capacity
14	48	10	0	1.9	13	13	91.2	—	—	—	Convoy too long
15	48	10	0	0.93	9.2	9.2	44.6	13.9	26	9,100	
16	36	11	11	0.91	7.4	7.4	32.8	12.8	24	8,400	

Notes:

a + b + c = 58 km
r = convoy length/distance between gates
Ships at 22.5 minutes spacing
10 minutes clearance between gate and first ship of convoy
15 minutes clearance between convoys
Maximum convoy speed 13 km/hr

If two-lane channels were to be extended inland from the coasts, capacity would be controlled by the length of the intervening single lane canal. Thus b and c of the general case would become zero and capacity would increase as the length of single channel decreases, as shown in Table 2.11.2 below.

Table 2.11.2 Capacity of single lane canal connecting dual lane canals

Single channel length (km)	r	Convoy length (km)	No of ships	Transits /year
58	0.345	20	5.1	7,000
50	0.56	28	6.7	8,400
45	0.733	33	7.8	9,800
41	0.902	37	8.6	11,200

Note: The convoy length of 37km gives 18.5 minutes clearance which is a little less than stipulated (20 minutes).

The maximum capacity occurs when the convoy length matches the space between the gates as shown in the last lines of the table. For lengths less than 41km the convoy length would be restricted and capacity would be reduced. No benefit would be gained if the gates were to be operated on a 12.5 hour cycle as to achieve a maximum capacity equal to that shown in the table would require 58km of single channel. This would be identical to the case considered in the second part of Table 2.11.1.

Dualling the single lane section of canal would double the capacities given in Table 2.11.2. With gates operated at 6.5 hour intervals the optimum length of the gated section would be 41km while for 12.5 hour intervals the gated section would comprise the whole length of the canal (58km) with a similar maximum capacity of 22,400 average ships/year (see Fig. 2.11.4).

2.11.3 Locked See Level Canal

An alternative way to operate a sea level canal would be to provide a single, low lift, lock to isolate the two oceans from each other. This would be placed at one end of the single channel section. The advantage of such a system would be that sufficient lanes could be provided through the locks to ensure that the capacity of the channel would determine the canal transit capacity. It would also allow any convenient cycle time to be used and would not be tied to the tides.

Considering the "average" ship with a separation of 22.5 minutes and a speed of 13 km/hr. If "a" is the length of single lane canal and a 12 hour operating cycle is used, the first ship to enter the canal at the end remote from the lock would arrive at the lock a/13 hours later. This would leave 12 -a/13 hours for successive ships to transit the lock. Based on existing operational times at Pedro Miguel, but recognizing that the fill/spill times would be less, the transit time might be:-

	Minutes
Secure mules	3
Move into lock	25
Fill/spill	5
Move out of lock	25
Spill/fill	5
	63 = 1.05 hours

The number of ships able to transit in the remainder of the 12 hour period would be (12 - a/13)/1.05 per lane of locks. With an arrival frequency of 60/22.5=2.67 ships an hour, the separation distance would control capacity when (Number of lock lanes)/1.05>2.67. Three lanes would satisfy this condition.

With a section of single lane channel, transit capacity would be dependent upon the length of restricted channel and the number of lock lanes as shown in the following table.

Table 2.11.3 Transit Capacity for Varying Lengths of Single Lane Channel

a(km)	Transits/day			Transits/year		
	1 lane	2 lanes	3 lanes	1 lane	2 lanes	3 lanes
58	7	14	20	5,100	10,200	14,600
45	8	16	22	5,800	11,600	16,000
29	9	18	26	6,500	13,100	18,900

Adopting longer cycles than 12 hours would reduce the effect of traveling time along the canal; for example with a 24 hour cycle, 29 km single lane section and 3 lock lanes the capacity would become 21,100 ships per year.

Dualling throughout the canal and providing six lanes of locks could give a capacity of 46,700 average ships a year.

2.11.3 Summary of Canal Capacities

Maximum transit capacities of the different schemes are summarized in the following table:

Table 2.11.4 Summary of Canal Capacities

Scheme	Operational cycle (hrs)	Length of gated section (Km)	Annual transits (average ships)
a. Locked canal			
Existing	--	--	12,400
Widened existing	--	--	13,100
New with single lane section	--	--	12,400
New dual lane throughout	--	--	13,100
Combined total of enlarged existing and new	--	--	26,000
b. Sea level canal			
Single lane throughout	6.25	24	7,000
"	12.50	58	11,200
Single lane between gates	6.25	41	11,200
"	12.50	58	11,200
Single lane with 3 lock lanes	12.00	41	16,700
"	12.00	29	18,900
Dual throughout	6.25	41	22,400
"	12.50	58	22,400
Dual throughout	12.00	any	46,700

In practice, transits are likely to be fewer in number because of the difficulty in achieving with regularity the control assumed. Among the factors which would reduce canal capacity are:

1. Intervals between ships exceeding those assumed.
2. Failure of ships to form into a convoy at the time required.
3. Insufficient ships to make up a full convoy.
4. Greater proportion of large ships than assumed.
5. Maintenance requirements.
6. Unforeseen stoppages during passage.

2.12 Conclusions

The number of ships which can pass through a canal in a given period depends upon safe separation distances between ships, convoy speed and the operational arrangements of the canal. It is also sensitive to the distribution of ship size in the fleet wishing to use the canal. Predictions of the fleet to be expected are not yet available and use has been made of a prediction for the existing canal in an earlier study. This showed a marked increase in the expected numbers of ships approaching Panamax size but did not include any VLCC or ULCC vessels. The properties of an "average" ship have been deduced from that prediction after taking into account the transit times through the existing canal and those properties have then been used to assess comparative capacities for different schemes.

The average ship approximates to a bulk carrier of 60,000 DWT. Intervals between ships in a convoy have been based on Suez Canal experience and the assumed convoy speed is that proposed for the Suez Canal when large bulk carriers form part of a convoy.

The existing canal has a capacity of about 12,400 transits per year of the average ship. This will be increased slightly to about 13,100 once the canal is able to operate as two lanes throughout its length. Similar capacities are predicted for the new locks although, with the proposed canal cross-section there are good grounds to doubt the possibility of safe two-way operation for the largest ships.

Experiments for the Suez Canal showed that it would be unwise to operate large bulk carriers in following currents in excess of 1 m/s. thus a sea level canal would need to include gates to control currents which would otherwise arise from the difference in water levels between the Caribbean and Pacific.

Various configurations of single and dual channels have been considered for a sea level canal. Any arrangement including a single lane section and tidal gates would be limited to a maximum of about 11,000 transits per year for a canal with tidal gates (possibly up to 19,000 using a lock system) while dual channel configurations would permit double that capacity or around 22,000 transits per year for a canal with tidal gates (possibly up to 47,000 using a lock system). Optimum arrangements of gate positions and operational cycle (the gates would be opened or shut either every 6.25 hours or 12.5 hours) would depend upon channel configuration. For a locked system the maximum potential of the channel could be achieved with transits through a single channel of up to 19,000 per year or through dual channels of 47,000 per year.

The choice between canal configuration is unlikely to be controlled by considerations of capacity but rather by the feasibility of construction, operation and cost. This study of capacity, however, identifies essential features of any configuration if it is also to develop its full potential for transit capacity.

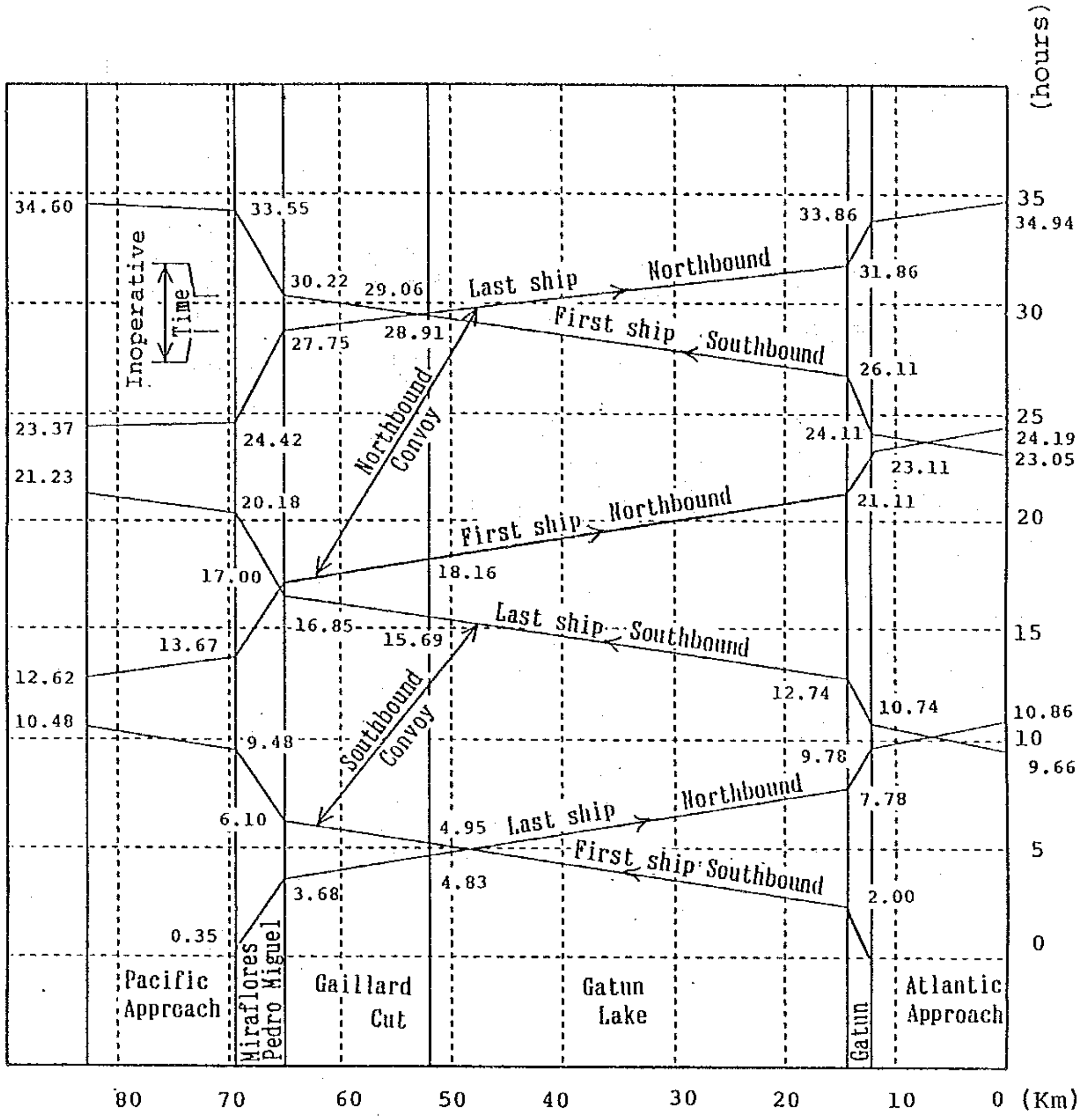


Fig. 2.11.1 Existing Locks: Average Ship Convoys

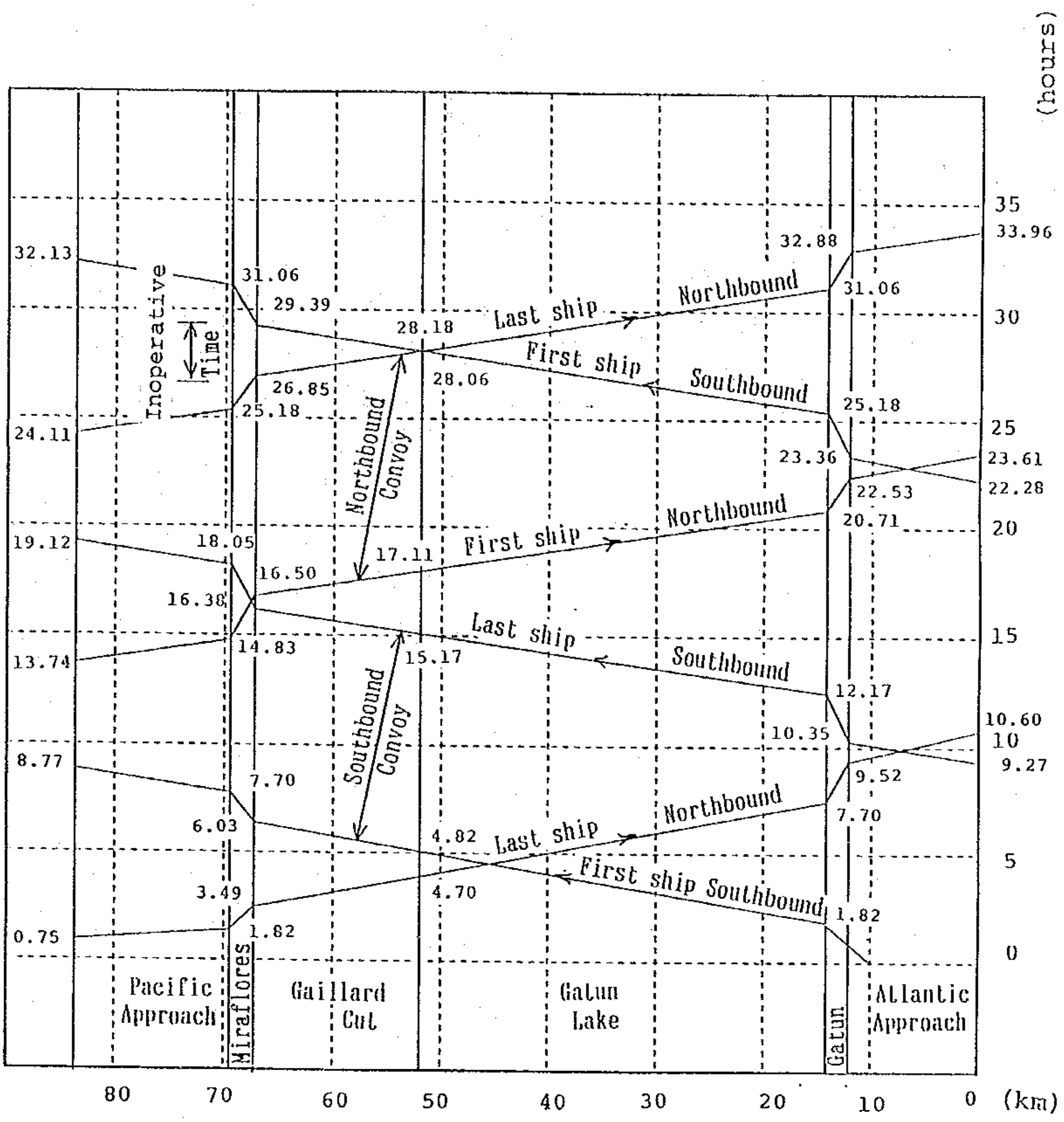
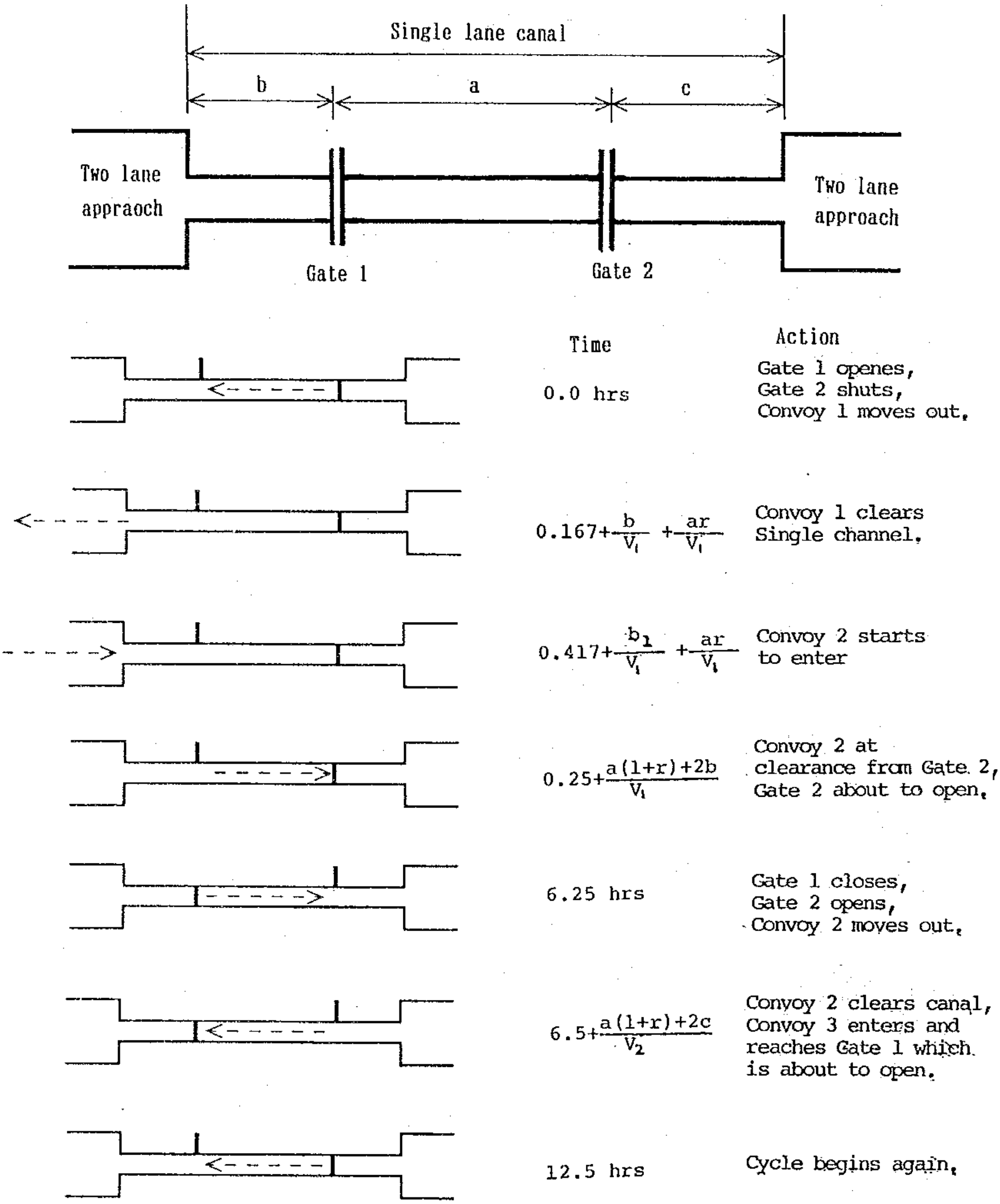
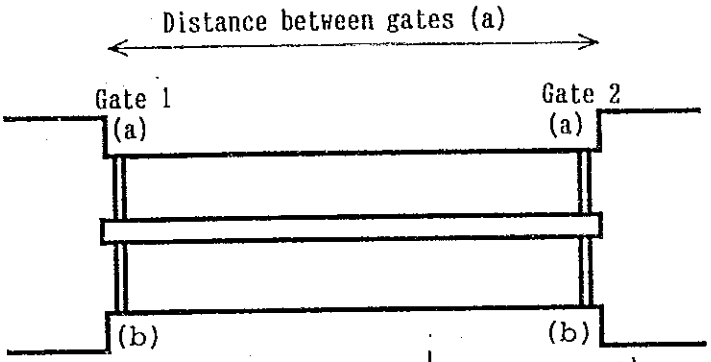


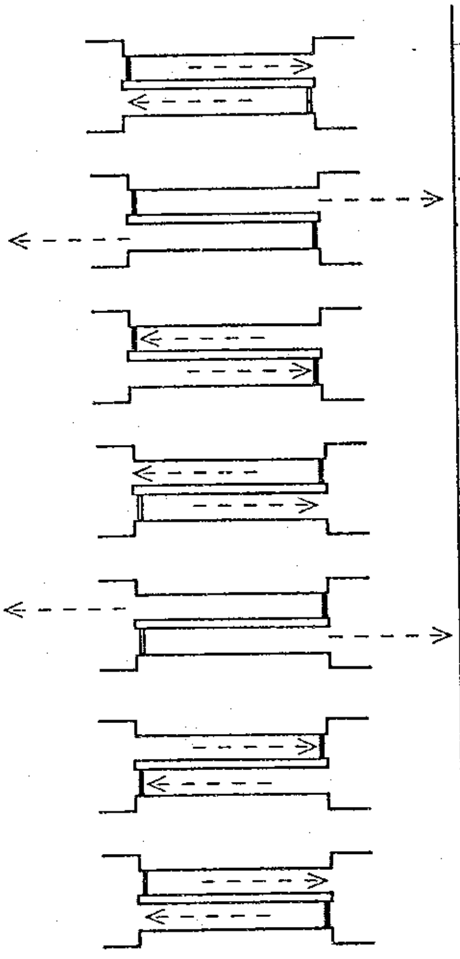
Fig. 2.11.2 New Locks: "Average" Ship Convoys



Time	Action
0.0 hrs	Gate 1 openes, Gate 2 shuts, Convoy 1 moves out,
$0.167+\frac{b}{V_1}+\frac{ar}{V_1}$	Convoy 1 clears Single channel,
$0.417+\frac{b_1}{V_1}+\frac{ar}{V_1}$	Convoy 2 starts to enter
$0.25+\frac{a(1+r)+2b}{V_1}$	Convoy 2 at clearance from Gate 2, Gate 2 about to open,
6.25 hrs	Gate 1 closes, Gate 2 opens, Convoy 2 moves out,
$6.5+\frac{a(1+r)+2c}{V_2}$	Convoy 2 clears canal, Convoy 3 enters and reaches Gate 1 which is about to open,
12.5 hrs	Cycle begins again,

Fig. 2.11.3 Single Lane Canal: Typical Operation Cycle





Time	Gate status * 1a	1b	2a	2b	Action
0.0 hrs	c	o	o	c	Gates operate. (Tide at Mean S.L.)
$\frac{a\ r}{V} + 0.417$	c	o	o	c	Convoys clear both lanes.
$\frac{a(1+r)}{V} + 0.25$	c	o	o	c	New convoys enter, Gates about to operate.
6.25 hrs	o	c	c	o	Gates operate. (Tide at Mean S.L.)
$6.667 + \frac{a\ r}{V}$	o	c	c	o	Second convoys clear both lanes.
$6.5 + \frac{a(1+r)}{V}$	o	c	c	o	Third convoys enter, Gates about to operate.
12.5 hrs	c	o	o	c	Gates operate. (Tide at Mean S.L.) Cycle complete.

*Legend o = open
c = close

Fig. 2.11.4 Two Lane Canal: Typical Operation Cycle

panama Canal (component study : engineering and cost estimates) phase 1 preliminary engineering
and cost estimates