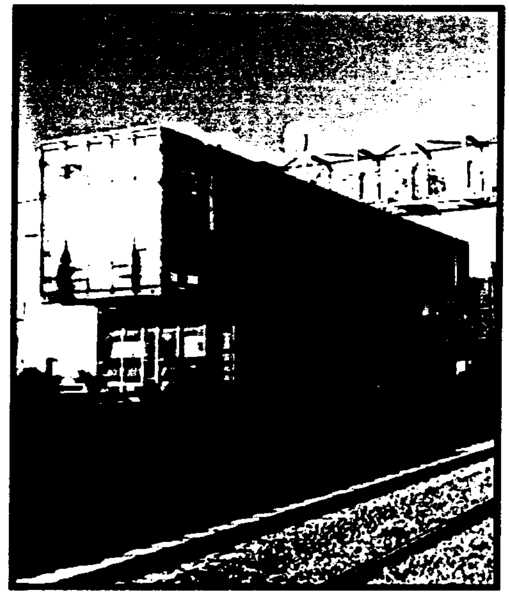
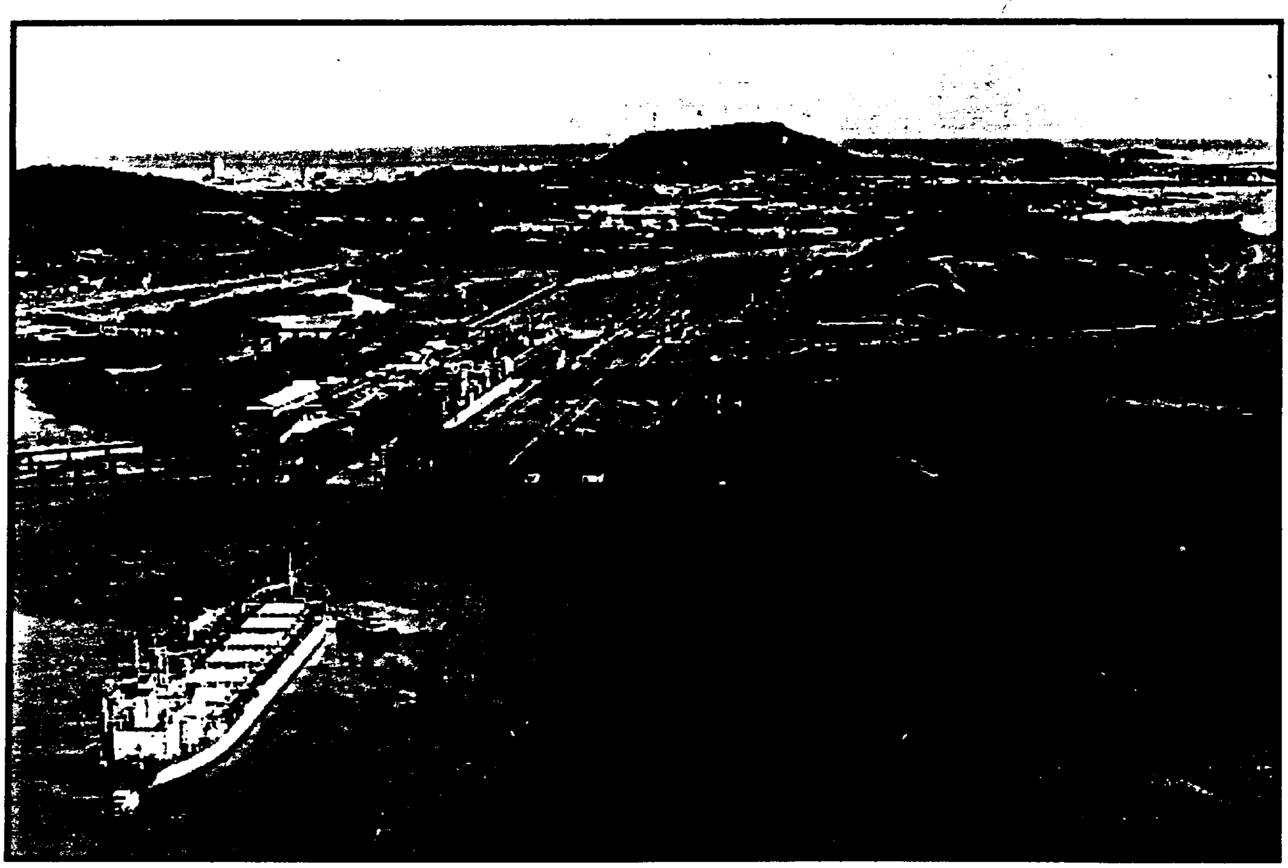
Independent Study
for the
Panama Canal Commission

Concepts Study for Canal Alternatives





September 1997

PANAMA CANAL COMMISSION

CONCEPTS STUDY FOR CANAL ALTERNATIVES

EXECUTIVE SUMMARY

During its 83 years of operation, the Panama Canal has provided safe, efficient and reliable transit of ships across the Isthmus of Panama. The size of its locks have served well in passing ships that need to use the Canal; however, these lock sizes are now a restriction as shipping technology changes and new transportation systems threaten the Canal's future viability. Modernization and improvements to the Canal need to be completed and the development of other cargo transportation systems planned to assure that Panama can continue to serve the World shipping industry efficiently in the 21st century.

In May of 1997, a specialized study team of experts in international water transportation and marketing, intermodal rail and highway transportation, other transportation systems, container port systems, traffic projections, economic analysis, and locks design and construction was established to evaluate, in concept, Canal alternatives for shipping ocean-going cargo across the isthmus of Panama. The study team leader was Mr. John C. Gribar, from the USACE, who assembled a team of representatives from private engineering practice, the academic arena, USACE, other US Government agencies, PCC staff and the Blue Ribbon Engineering Committee. The team evaluated, in concept, the transportation of cargo across the Isthmus of Panama by water, land (rail, highway, pipeline, conveyors) and air.

An analysis of Panama Canal Commission (PCC) capacity studies, historical and current operating statistics, and PCC provided updated traffic forecasts shows that Canal capacity will be exceeded in 10-12 years. Currently planned and on-going Canal improvements will provide only limited and temporary relief. The use of the Differential Global Positioning System for ship movement in poor visibility conditions can provide some additional ship capacity, but this also will be for the short term. Newly completed trade and traffic forecasts project that the number of Canal transits and ships with beams of 100 ft or more will continue to grow. The number of transits will reach a point where Canal Waters Time is unacceptable to Canal users by 2010 and will require that an additional two traffic lanes be built to provide transit service through the year 2040 and allow major overhaul of the existing locks.

Canal use for the trades in dry and liquid bulk is growing, and the potential for significant increases in containerized volumes is evident. The alternative of a landbridge, rail and highway, for shipment of cargo across the Isthmus presents some promise in providing service to container liner operators. However, very limited trade flows and commodity types could be reasonably accommodated by these supplemental systems. It would be prudent to allow the Government of Panama to undertake this complementary Canal system development. The development of a corridor with double track rail service and highway connections is modest in cost and will also benefit the Panamanian economy.

The ports on both sides of the Isthmus are currently being developed as transshipment hubs without any high-volume provisions for transisthmian shipment. Development is for container operations only, and existing land use and expansion possibilities are severely restricted. If full development of these terminals occurs at these sites, it will have a negligible effect on Canal operations well into the future.

The existing pipeline in Chiriqui offers the greatest potential to affect Canal operations as it did in the 1980's. However, projections for oil usage and trade flow in this commodity do not indicate that this will occur.

Major shipping routes have advanced to using post-Panamax ships especially for container transport. Post-Panamax and beyond-post-Panamax ships continue to show an increase in the number of new ships being built and have the potential for significant use of the Canal. A deepening of the Canal to a minimum of 50 ft would provide service for these large ships if compatible size locks are constructed. This is a dramatic departure from the Canal Alternatives Study, in which deepening of the Canal to 69 ft and 79 ft was indicated. With the implementation of the Enhanced Vessel traffic Management System, passing lanes could be utilized for post-Panamax ships in the Cut until sufficient ship traffic is developed to warrant full Cut-widening. New lock sizes should be 150 to 160 ft wide, 1200 ft long, and have a depth over the sills of 60 ft. This will provide flexibility for expansion well into the future.

Analyses of a sea-level canal or lock-type canal at another location shows that these alternatives are not feasible solutions for providing additional capacity. These alternatives are very costly and have major problems such as adverse environmental impacts to overcome. The economic benefits have not been shown to exist in previous studies. Supporting infrastructure and ports would also have to be developed. Expansion of the existing Canal is the logical alternative. This would be the overall cheapest alternative with minimal environmental impacts. Any new site selected should evaluate long-range considerations and have flexibility and provisions for continuing future expansion beyond 2040.

The major problem for Canal expansion is the availability of water to transit the projected number of ships in this water-based system. Triple lift locks use the least amount of water per lockage and are the logical choice to extend water use but are the most expensive to build. In consideration of the criticality of available water, triple lift locks appear to be the choice for construction. Double lift locks may be the most suitable for Canal use considering cost, having available water and lockage time. The additional water requirements for Canal expansion need to be defined and sources developed for the long term. This is the most critical item, and its in-depth analyses will conclude the need for lifting some ships by artificial means that use little or no water. Innovative and non-traditional design and construction methods for new locks can decrease new lock costs by 15-25% over traditional methods.

Vertical lifts that do not use water are available for handling the ships, but the level of technology today appears to be suited for only smaller ships. Providing a lift to possibly accommodate ships with beams of 80 ft or less and lengths of less than 600 ft account for 50-60% of the ship transits based on PCC records dating back to 1980. This would be a significant savings in water usage. Providing a new lock for post-Panamax ships, a non-lock lift for smaller ships, and rehabilitation of the existing locks would provide Canal flexibility now and into the future.

The following items are recommended for continuing and follow-up action:

1. In consideration of the updated transit forecasts and traffic implications, determine the maximum water availability at an 80-90% reliability level, and relate it to the number of sustainable traffic lanes these levels will support. Additional reservoirs need to be identified.

2. Canvas Canal users as to their projected plans for use by ship size and transit numbers into the future.

3. Develop a master plan for Canal expansion that will address present needs and serve into the future beyond 2040.

4. Determine lock sizes and type of lift to be used based on the anticipated ship size distribution.

5. Develop site-specific costing for the reasonable lock locations for Canal expansion. Consider consolidation of operations and flexibility for future development at the sites.

6. Perform an in-depth analysis, and develop cost and use data for non-water dependent ship lift (bath tub) systems that will raise and lower the smaller ships.

PANAMA CANAL COMMISSION

CONCEPTS STUDY
FOR
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I. INTRODUCTION

A. Background

The Panama Canal has been operated and maintained since August 15, 1914, placing it in its 83rd year of providing service to the world. At the time it was constructed, 95% of the ships that could transit the Canal were less than 600 ft long; the largest, the IMPERATOR, was 919 ft long. As time has passed, Canal transits steadily increased both in the number of ships that transited the Canal and the size of the ships. Today, the Panama Canal lock sizes, 110 ft wide by 1000 ft long, can pass 93% of the world's ocean-going ships. Ships larger than the locks have been designed for specialized services and are used on trade routes not involving the Panama Canal. In essence, the Canal can pass all of the ships that need to use the Canal. The Canal currently operates at or near capacity and passed its 800,000th ship in June 1996, with 15,187 ships transiting in fiscal year (FY) 1996. The Canal average daily capacity is currently 37-38 transits per day at a CWT of 24 hours, which is often exceeded in the number of ships desiring to use the Canal and causes delays to the shipping industry. Over one-third of the shipping business consists of large vessels (Panamax) that are restricted to one-way daylight transit through the narrow eight-mile long Gaillard-Cut. A program to widen the Cut was started in 1992 and when completed in 2002, will allow the Panamax vessels unrestricted two-way transit throughout the waterway. This effort, along with other ongoing improvements and modernization, will increase Canal capacity to about 43 ships per day which will still be exceeded by demand on many days. When the average demand approaches the average capacity, delays increase dramatically and reliability suffers.

This triumph of man over disease and engineering problems stands proudly as one of the world's greatest engineering feats and continues to serve the world's shipping industry. However, the Canal has undergone only modest physical change during its history, and the lock size limitations have determined, to a large extent, the composition of the world's ocean-going fleets and development of shipping ethnology. Technology changes to ship design and transportation systems are now driving the development of shipping alternatives that threaten the Canal's future viability. After more than 80 years of operation, Canal capacity is and will be exceeded after ongoing improvements are completed. The improvements underway will only provide a 20% increase in capacity. Expansion of the current Canal and perhaps the construction of other cargo transportation systems across the Isthmus of Panama need to be planned to ensure Panama continues to serve world shipping efficiently in the 21st century. The Canal's future depends on the continued growth and development of the world's economy. As the economy grows, so will the volume of traffic using the Canal.

An independent Tri-National Study, the Canal Alternatives Study (CAS), was undertaken several years ago and completed in 1993 to explore the feasibility of constructing a sea-level canal or a larger set of locks, locks that would be wider, longer, and deeper. Larger locks would allow the world's shipping industry to explore options that would provide better economies in shipping cargo and allow the Panama Canal Commission (PCC) to provide better service to its customers. These studies estimated the high-rise locks alternative to cost approximately $6.86 billion in 1990 dollars. It is unlikely that an investment of this magnitude would be cost effective.

B. Purpose

The purpose of this study was to identify, at a concept level, potential methodologies and alternatives for shipping cargo across the Isthmus of Panama that achieve the same objectives but are in addition to the Canal system while minimizing investment costs. The modes of cargo transportation across Panama were not restricted. Alternatives included innovative and non-traditional lock design and construction techniques, lock sitings, and combinations that could provide substantial cost reductions from previous lock concepts. Alternatives for a land bridge either in place of transportation across the Canal or supplemental to the Canal were also considered. The alternatives are presented to provide at least the same level of service to the Panama Canal's customers for 50 years into the future.

C. Scope

This study addresses and analyzes, in concept, the transportation of cargo across the Isthmus of Panama by water, land (highway, railway, pipe, conveyor) and air. It identifies potentially economical new lock designs and alternative transportation concepts, or a combination thereof, that could be used for 50 years into the future. Potential techniques, methodologies, and alternatives are presented that could be used for development of cost savings initiatives. The presented concepts are considered realistic and visionary and are futuristic concepts to achieve cargo transportation. The concepts are presented in schematic, diagrammatic, photographic, and written form. Each alternative is accompanied by an evaluation or rationale for development or consideration. Updated traffic projections as separately prepared and provided by the PCC were used in development of the alternative concepts. Selection of one alternative over another or combination usage are indicated for the particular commodity group and traffic projections.

D. Methodology

A broad-based multi-specialized team with representation from the U.S. Army Corps of Engineers (USACE), other U.S. Government Agencies, private engineering practice, academic arena, PCC, and the Blue Ribbon Engineering Committee (BREC) performed the study. The study team has expertise in innovative and non-traditional lock design and construction, transportation systems, container ports, rail systems, the Canal system, transportation routes, traffic projections, and economic analyses.

The study team gained a general orientation of the Canal from PCC provided information packets. Copies of the treaty map were distributed to the team members and provided a valuable orientation of the Canal and its features. It accurately locates the ports, Canal system, entrances, railway, roads, and airports. The PCC updated its traffic projections and extended them for 50 years into the future. These updated traffic projections were compared to recent actual transit numbers and cargo records for trends and significant changes. An on-site orientation of the existing facilities, capabilities, and condition was made in mid-June 1997. The orientation included visits to the ports and terminals at the Pacific and Atlantic entrances, Miraflores, Pedro Miguel and Gatun Locks, Gaillard-Cut, the airport at Colon, viewing the railroad at both terminus and along the Canal route, the entire Canal route and traveling across the Transisthmian highway. The Executive Summary of the CAS was used for reference and comparison throughout the Study.

The entire team met in the BREC offices, Building 743, during the week of June 23, 1997. Briefings were received on the business aspects of the PCC, Canal capacity analyses, traffic projections, and forecasts for mega-container ships. A "brain-storming" session established a breadth of viable alternatives for consideration.

The following objectives and criteria were developed for use in evaluating the alternatives:

Objectives

- Increase customer service and system reliability
- Enhance system maintainability
- Maximize market share and system competitiveness
- Enhance future system flexibility

Criteria

- Economic feasibility/financial feasibility (plausible)
- Stewardship of natural resources
- Prudent system revenue management
- Add new service capabilities (flexibility)

From the objectives and criteria, the alternatives were reduced to the most reasonable and realistic ones for definitive consideration. These alternatives were individually evaluated and in combination with other alternatives and are discussed in this report.

E. Study Team

The study team, including PCC and BREC participants, was composed of the following members. Vitaes for the individual team members are found in Appendix B.

JOHN C. GRIBAR - STUDY TEAM LEADER
Chief, Design Branch, USACE, Pittsburgh District; Structural Engineer with over 33 years experience in the planning, design, and construction of navigation and flood control projects, including innovative and non-traditional methods. Study team leader for the Panama Canal O&M Study completed in January 1997.

CARL D. MARTLAND
Senior Research Associate and Lecturer in the MIT Department of Civil and Environmental Engineering; Mathematician and Civil Engineer with over 25 years experience in teaching and conducting freight and rail transportation studies including reliability, intermodal operations, capacity, maintenance, and operations control.

MICHAEL S. BRONZINI
Director, Center for Transportation Analysis, Oak Ridge National Laboratory; Civil Engineer with over 29 years experience in transportation research and consulting. Technical expertise in waterway and multimodal transportation systems, with prior experience with the Panama Canal.

JAMES D. PUGH
Director of Marketing - Maritime Services, Black & Veatch Special Projects Corporation; Business graduate with over 25 years experience in port master planning, port operations analysis, international transportation and market assessments. A former Executive Director and CEO, Port of Houston Authority.

M. JOHN VICKERMAN
Principal, Vickerman-Zachary-Miller/TranSystems; Civil Engineer with over 26 years experience in the planning and design of marine and intermodal rail transportation

facilities. Extensive experience with international ports of entry and container ports.

BYRON K. MCCLELLAN
Chief, Design Branch, USACE, Louisville District; Civil Engineer with 27 years experience in the planning, design, and construction of navigation and flood control projects, including innovative and non-traditional methods.

DAVID A. WEEKLY
Chief, Navigation Center, USACE, Huntington District; Civil Engineer with over 22 years experience in all facets of navigation systems studies, including traffic projections and economic analyses.

FRANK ZOVACK
Chief, Electrical-Mechanical Design Section, USACE, Pittsburgh District; Mechanical Engineer with 25 years experience in the planning, design and construction of the mechanical and electrical features of navigation projects.

PCC REPRESENTATION

Mr. Richard Horne, Deputy Director, Office of Executive Planning

Mr. Agustin Arias, Office of Executive Planning

Mr. Carlos Alvarado, Deputy Director, Marine Bureau

Mr. Maximillan DePuy, Geotechnical Engineer, Engineering and Construction Bureau

BREC REPRESENTATION

Mr. Roberto Roy, Chairman

Mr. Ernesto Ng

Ms. Gabriella Russo, Administrative Support

II. BASELINE CONDITION

The baseline condition of the Panama Canal for the purposes of this study consists of the existing Canal and its current infrastructure and operating procedures, plus the physical and operational improvements that are currently planned and/or being implemented by the PCC.

A. Existing Canal

The existing Panama Canal comprises basically the locks, channels, lakes and supporting infrastructure that have been in place since the Canal opened in 1914. Over the years, a number of channel, infrastructure, operational improvements and equipment upgrades have occurred, and scheduling practices have evolved to keep up with the changing number and mix of ship sizes. The current physical and operating conditions of the Canal were extensively documented in the June 1996 report, Panama Canal Operations and Maintenance Study, prepared for the PCC's Board of Directors by the USACE.

The existing Canal is operating very near its operational capacity, which is currently estimated to be about 38 transits per day on the average. If the Canal traffic grows at the rate indicated in the current forecasts, the Canal's operational capacity will be exceeded within only a few years even with ongoing improvements. In addition to being restricted by the number of ships that can transit the Canal, it is also restricted by the size of ship. Panamax-size ships that have a beam of up to 106 ft and a length of 965 ft are the largest ships that can transit the Canal. The channel draft of 39.5 ft is also a restriction. Post-Panamax ships have been and continue to be built that are wider, longer, and deeper and are in service on the world trade routes. These ships are designed for specialized service but can not use the Canal.

A critical aspect of the current near-capacity operating mode is that there is virtually no opportunity to close a lane at one of the locks to perform extended maintenance and needed rehabilitation of the aging locks. A shut down of one of the two traffic lanes for ten days produces a backlog of ships awaiting transit that could exceed 120 ships, and requires up to four weeks of intensive full capacity operation to work off this backlog. Operation in this mode is not sustainable. These high traffic levels and attendant extra wear on the lock equipment, or a component failure, will require either more frequent or lengthier shutdowns for maintenance or repair. This would lead to extensive queues and unreliable service, producing Canal Waters Time (CWT) values of up to 120 hours, well beyond what is acceptable to the Panama Canal's customers. In addition to lengthy CWT, ships transiting the Canal would be subject to great variations in CWT and not be able to provide reasonable schedules or service to their customers. CWT is the number of hours it takes a ship to transit the Canal from the time it arrives at the anchorage and is ready to transit to the time it reaches the anchorage on the opposite

Ocean. The Commission currently has the goal of providing a CWT of 24 hours but is operating at a CWT of about 30 hours.

B. Near-Term Canal Improvements

In response to the Canal's growing demand and high level of capacity utilization, the PCC has embarked upon a series of near-term improvements and modernization program that will raise the Canal's operational capacity to an average of about 43 transits per day by the year 2002. These include:

1. Gaillard Cut Widening
2. Procurement and Modernization of Mobile Equipment
3. Replacement of Lock Controls and Machinery
4. Modernized Traffic Management System

1. Gaillard Cut Widening

The PCC is presently engaged in a long-term project to widen the Gaillard Cut from its present minimum width of 500 ft to a new minimum of 630 ft in straight sections and 730 ft in the curved sections. The project has also been designed to straighten the Cut. The completion date of this project has recently been advanced to the year 2002 from the original date of 2014. The widened Cut will allow relaxation of vessel traffic regulations that presently prohibit two-way traffic of large vessels, and that restrict certain classes of vessels from transiting the Cut during darkness. The resulting changes in vessel scheduling practices will eliminate gaps in traffic arrivals at the locks, which will increase the operational capacity of the Canal and eliminate some causes of increasing CWT.

2. Procurement and Modernization of Mobile Equipment

To allow greater utilization of the Canal, particularly after the Cut-widening project is completed, the PCC is also procuring added mobile equipment. The tugboat fleet will be increased in stages from 17 tugboats to 24 tugboats, and fleet replacements will also continue to occur on a regular basis. In addition, the locks' locomotive fleet is being increased from 82 to 108 units with the acquisition of 26 new and modernized locomotives. Consideration is being given to replacing the entire fleet with these new modern and more efficient locomotives. The new units will be needed to allow greater use of relay operations to maximize the operating capacity of the existing locks.

3. Replacement of Lock Controls and Machinery

The existing mechanical systems that operate the locks miter gates and valves are the original system from 1914 and will be replaced with modern hydraulic systems. In addition, the existing locks controls, which are manual, will be replaced with automatic systems. Both of these improvements will reduce lock downtime and increase the safety of lock operations.

4. Traffic Management System

The Commission is implementing an Enhanced Vessel Traffic Management System (EVTMS), which will augment the existing Vessel Traffic Management System (VTMS) with advanced computer utilization, software, display, and automated tracking technology. The existing scheduling system is essentially a manual operation with only a few supporting operations being automated. The EVTMS will provide fully automated tools for vessel and resource scheduling and rescheduling, real-time vessel and resource tracking, graphical displays and user interfaces, and on-line access to data for authorized users. This system will permit more efficient lock operations and equipment utilization, and increase the number of transits. Studies are also being performed concerning a Global Positioning System (GPS) for use on ships in navigating the Canal during poor visibility conditions.

C. Other Transportation Systems

Currently, there are no other cargo transportation systems operating across Panama. A pipeline for moving crude oil from the Atlantic Coast to the Pacific Coast exists in Chiriqui Province with a capacity of 800,000 barrels per day but is not in operation. Docking facilities, terminals and storage tanks to support this operation are in place.

The former Panama Canal Railroad, which once carried cargo and passengers across the Isthmus, has fallen into disrepair and will need substantial upgrade to serve as a viable transportation system. The current operation is marginal at best. Kansas City Southern Railroad has been awarded the concession by the Government of Panama to upgrade, operate, and maintain the railroad as a land bridge for shipment of cargo across the Isthmus. They have requested an increase in the width of the right-of-way, but their plans are unknown at this time.

The Government of Panama has also awarded concession contracts to Hutchison International for development of ports at Balboa and Cristobal. Evergreen, Hutchison, and Manzanillo International Terminal (MIT) are currently operating and developing container terminals at Coco Solo and Cristobal on the Atlantic Ocean side of Panama. These terminals are used as transshipment hubs but do not ship cargo (containers) across the Isthmus on a routine basis. MIT expects to pass 325,000 containers through its hub this year and will have an eventual capacity of 750,000 containers. Transshipment consists of moving containers from one ship to another, usually after some storage time period at the terminal and typically from smaller ships that focus on coastal trade to larger ships that are used on oceangoing routes.

The container terminals at MIT (**see photo 1**) and Evergreen (**see photo 2**) were toured and the layout and operation viewed. These facilities have been planned mainly as and are being developed as transshipment hubs only at this time. There are no provisions or accommodations being made for railway (**see photo 3**) or highway access into these terminals. With the security at the gate entrance to the MIT terminal, it would be difficult to sustain a high volume of highway container movement across the Isthmus. Also, once these terminals are developed for truck operation, it will be difficult to adapt them for high volume rail operation. MIT plans to integrate rail operations but the connection will be outside the terminal and across the road from it. This operations will entail additional handling costs.

The port of Balboa, situated at the Pacific Entrance to the Panama Canal, is a strategic location, as a transshipment hub for Central and South America in the same manner as the ports at Cristobal on the Atlantic Ocean side of the Canal. Most ships calling at the ports transit the Canal. Additional ships are expected with improvement of facilities and services and the construction of new container terminals. A report completed in March 1997 by Japan International Cooperation Agency for the National Port Authority of the Republic of Panama proposed a Master Plan for the Port of Balboa. The Master Plan as described is for a container transshipment hub and as such does not provide any dry or liquid bulk storage facilities. The terminal will have two consecutive berths for post-Panamax, container type ships, each 350-m long. The terminal is designed for a capacity of 800,000 twenty-foot equivalent units (TEUs) per year. It also does not integrate rail use within the terminal operation. The railway is specifically noted as being separate and on the other side of the road from the terminal and the master plan does not show any major highway connection. This operation will allow some transisthmian shipping, however, it will not allow for any high volume movement. Container cargo through the port of Balboa from the Free Zone (medium case) is forecast as 34,000 TEUs in 2015.

The report considers the port at Diablo to be a temporary operation and severely restricted from growth by the surrounding community. To accommodate expected container traffic growth, the terminal is recommended to be moved to Farfan at the west side of the Canal entrance around the year 2015.

A highway exists across the Isthmus of Panama, not parallel to the Canal, that connects Balboa on the Pacific Ocean side with Colon on the Atlantic Ocean side. This is a narrow two-lane highway with limited passing lane opportunities that is not suitable for dependable transportation of cargo. The Government of Panama has plans to build a modern transisthmian highway, but planning and construction drawings for the highway as well as a schedule were not available.

III. TRAFFIC FORECAST ANALYSIS

A. Purpose

This section compares and analyzes the traffic forecasts and capacity estimates of the Canal, as presented in the CAS and recently updated by the PCC. It also evaluates the need for any capacity expansion.

B. Traffic Forecasts

In 1991, the CAS contracted the WEFA Group, with subcontract support from Richardson Lawrie Associates (RLA) and BST Associates, to develop traffic projections for the years 2020 and 2060 for the existing Canal and four alternative routes through the Republic of Panama. This was known as the Commodity and Traffic Projections Study. The base year for traffic was calendar year 1990, and the study took into account the capacity of the Canal, as determined by the Operating Characteristics and Capacity Evaluation Study.

In 1997, the PCC contracted with ICF Kaiser International (ICF Kaiser) to perform long-term projection of cargo flows through the Canal, an analysis of the types and sizes of the ships, the number of Canal transits, and the implications for Canal capacity expansion. These forecasts were based on FY 1995 and extend to 2040.

A comparison of the two forecasts is shown in **Table III-1** with the actual number of Canal transits given for 1990 and 1995. The ICF Kaiser forecasts translated ship transits into constrained and unconstrained number of transits. In the constrained case, the maximum size ship that can transit the Canal is assumed to be the Panamax size. In either case, the ICF Kaiser forecasts of ship transits significantly exceed those made during the CAS study, as clearly shown on Chart III-2.

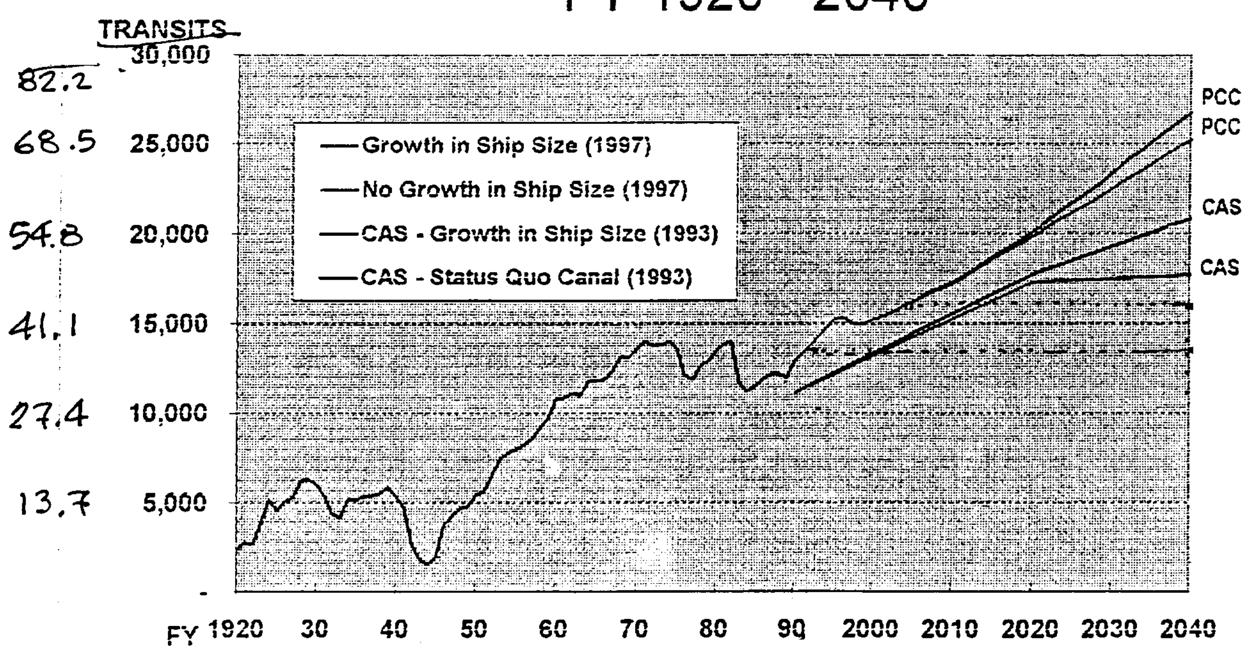
Table III-1. Comparison of CAS and 1997 PCC Traffic Forecasts.

	Tonnage (1,000)		Total Transits					
					PCC			
Year	CAS	PCC	CAS	Daily Average	Unconstrained	Daily Average	Constrained	Daily Average
1990	157,472	157,073	11,162	30.6	13,325	36.5	13,325	36.5
1995	171,826	190,303	12,013	32.9	15,136	41.5	15,136	41.5
2000	187,488	197,067	12,928	35.4	15,363	42.1	15,363	42.1
2010	223,226	242,435	14,974	41.0	17,427	47.7	17,387	47.6
2020	265,962	304,030	17,359	47.6	20,288	55.6	20,038	54.9
2030	268,634	371,870	17,539	48.1	23,547	64.5	22,615	62.0
2040	271,332	446,278	17,719	48.5	26,921	73.8	25,044	68.6
2050	274,058	NA	17,898	49.0	NA		NA	
2060	276,529	NA	18,078	49.5	NA		NA	

CHART III - 2

Total Oceangoing Transits

FY 1920 - 2040



C. Capacity

Panama Canal capacity is typically measured by the PCC in terms of the average number of ship transits that can be accomplished in a 24-hour period. Separate capacity estimates exist for each Canal description (as defined by operating policies and physical characteristics). Capacity utilization is expressed as the average time it takes a ship to transit the Canal from the time it reaches an anchorage, is ready to transit, and includes waiting time to transit (i.e., CWT).

The CAS made an estimate of capacity and delay for the status quo condition, which assumed the Gaillard Cut was widened. This estimate, obtained from a simulation model, was defined by the curve

$$d = Dq/(Q - q), \text{ where:}$$

d = average delay,
D = average delay at a $q = Q/2$,
Q = annual traffic capacity, and
q = traffic per year.

This equation does not include the travel time, which averaged about 10.4 hours during 1994-1995. In this case, $Q = 18{,}569$ transits and $D = 0.9389$ hours and a CWT of 24 hours would be obtained at 47.6 transits per day. However, a sensitivity analysis for this condition using different fleet assumptions found $Q = 16{,}476$, $D = 0.8001$, yielding 43.3 transits per day at a CWT of 24 hours. Note that for the simulation analysis, only two 11.5 day lane closures were assumed, about half the latest yearly average.

The PCC's primary program used to determine capacity is a combination of analytical tools based on queuing theory and a computerized CWT Simulation Model that establishes a capacity factor (capacity/arrivals) for a 24 hours CWT. The capacity factor is determined by using an iterative process which matches arrivals to a capacity matrix and applying the process at each level of arrivals until a CWT of 24 hours is obtained. The programs consider ship mix, Marine Traffic Control Center rules (hypothetical schedules), resources required, lane reversals, fog, ship interaction, closures, and ships that are routinely cut from the schedule. The current model accounts for regularly scheduled closures and assumes that 2 ships per day are cut from the schedule, one for random changes in the schedule and another for random lane outages of short duration. An application of this program (September 1996) assuming the Gaillard Cut was widened provided the results shown in Table III-3 and Chart III-4.

CHART III-4

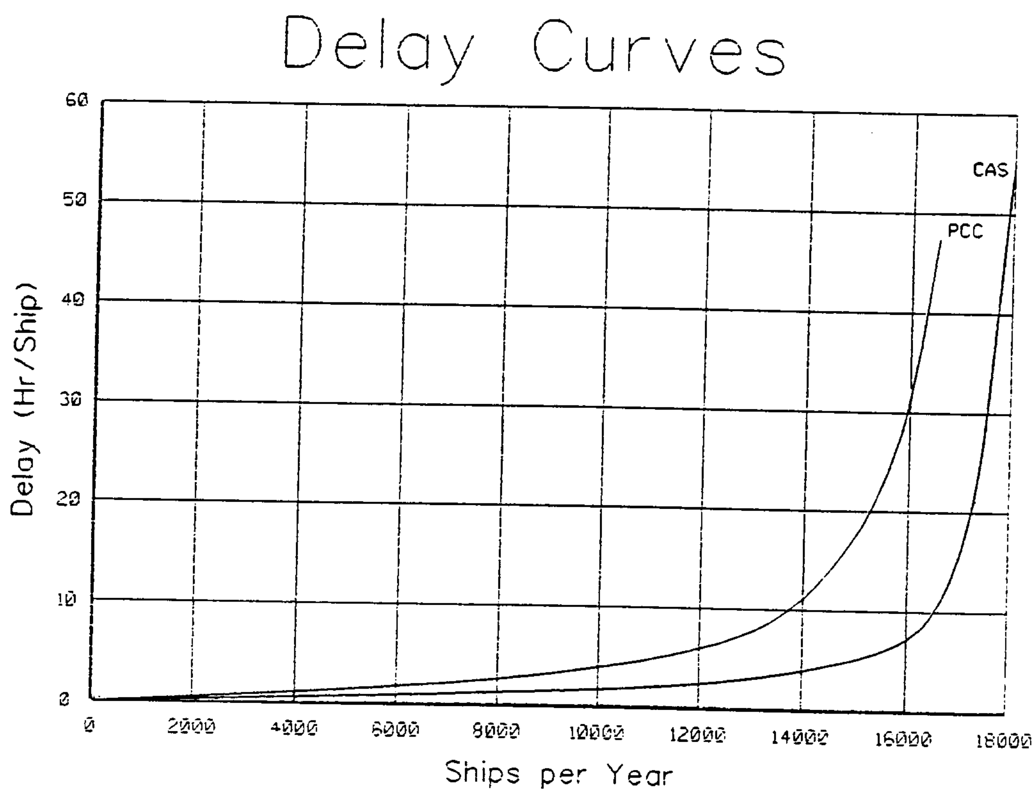

Delay Curves
Delay (Hr/Ship)
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Ships per Year
CAS
PCC

Table III-3. Summary of Findings for Canal Waters Time Model.

Traffic		Avg.
Per Day	Annual	CWT
39.9	14,564	26
40.5	14,783	23
40.9	14,929	24
41.3	15,075	25
42.3	15,440	27
43.4	15,841	32

This data was used to calculate a delay curve and resulted in a Q = 17,667, D = 2.536, and 40.9 transits per day at a CWT of 24 hours (assuming 10.4 hours of travel time). Using this equation, CWTs of 30, 36, 44, and 95 hours would be reached at 43, 44, 45, and 46 transits a day, respectively, showing how quickly service deteriorates as the demand approaches the maximum physical capacity of the system. According to the ICF Kaiser forecasts, 46 transits a day would be exceeded in the year 2007 in both the unconstrained case and the constrained forecast. The Cut-widening is scheduled for completion in 2002.

D. Traffic Forecast Summary

Panama Canal traffic growth has been tied closely to the strong growth in world trade. As world population increases, traffic through the Canal will also increase. However, the size and number of lock lanes, as well as trade patterns, limit growth through the Canal. Canal traffic is also tied closely to some key bulk commodities even if revenues are tied closely to liner trade, automobile carriers, and passenger cruise ships (36% of total revenue in 1996). If the Canal has the capacity to handle the cargo that wants to pass through it, there should be a steady long-term growth, 2.2 to 2.6%, from 2000 to 2040. Cargo volume is expected to more than double from 198 million metric tons in 1996 to over 446 million metric tons in 2040. Along with this growth, the mix of cargo is expected to change. Containerized cargo should see a substantial growth from 12% of the total in 1997 to 27% in 2040. Tanker trade will see some growth from 18% to 23% over the same period. Dry bulk cargo is expected to substantially decrease from 51% in 1997 to 31% in 2040. General and Ro/Ro cargo should enjoy about the same market share. Canal traffic by cargo type is shown on Chart III-5.

Liner trade is expected to grow faster than total world trade. World trade in containerized cargo has averaged 6% per year while growth in total TEUs has been even faster. These changes will lead to some adjustment in traffic by route. The seven most important Canal routes accounted for 68% of the traffic in 1990, but by 2040 these seven routes are expected to account for only 46% of the total traffic. Other more quickly growing routes will continue to grow.

CHART III - 5

Canal Traffic by Cargo

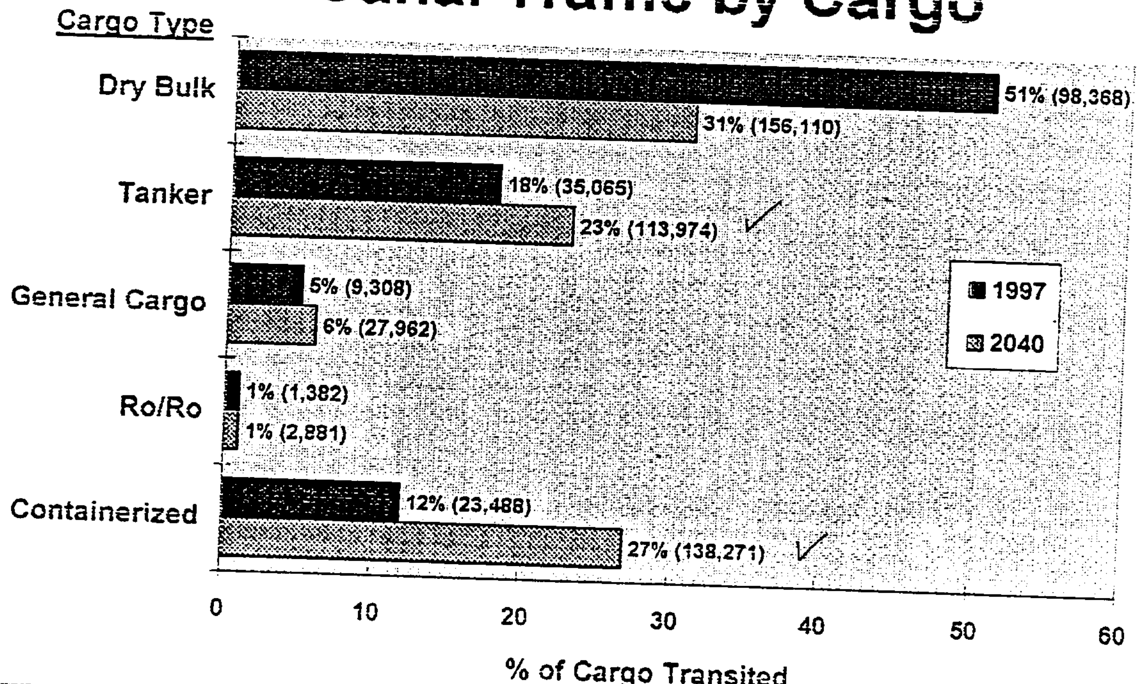
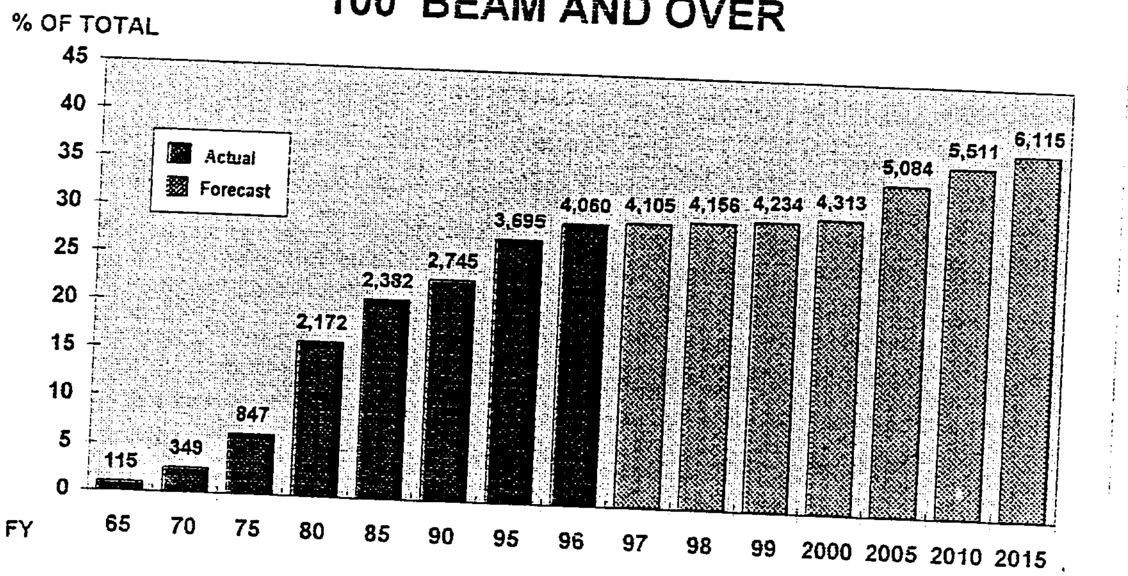


CHART III - 6

Oceangoing Transits

100' BEAM AND OVER



In analyzing the traffic forecasts, the future projections are for significant increases in the number of transits for both the constrained and unconstrained cases. Total transits in 1995 were 15,136 and are expected to grow to 25,044 total constrained transits or 26,921 total unconstrained transits by the year 2040. From 1990 to 1996, cargo volume through the Canal rose by 40,000 tons while the number of transits increased by 1518, an average of 250 transits per year. The forecast calls for larger ships and a higher ratio of ship utilization as will be addressed later. The number of ships that have a beam of 100 ft or more is expected to increase slowly until 2005 but increase markedly after that date, as shown on Chart III-6.

Chart III-7 shows the ICF Kaiser forecast for Canal transits for both the constrained and unconstrained cases. The forecasts for the CAS have also been added for comparison. Recent forecasts show much higher traffic demands than previous studies. The capacity for the existing locks after Cut widening is 43 transits per day while the current capacity for a CWT of 24 hours is 38 transits. Current capacity/transit estimates that take into account maintenance outages and less efficient ship mix reveal a decrease in capacity while CWT increases. Assuming that future lock traffic lanes will be constructed and that one additional lane will have a capacity of 20 ships per day, Chart III-7 clearly indicates the need for immediate capacity expansion to accommodate traffic to 2040 and expansion into the future beyond 2040.

As can be seen from Chart III-2, traffic steadily grew from 1950 to about 1975. From 1975 to the present, there have been ups and downs but a recent steady growth. Projecting the average increase in traffic of 250 ships per year from 1990 to 1996, the Canal will reach capacity for the existing locks in about 7 years or about 2003 - 2004. This compares favorably with the model calculations. In fact, at a CWT of 24 hours, capacity of the Canal is now exceeded and is rising to a point where service is unsatisfactory to Canal users.

IV. MARITIME TRADE TRENDS

A. Products

1. Bulk Liquids Transport

There are likely to be only small changes in the transport of bulk liquids in the near future in the trades affecting the Panama Canal. The movement of crude oil is the dominant bulk liquid commodity flow (see Chart IV-1), and this is unlikely to change unless major new finds occur. The shift to the movement of refined products should continue to increase due to the rationalization of refining capacity. This may result in modest increases in handy-size (30,000 dead weight tons, or DWT) and Panamax

CHART III - 7

Total Oceangoing Transits

FY 1990 - 2040

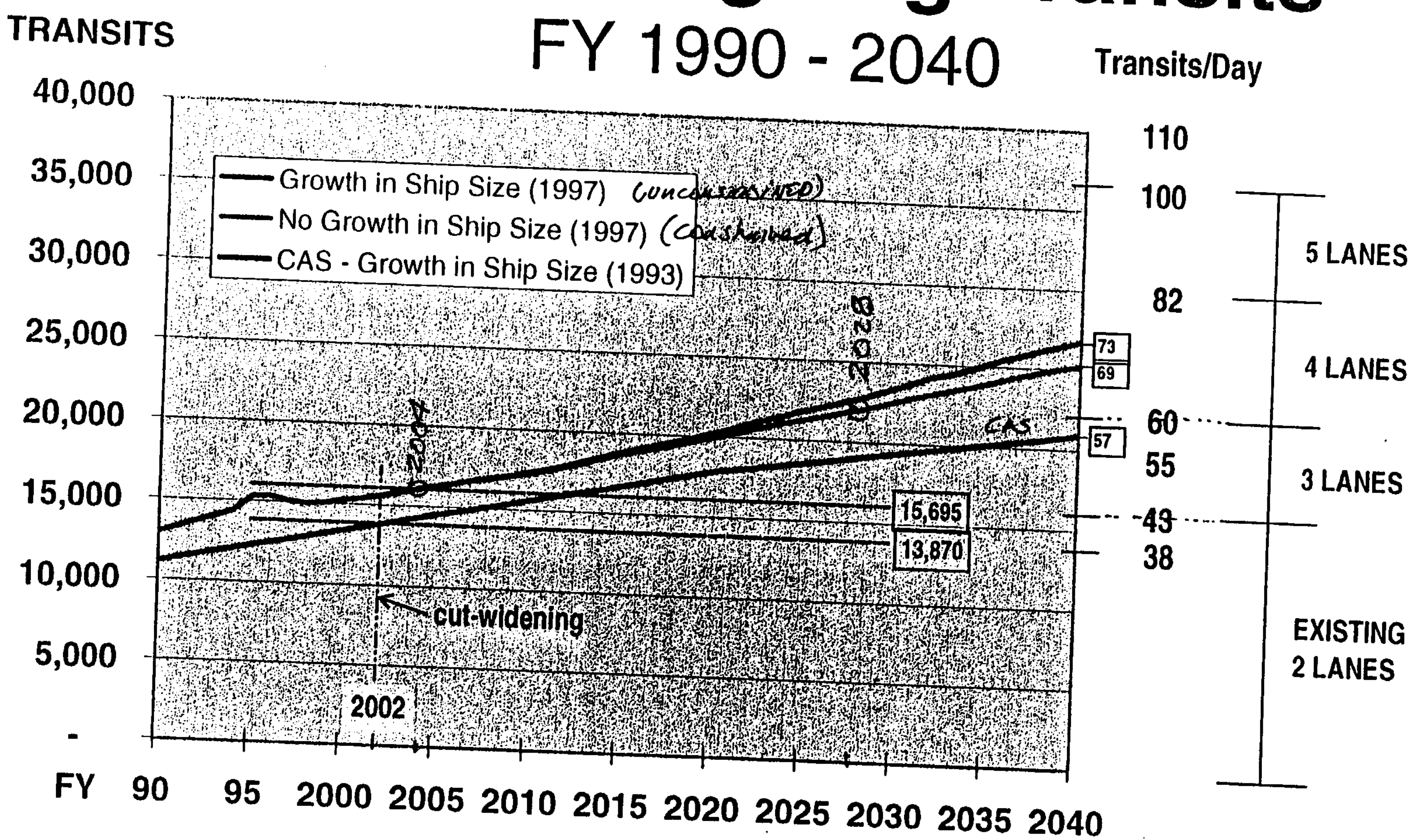
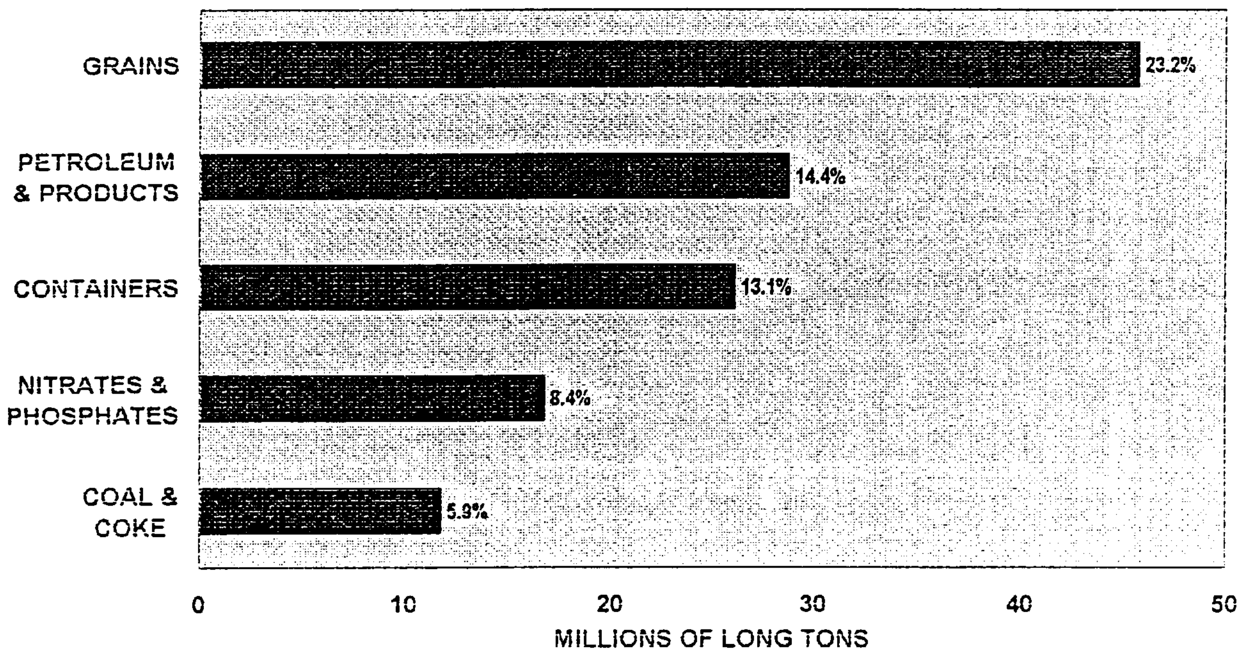


CHART IV - 1

Principal Commodity Groups
FY 1995



(60,000-70,000 DWT) tank ships for moving products to the growing South American markets from U.S. and Caribbean Basin producers.

The shipment of liquid chemicals is also expected to remain in the parcel (12,000-15,000 DWT) tanker trades because the demand requirements are relatively small and the values per ton dictate only limited storage capability at consumption points. Edible oils will also experience growth due to the expanding economies in Latin America, but the demand is also small in shipment sizes and not susceptible to significant economies of scale in transport due to the storage requirements.

Ship owners in the tanker trades seem to place a premium on flexibility to enable the redeployment of ships in various trade lanes. With the exception of oil bulk ore ships and dedicated crude carriers, most tankships have the greatest flexibility if they are handy or Panamax size. A contributing factor to concentration of the fleet in these sizes is the use of these ships in tramp and spot charter markets, which means that ability to travel to the vast range of ports, with their draft limitations, is very important for continuous usage.

The foregoing would seem to indicate that tankship transits will increase modestly over the next few decades, but the size of ships will probably continue to be limited to handy and Panamax sizes. This would be consistent with current shipowners' plans for building new ships and deployment schemes that rely on flexibility to move between trades and handle commodity movements in less than 70,000-ton lots. The exception is shipments of crude oil, but that is unlikely to change from current supply patterns absent major new sources being developed.

2. Dry Bulk Transport

The dry bulk trades are dominated by the movement of coal, iron ore, and grains. Some other bulk commodities move in smaller quantities, such as potash, phosphate, sugar, and salt, but these are generally inter-regional movements that require only smaller ships in the 15,000-30,000 DWT range. Forecasted trends in consumption of these other bulks would indicate that demand would mirror overall trade growth.

Coal supply from Australia to Asia and South Africa to Europe will likely continue as the major movements requiring large bulk ships. The supply of steam coal from U.S. mines should remain relatively constant in the near term, but the movement to limited on-site storage at electric utility users will mean that larger shipments in this market segment are unlikely. Consequently, handy size and Panamax bulkers are the preferred ship because they are easily redeployed in other markets when steam coal is fluctuating in demand markets or supply sources. Colliers (100,000-120,000 DWT) and Cape (120,000-150,000 DWT) size ships should find a stable market in industrialized countries because coal is traded in these markets and the distribution volumes allow larger shipment sizes to be moved. However, the supply of steam coal to Latin American markets is likely to grow slowly in the intermediate term because the pace of new generating capacity is being limited by development time.

Worldwide movements of iron ore are not likely to change appreciably because the sources of supply are limited, and the rationalization of steel production indicates that existing mills will probably meet new demand. This is manifest by the continuing growth of mini-mills to serve both developing markets and economic expansion in existing markets. The addition of basic steel-making capacity in Latin America should be limited and would probably require modest supply, most likely to be sourced from Brazil.

Grains represent the most significant growth market for Canal movements in the dry bulk category of cargo. The United States should continue to be a major supplier of grains to the world. But it is expected that other countries will continue to develop their own food production capability, and the supply from outside sources may decrease slightly over time. This would indicate that shipment sizes might not support post-Panamax ships in large numbers to serve this trade. There is also major competition in the grain markets from other countries that will limit the volumes originating from North America. Grains are also traded on the world commodity market, which means that flexibility in ship size and deployment will remain important to shipowners to maximize their opportunities for charter in these trades and other cargo markets.

As is the case with liquid bulk ships, owners are very interested in maximum flexibility for deployment of ships in various trades and to the maximum number of world ports. It would seem prudent for them to continue to focus on handy and Panamax size ships to keep their advantage in the charter and tramp markets. There may, however, be some small movement to contracted tonnage in specific products where backhauls are always available or economics may dictate a one-way loading is desirable.

3. Containers

Since the invention of the standardized shipping container in the 1950s, more and more oceangoing trade has utilized containers. The average growth of containerized trade has varied through the last 20 years by trade route but has consistently averaged a 6% annual growth. The use of containers has allowed for much greater efficiencies in cargo handling in ports. Cargo-handling equipment has been adopted to match the container sizes, promoting greater and more predictable cargo movement throughput for a given time period of loading or unloading a ship.

Because many containers can also be loaded directly onto trucks or rail-cars, containers have fostered the growth of "intermodal" transportation of freight, whereby cargo travels in a container via various "modes" of transport (ship, rail, or truck) all the way to its destination without the container having to be opened, loaded, or unloaded along the journey.

The type of cargo that is economically most appropriate to containerize is composed of individual units that are small in size but not so small that the cargo is actually a loose physical material. Coal, grain, and certain minerals are examples of loose physical materials that are usually not containerized. Liquid cargo is usually not containerized, either, although there are "bladder" containers that can be used for this purpose. Typical containerized cargoes include electronic products, machinery, consumer goods (including clothing), printed materials, and certain food items.

Growth in container trade has been a result of two major factors. The first is the containerization of previously non-containerized cargoes. The second is the major growth in world trade and economic interdependence in general that has occurred in the second half of this century. Related to this second factor is the fact that much manufacturing has shifted from traditionally advanced economies in Europe and North America to other economies in Asia, Latin America, and elsewhere. Consumption of manufactured goods has also grown worldwide as well.

Container traffic tends to be concentrated at ports that have excellent road and rail connections (to take advantage of intermodal movement capabilities) and that are in or near major consumption or manufacturing regions. Other ports tend to mostly perform "transshipment" of containers from one ship to another (usually after some storage time on land), typically from smaller ships that focus on coastal trades to larger ships that are used on oceangoing routes.

Not all ports are large-scale container-handling ports, although most ports have some kind of container handling capability. Container traffic will flow to ports that have the best intermodal connections, geographic and economic characteristics, cargo-handling capabilities, and relatively lower costs. According to the 1996 Containerization International Yearbook, the largest container ports in the world are in Asia (especially Hong Kong, Singapore, the ports of Taiwan, Busan [South Korea], and Kobe and Yokahama [Japan]), North America (especially Los Angeles/Long Beach and New York/New Jersey), and Europe (especially Rotterdam, Hamburg, and Antwerp).

North American liner (regularly scheduled) shipping activity on the Pacific and Atlantic coasts has become dominated by container traffic. The U.S. Department of Transportation's 1995 Status of the Nation's Surface Transportation System notes that in 1994 approximately 89% of trans-Pacific and 72% of trans-Atlantic liner cargoes were containerized. Additionally, roughly 65% of U.S. liner trade with Latin America was containerized.

According to the U.S. Department of Transportation's Maritime Digest-Liner for August 1996, the trade routes of the world can be roughly separated into two categories: East-West routes and North-South routes. For example, North American-Asian trade is an East-West route, whereas inter-Americas trade is on North-South routes. What are called "round the world" or tri-continental (East Asia-Americas-Europe) routes represent 24% of East-West containership trade activity. Inter-Americas trade is some 9% of North-South activity. East-West routes comprise roughly 73% of containership deployment worldwide versus 27% for North-South routes.

East-West containership service routes not only represent a majority of the world container trade but are also serviced by ships that are typically larger and faster than those used on the North-South routes. East-West ships are, on average, roughly three times the size (38,300 vs. 12,200 DWT) and approximately 25% faster (20 vs. 15.4 knots) than North-South containerships.

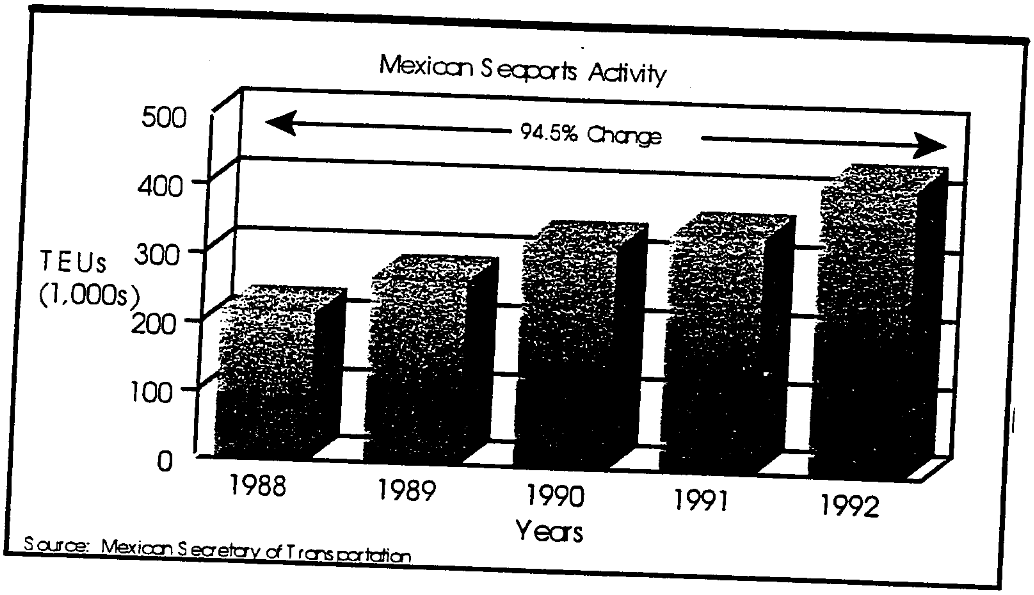


Fig. A. Containerized Cargo - Mexican Seaports Activity

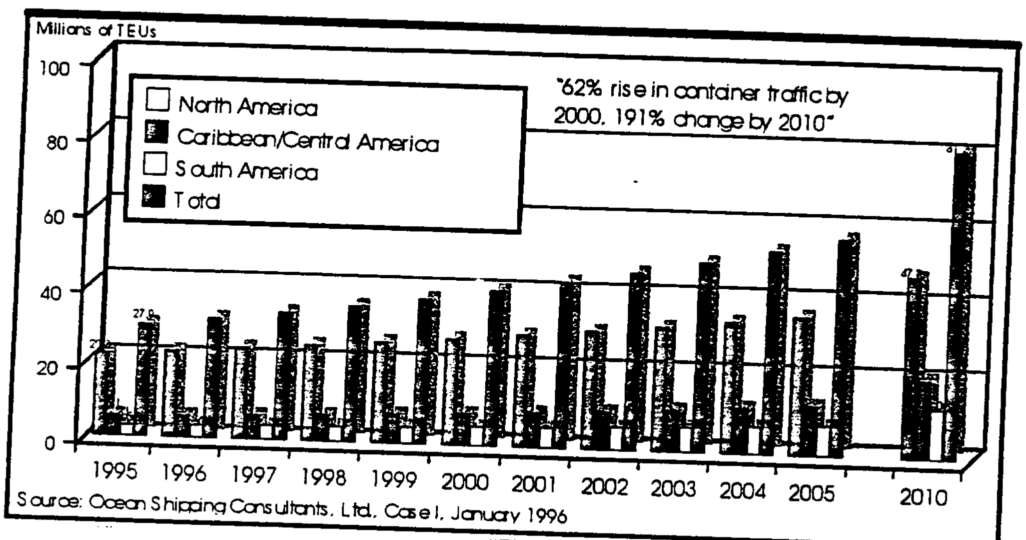


Fig. B. Forecasted Container Port Demand to 2010 for the Americas

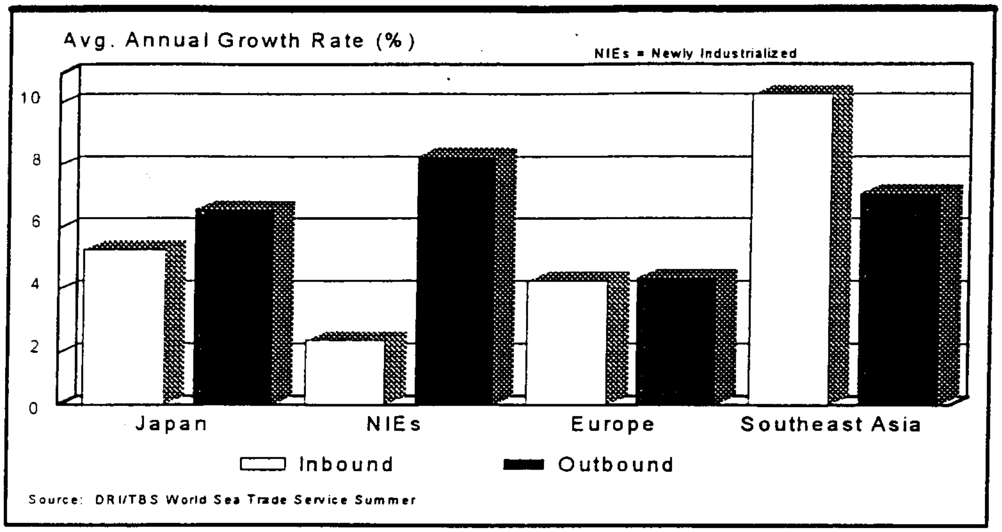


Fig. C. U.S. Containerized Trade Growth by Trading Partner

4. Neo-Bulk and Break-Bulk Cargo

Certain types of cargo are not appropriate for putting into containers, as stated in the discussion of containers (and containerships). One such type of cargo is liquid bulk—liquids such as petroleum and certain kinds of chemicals that can be pumped directly from the ship to storage facilities via pipelines. Certain types of non-liquid cargo, known as dry bulk, is of such a nature that it too can be pumped via pipelines or at least carried on conveyors. Dry bulk cargo is "fungible" in that each part of it is indistinguishable from any other part. Examples of common dry bulk goods are grain, cement, and coal. Other than dry bulk, there are other types of non-liquid cargo that are either not appropriate for containers or for whatever reason are not containerized: neo-bulk and break-bulk, respectively.

The great advantage of containerization is that it allows for storage in uniformly sized and shaped units. Neo-bulk cargoes don't need to be put into containers because they are "unitized" in some standard form already.

Neo-bulk cargo ships are those that carry one kind of neo-bulk cargo. Some examples of neo-bulk cargoes are the following: automobiles, unitized lumber, wood pulp, and steel. Automobiles are usually moved in what are known as "pure car carriers." These are "roll on/roll off" vessels: the cars are driven on- and off-board. The unit in this case is the automobile itself. Lumber can also be stacked and wrapped into standard-sized units. Wood pulp, which is really an intermediate form of paper, is typically put into office desk-sized bales. Steel may be shipped as slabs, plates, or various "shapes." Pig iron is usually transported in ingot form.

In all these cases, the cargo has already been put into a standardized unit for land transport. Because it will be transported in this fashion again, it is not necessary to containerize it as well, which would be an unnecessary step that would not yield benefits outweighing the expense and effort of containerization.

Non-unitized bulk cargo that does not fall into the categories of liquid bulk or dry bulk is called "break-bulk." Ships that carry more than one kind of neo-bulk or break-bulk cargo are known as break-bulk carriers, and their cargo is all referred to as "break-bulk." Examples of non-unitized bulk cargoes would be anything that has been put onto wooden pallets for shipment: machinery, paper products, some agricultural products, etc.

Neo-bulk and break-bulk cargo ships may sometimes experience competition from what is known as "backhaul" operations. If there is an imbalance of trade, container ships that run regularly scheduled routes frequently run the risk of making return voyages with empty containers (what is known as "shipping air"). Unitized and non-unitized bulk cargoes can often be containerized and shipped at fairly low rates in order to avoid this problem. A similar situation occurs with "pure car carriers." These typically arrive at the United States from Japan or Korea with automobiles for the North American market. However, very few cars are exported from North America to Japan or Korea. The car carrier can take some neo-bulk or break-bulk cargo on its return voyage to avoid a completely empty ship.

The trade of automobiles has been fueled by a boom in automobile production and is growing at a 4% annual rate, while steel has experienced a slightly lower annual growth of 3.9% between 1985 and 1995. In general, neo-bulk cargoes are expected to grow at a slower annual rate than containerized cargo, because containerized cargo tends to support manufacturing trade, which appears to be less sensitive to economic difficulties than other trade.

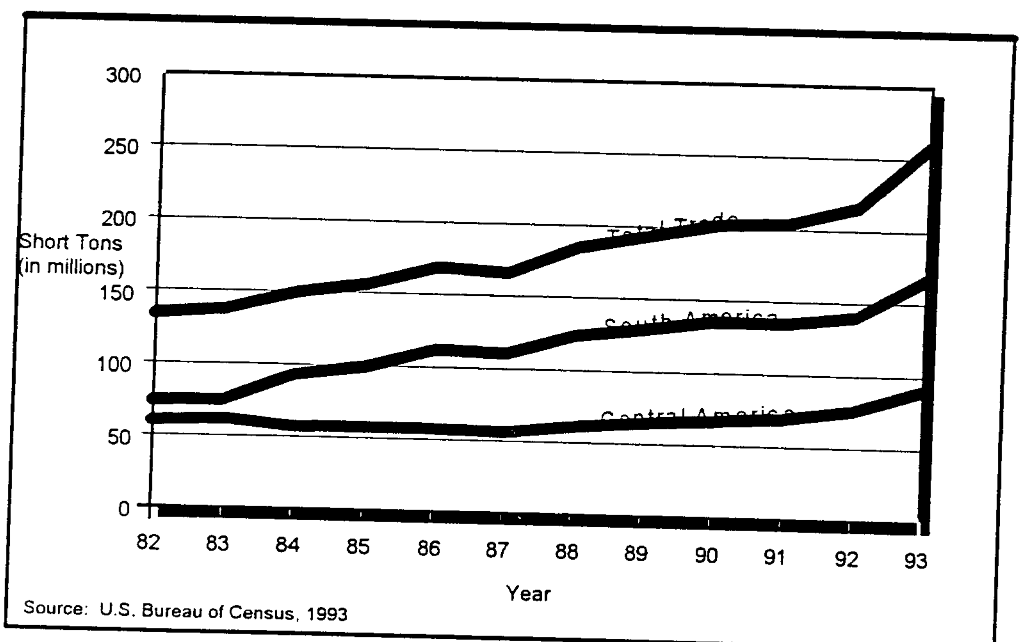


Fig. D. U.S. / Latin America Trade Growth

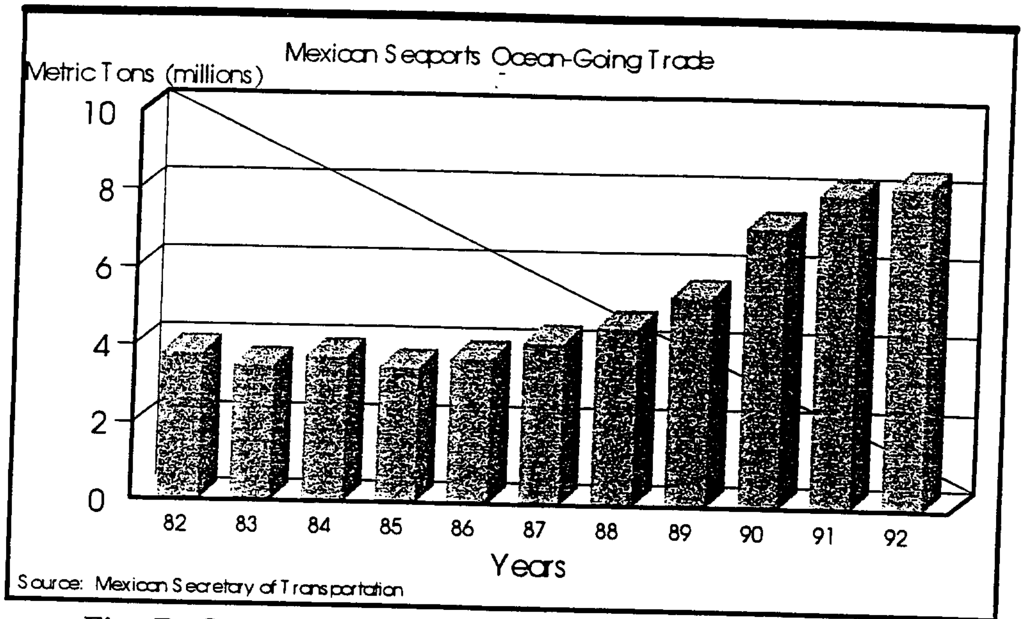


Fig. E. General Cargo Tonnage - Mexican Seaports

B. Container Ships and Cargo Projections

Ongoing changes in container ship design and deployment, directed by the economics of international shipping, will trigger fundamental and wide-ranging changes in the development of worldwide carrier itineraries and port infrastructure. This section discusses market/industry trends and projected impacts on waterside infrastructure.

1. Container Market and Trade

World container trade continues to grow at a rapid pace. Between 1991 and 1995, world container trade has grown at an incredible rate of 9.5% per year, reaching more than 134 million TEUs in 1995. Growth in the U.S. trades has been somewhat lower but still extremely rapid at 6.0% per year to reach more than 21 million TEUs in 1995. An increasing share of this trade will be carried on next-generation "mega-container ships," which are longer (1000 ft or more), wider (17 or 18 containers across) and deeper draft (up to 46 ft) than their predecessors. Some of these ships are already in service, and many more are planned for deployment. These ships are currently used on routes that do not use the Canal.

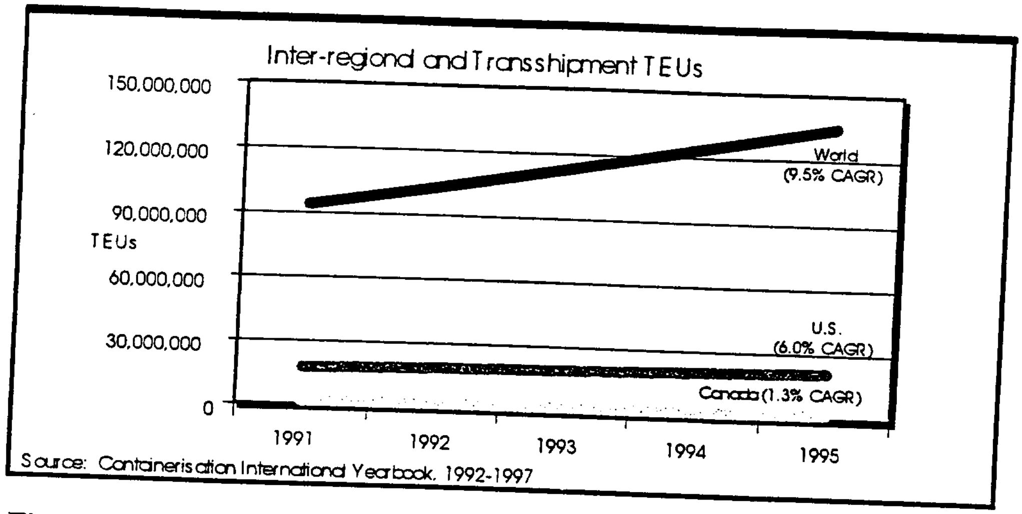


Fig. 1: World Container Port Traffic, 1991-1995

The leading world container ports in 1995 were Hong Kong (12.5 million TEUs), Singapore (10.8 million TEUs) and Kaohsiung (5.2 million TEUs). Long Beach, the leading U.S. port, ranked seventh. Among U.S. ports, the leaders in 1995 were Long Beach (2.8 million TEUs), Los Angeles (2.6 million TEUs) and New York/New Jersey (2.3 million TEUs).

This strong growth is forecasted to continue well into the future. Looking at inter-regional movement of loaded containers (excluding empties and transshipment moves), worldwide growth is forecasted at a Compound Annual Growth Rate (CAGR) of 8.0% through the year 2000. Looking at all container moves, U.S. growth is forecasted at 7.8% through 2010.

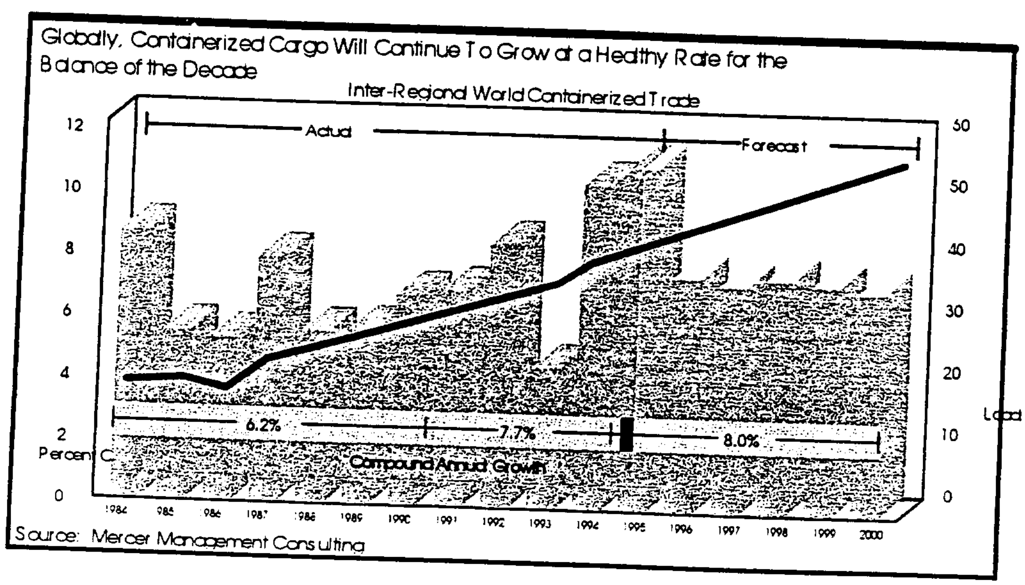


Fig. 2: Inter-Regional World Containerized Trade

Different regions of the United States will grow at different rates. The highest container growth is forecasted for the Gulf ports (13.1% CAGR) and the Southeast ports (7.6%). Northwest ports (Oregon to Alaska) are forecasted at a CAGR of 7.2%, while Southwest ports (Oakland to San Diego) are forecasted at a CAGR of 6.3%.

2. Future Ships and Market

To move these increasing volumes, some ocean cargo carriers have ordered larger, faster ships. One advantage is that with increasing size and speed, the transport cost per TEU slot is reduced, provided that these slots can be filled with revenue cargo.

As of November 1996, the large majority of ships in the world container fleet were in the "Feeder" class (less than 1000 TEUs). The 36 mega-ships (post-Panamax ships in excess of 4,500 TEUs) in service accounted for only 1% of the total fleet by number. However, 45 mega-ships are currently on order, representing 8% of the order book and about 18% of the new capacity on order.

Recent and planned deployments through 1997 include six ships by COSCO, 5 by Hanjin, and 5 by Hyundai, all in excess of 5000 TEUs. The largest is the "Regina Maersk" class at 6000 TEUs. These ships are in the Far East/Pacific and Far East/European trades and will not transit the Canal. In addition to the planned 1997 deployments, there are another 28 mega-ship orders, including P&O/Nedlloyd's order for six container ships with capacities of 6674 TEUs—the largest in the world.

In 1990, less than 6% of U.S. containerized cargo was handled on ships of 4000 TEUs or more. By 2010, almost 30% will be handled on ships in the 4000- to 6000-TEU class, with more than 9% on ships in the 6000- to 8000-TEU class.

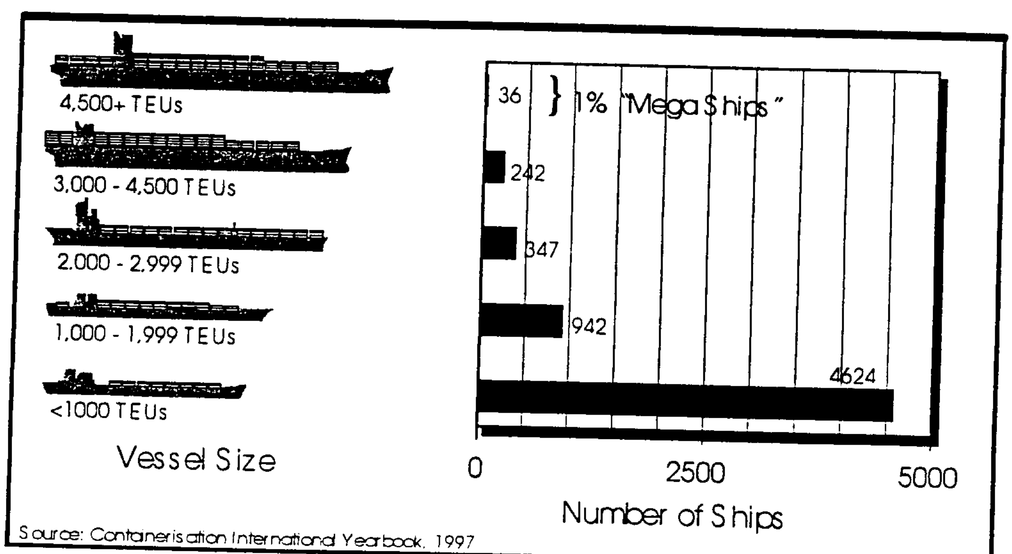


Fig. 3: World Container Ship Fleet as of November 1996

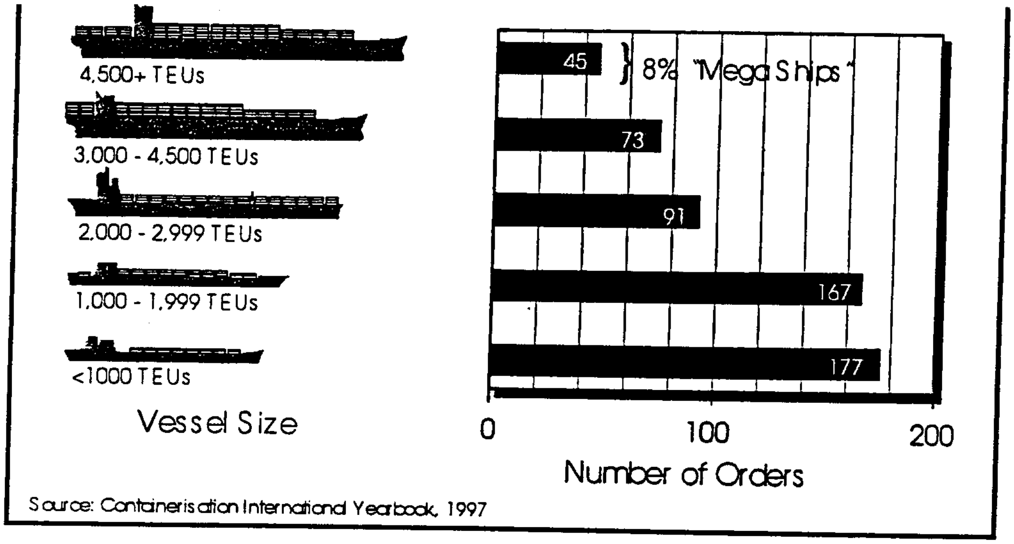


Fig. 4: World Containership Orders as of November 1996

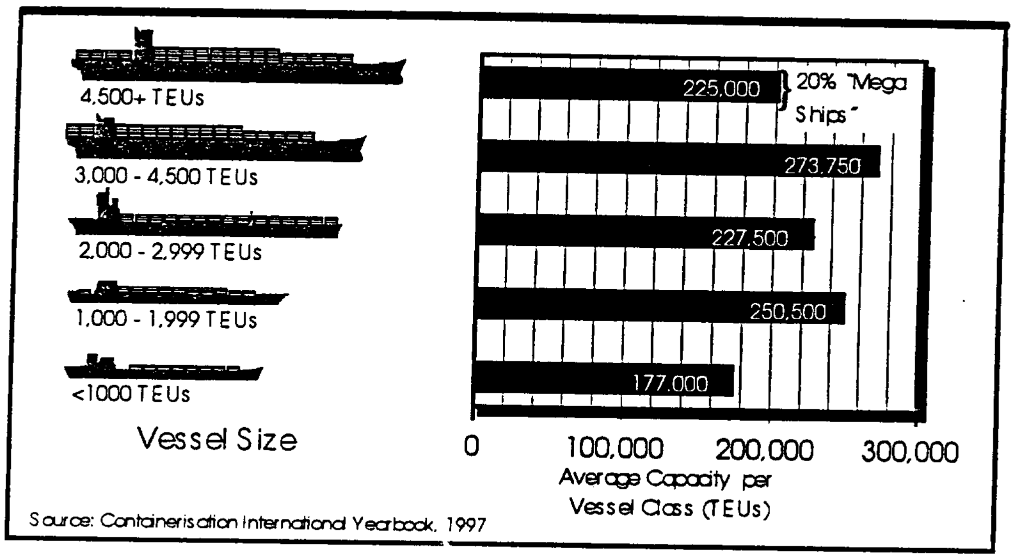


Fig. 5: Estimated Capacity of World Containership Orders as of November 1996

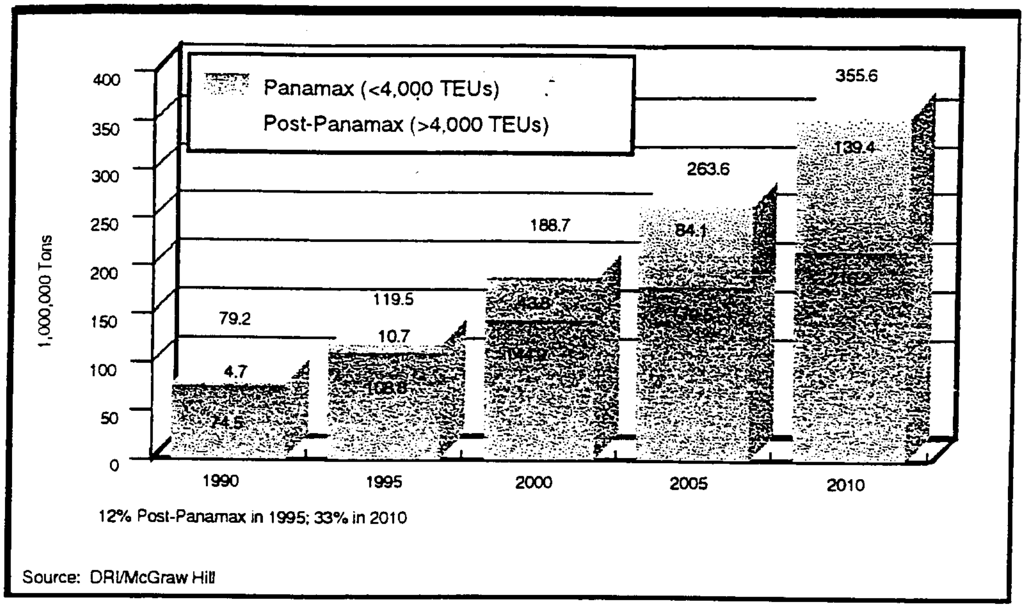


Fig. 6: U.S. Containerized Tonnage Forecast—Panamax vs. Post-Panamax Vessels

Ports that can accommodate mega-ships are in a position to capture this market; ports that cannot accommodate mega-ships could lose a substantial share of their potential future growth. However, "smaller" ships in the Panamax (2500 to 3999 TEU) class are forecast to maintain their current share (36%) of cargo. In 1990, these ships handled more than 29 million TEUs; just by maintaining their share, their total tonnage will more than quadruple to 128 million TEUs in 2010, making them the most heavily used class of ship in the world fleet. This is critically important, because it suggests that ports that can accommodate these ships (but not mega-ships) will continue to play a major role in future U.S. shipping.

The physical and operational characteristics of ships change as their capacity increases, placing increasing demands on navigation channels, port infrastructure and landside access capabilities. Panamax ships (the largest that can transit the Panama Canal) average 896 ft in length and not more than 106 ft across the beam, with a draft just over 39 ft. The largest post-Panamax ships in the fleet today average around 925 ft in length and 125 ft across the beam, with a draft of over 43 ft.

Looking at four of the newest mega-ships, the Regina Maersk, Hanjin London, Hyundai Independence, and APL C-11 class, the maximum length (1049 ft) and beam (140 ft) belong to the Regina Maersk, while the maximum drafts (46 ft) are shared by the other three ships. HDW in Europe has proposed an 8000 TEU ship that is 1099 ft in length.

Much larger vessels are technically feasible. However, it will become increasingly difficult for container ships between 7000 and 8000 TEUs to make required speed (24 knots or more) using today's single-engine propulsion systems. This barrier may be overcome through advances in propulsion systems and hull design, or by adding a second propulsion shaft. With a second shaft, ship cost can jump dramatically, but the cost per TEU slot can be minimized by making the ship as large as the new propulsion capacity allows. In fact, P&O Containers has raised the idea that the largest single-propulsion ship (say 7500 TEUs) could be doubled in capacity to 15,000 TEUs by adding a second propulsion shaft; they opine that "the ship is a flight of fancy ... but such a ship is within the current state of the shipbuilder's art."

Other factors may be more significant in setting a maximum containership size. First, is there a deployment scenario that would allow a shipping company to keep the ship full enough and in motion often enough to pay for itself? Second, can you find water sufficiently deep to meet vessel deployment requirements? Third, can you find a terminal to handle it? Fourth, can you afford extensive transshipment and landside rail and truck transportation to serve markets outside your ports of call? With increasing ship size, the deployment options and potential ports of call become sharply limited, and at some point it becomes uneconomic for ports, the USACE, and others in the freight movement chain to improve their access and infrastructure to service these ships.

It may be hard to imagine much use for a ship larger than 8000 TEUs or drafting more than 46 ft due to the limited itineraries these ships would have and the channel depth constraints that would have to be overcome. But history is clearly against such limit setting. Ten years ago, few imagined a 6600 TEU ship, and today it is under construction. It is possible that certain high-traffic corridors (e.g., Hong Kong to Long Beach/Los Angeles or Seattle/Tacoma) might see ships larger than 8000 TEUs in pendulum services or hub-and-spoke strategies.

Besides mega-ships, there is another important trend in containership development—very fast containerships, such as FastShip Atlantic and Japan's TechnoSuperLiner. The next few years will be important in determining the penetration of these technologies and services into the marketplace.

Finally, the extent of new shipbuilding raises the question of potential over-capacity. There are about 4.8 million TEU slots in the existing fleet. With 1.1 million TEU slots in ships (of all sizes) on order, the capacity of the world fleet will soon be increased by 22%. Will the market be able to absorb this new slot capacity?

3. Impacts on Infrastructure and Channels

To handle these next-generation container ships, as well as overall increases in container traffic, U.S. ports will require significant and costly p[illegible] improvements. Depending on the port, required improvements could includ[illegible] navigation channels, larger turning basins, larger and faster wharf cranes, lar[illegible] terminals with more land for container storage, upgraded intermodal rail conne[illegible] (preferably on-dock), and upgraded highway access.

Panamax ships typically draft 38 ft and are restricted by the available over the lock gate sills. Allowing 2 ft for vertical ship movement and 2 ft for underk[illegible]el clearance, these ships require a 42 ft deep channel. With post-Panamax vessels, draft increases to around 42 ft (fully loaded), and a minimum 46 ft deep channel is required. With mega-container ships, typical draft is estimated at 46 ft (fully loaded), requiring a minimum 50 ft deep channel. The channel would have to be deeper in the ocean entrances.

Looking at current permitted navigation channel depths at U.S. container ports, the West Coast has four ports at 50 ft or deeper: Seattle, Tacoma, and Vancouver (BC) in the north and Long Beach in the south. On the Atlantic coast, 50 ft are provided at Halifax (NS), Baltimore, and Hampton Roads. No container port on the Gulf Coast provides 50 ft.

Ports that can provide channel depths of 50 ft or more are clearly advantaged, as they can handle fully loaded mega-ships as the sole U.S. port of call, or as the first in/last out call on a multi-port service. However, shallower-draft ports should do well over the next two decades because (1) smaller ships are projected to handle the majority of tonnage through 2010, (2) light-loaded mega-ships can call at these ports on second-in/second-out services, and (3) overall container traffic is expected to more than double by 2010.

4. Terminal Design and Equipment

As container ships have become large and wider, wharf cranes have evolved to serve these vessels. Panamax cranes (less than 144 ft outreach) serve Panamax ships (106 ft beam, with containers stacked-in up to 13 rows across the beam). Post-Panamax cranes (144 to 158 ft outreach) serve ships between 13 and 16 containers wide.

The first mega-ships were designed with 40.0-m beams (about 16 wide) and could be handled by the largest post-Panamax cranes. However, the emergence of wider mega-ship designs forced the development of the Beyond post-Panamax (BPP) crane (greater than 158-ft outreach) to handle 170-wide and 18-wide ships.

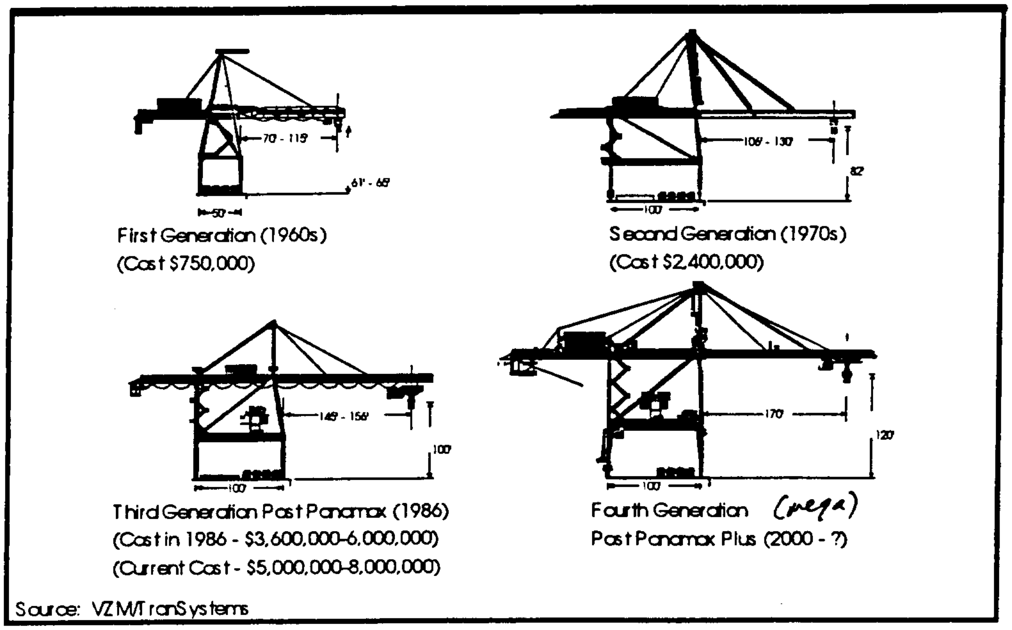


Fig. 7: Container Crane Evolution

In 1995, Panamax cranes dominated with world crane population (77%), while BPP cranes accounted for just 3%. This percentage is changing rapidly. Looking at deliveries from 1996 through 1998, BPP cranes represent 44%, with Panamax at 30% and post-Panamax at 23%. This trend is even more pronounced in North America, with BPP cranes representing 55 of 66 deliveries (83%).

Size	Ship Handling	Operating In 1995	1996 - 1998 Deliveries*	U.S./Canadian Orders 1996 - 1998
Panamax (<144' outreach)	13 wide 32.2m beam <4000 TEU	77%	30%	7
Post Panamax (144' - 158' outreach)	16 wide 40.0m beam 4000-6000 TEUS	19%	23%	4
Beyond-Post Panamax	17 wide + 42.5m + beam 6000 TEU +	3%	44%	55

* A total investment of $1.2 billion dollars.

Source: Containerisation International, AAPA and P&O Containers

Fig. 8: World Crane Population—Existing and On Order

How many BPP cranes will it take to unload a mega-ship? This depends on a number of variables, including the size of the ship, percent of ship cargo to be offloaded/ loaded, productivity of the cranes, and the amount of time the ship can remain at berth. In normal services, a ship makes several calls and offloads/onloads a relatively low percentage of its cargo at each port. With larger ships, fewer calls would be made and a larger percentage of cargo would be offloaded/onloaded at each port. A single-call service to a major hub might involve offloading and onloading 85% of ship capacity (with 15% assumed as a typical factor for empty slots).

If a 5000-TEU ship makes one U.S. call, 8500 TEUs would be handled (using an 85% load factor). With an assumed BPP crane productivity of 25 lifts per hour (45 TEUs), a total of 189 crane-hours would be needed. With four cranes working the ship, time working at berth would be 47 hours, which is longer than most current container ship calls. Adding cranes reduces working time (38 hours with five cranes and 32 hours with six cranes), but these times are still longer than current one-day turnarounds. These figures would be reduced, of course, if the ship made two or more North American calls and loaded a smaller percent of its capacity at each.

How much backland is needed to serve each berth? Historically, the ratio of backland to berth has increased as ship size has increased. This is due to the disconnect between wharf activity (rapid, round-the-clock transfer when ships are at berth) and gate activity (more regular, 8-hour-a-day vehicle movements). Terminal storage serves as an intermediary between these two flows, with "dwell time" (the amount of time a box spends stored in the terminal) as the key variable. As larger ships are unloaded more rapidly and the disconnect between land and water flow rates becomes greater, larger terminal storage areas become necessary.

To Turn a Mega-Ship in 24 Hours, U.S. Crane Productivity Will Need to Increase Dramatically

Vessel Size	Working Time with Five Cranes		
	25 lifts/hr (45 TEUs/hr)	35 lifts/hr (63 TEUs/hr)	45 lifts/hr (81 TEUs/hr)
5,000 TEUs 85% offload/ onload	38 hours	27 hours	21 hours
6,000 TEUs 85% offload/ onload	45 hours	32 hours	25 hours

Source: VZM/TranSystems

Fig. 9: To Turn a Mega-Ship

Operationally, there are a number of things a terminal can do to reduce the amount of storage required (denser stacking, longer operating hours, use of Intelligent Transportation Systems technologies, on-dock rail, etc.). If, however, it is assumed that terminals continue to operate more or less as they do presently, then backland-per-berth requirements would increase as a function of ship size. The generally accepted ratio for state-of-the-art terminals for post-Panamax ship is 50 acres per berth. With design ship sizes increasing by nearly 50%, it may be appropriate to increase the backland per berth by a similar factor, to 75 acres per berth. More research and simulation modeling will be needed to fine-tune this number.

These terminal design parameters assume an origin/destination port with very little ship-to-ship transfer. If ship-to-ship transfer is a large percentage of overall terminal throughput, the need for wharf and crane capacity is changed in direct proportion to the number of transshipped TEUs (which are counted on both inbound and outbound moves). Storage requirements change by half the number of transshipped TEUs (since there is one storage event for two wharf moves). Gate and landside access capacity is needed only for the non-transshipped TEUs.

Alternatively, transshipment cargo could be handled at separate terminals specifically designed for that purpose. A 450,000 TEU/year transshipment terminal might have 2500 linear feet of berthing (two mega-ship berths at 1250 ft each), an area of 75 acres, and a very small gate. This terminal would be only 1300 ft deep, about half the depth of a non-transshipment terminal.

Another way to handle transshipment is through "midstream" terminals. These are water areas in which a barge-mounted crane can be positioned between two ships. The crane lifts the box off one ship and onto another, possibly with an interim point of rest on the barge. The advantage of this operation is that it requires no land area; the disadvantages are that the barge-mounted cranes are slower than shoreside cranes, there is little room for interim storage/repositioning of boxes, and both ships must be in the same place at the same time. This is not theory. It is estimated that about 30% of Hong Kong's transshipment is handled this way, and New Orleans is also doing midstream transshipment.

A different design strategy for a transshipment terminal uses a finger pier with container cranes on each side and storage in the center. This allows ships to berth on either side, and at different times or simultaneously. This strategy is currently being used in Singapore.

C. System Trends

There are a few significant trends that must be considered when planning for the future in sea trades. These trends affect both the fleet size and ship characteristics. The volatility of world trade and political uncertainty may continue to influence the movements of both raw materials and finished products, but it seems unlikely that international trade will do anything but grow. This would necessarily mean that the capacity of the transportation system will have to increase to meet this growth. The key is to build flexible components that meet these needs cost-effectively.

The continuing globalization of companies will mean that management will focus more effort on logistics and distribution systems that optimize market share and profitability. The current transition to just-in-time inventory management should be expected to expand into all facets of the supply chain. The experience gained to date would indicate that there are significant operating economies in better management of inventory levels and deployment. Regardless of current interest rates, the costs of carrying inventory will continue to be the major consideration in business logistics and therefore will continue to put pressure on transit times and consistency of schedules for cargo movements.

The lowering of trade barriers worldwide will necessarily result in increasing availability of both consumer products and industrial goods. In some of these markets segments the use of indigenous production may better serve local consumption, but there is likely to be a general increase in overall trade volumes that will result in higher cargo movements for the next few decades.

This increase is forecast to be in finished products and goods in process, which translates into substantial increases in containerized shipments. The high costs of handling products will also mean that the use of unit load devices will continue to be evaluated for a larger share of commodity movements, especially in segments having modest demand or limited storage availability. But the expense of handling bulk commodities, relative to their value, would favor larger shipment sizes and automated handling systems that limit the number of physical handlings and the investment in unit load devices and that avoid the constant problem and costs of empty returns.

These trends indicate that the volume of trade transiting the Panama Canal will continue to increase, particularly in container shipments. The availability of physical facilities to handle larger containerships will thus be important to maintain the competitive position of the Panama Canal. It would also be advisable to insure that a greater proportion of larger ships could be accommodated at reasonable CWT to maximize the opportunities for use of the Canal by bulk ships in the dry and liquid trades. It is obvious that ships will increase in size over time. But the increase will be most profound in container ships, with bulk vessels continuing to migrate to handy and Panamax characteristics because of their deployment in non-liner services and a multiplicity of trades.

V. UNIVERSE OF CANAL ALTERNATIVES

A. Objectives

In simple terms, this study addresses, in concept, the transportation of cargo and passengers across the Isthmus of Panama and is unrestricted in the mode of transportation. To address these concepts, the team brainstormed all conceivable concepts that could move cargo by water, air, railway, highway (public or dedicated), pipe, and conveyor. The passenger industry represents only a very small percentage of the transits, and the standards for that industry are established. All methods of transportation were considered independently and in combination with other methods.

B. Criteria

In developing a list of alternatives for consideration, the concept had to be definable, realistic, and feasible for development and use. Items considered for transportation were categorized as break-bulk, neo-bulk, containers, dry bulk, and liquid bulk. The following is a listing of the alternatives developed and discussed. Discussion is provided for alternatives eliminated at this stage of the process. Items without discussion and some with are evaluated later in this report.

C. Alternatives

1. Water

a) Locks

1) Existing Locks

2) Additional Locks
One high rise - Pacific & Atlantic
One double lift - Pacific & Atlantic
Three Locks - one at each site
Combination Locks – sizes vary by site

b) Other methods

1) Submerged tractor guide-way.

This is a submerged track or guide rail with a towing bit attached to it. It is anchored to the bottom of the channel and positioned to allow two lanes of traffic. The operation of the towing bit could be automated to control ship movement across the lake and through the Cut.

This method of providing automated Canal transit could offer significant reductions in operating costs and improvements in safety. The substitution of automated ship movement for current operating methods would reduce the human element and its consequent fallibility. This could lead to substantial improvements in Canal transit time through fixed ship spacing and variable speed controls that would increase system capacity without additional lock construction. The technology exists to construct this type of ship progression system in the near term. It is currently used by the U.S. Navy and others in various applications, such as target towing.

The potential benefits of this type of automated system warrant a detailed analysis to ascertain the costs, benefits, and likely obstacles to implementation. The PCC would then have the detailed information necessary to make an informed judgment about the use of this system on a stand-alone improvement basis or parallel track with lock additions. The disadvantages of this system are less flexibility in ship maneuvering (e.g., meets and passes), continued need for standby tugs and pilotage, potential modification for ships, possible high maintenance costs and unreliability, and large investment cost.

It would seem prudent to investigate any types of automation, which would reduce the direct labor inputs and improve system reliability and safety. The industrial conveying and material handling technology available today would indicate that possible applications to ship movement are numerous and could increase lock system efficiency.

2) Syncro-lift ; Elevator-type lift

This would be similar to the syncro-lift in operation at Industrial Division. A ship could move onto the platform and as the syncro-lift is operated, the ship is accepted into cradles and raised or lowered. A variation of this system is a tank with sealed doors at each end whereby the ship would be floated in and out of the tank (bathtub). This will require that a supporting chamber be built similar to a lock but require a more substantial structure than normally provided because of the heavy ship loads involved with Panamax and/or post-Panamax ships. Movement of the lift is likely to be somewhat slower than the filling or emptying of a chamber. Maintenance is also higher than the mechanical operation of a traditional lock and more difficult with the lift's underwater features. Counter-weights could be used to lessen power requirements. This system is further discussed later in this report.

3) Incline (European System)

This is a variation of the syncro-lift where a ship is moved onto a platform, accepted in a cradle and mechanically moved up an incline structure with a 5% to 10% slope as shown on Fig. 1. This technology is well developed for smaller ships. Because of the heavy loads involved, movement will be slow and require an incline of considerable length. Construction of these features would be more than a traditional lock as it only has reasonable application to small ships. Previous studies conducted by the USACE have shown that inclined lifts and these variations are not cost competitive with traditional lock designs. This does not have application for the Panama Canal.

4) Cranes

Cranes could be used to lift the ships on slings or on a cradle. This would require the use of extremely large cranes with the need for the cranes to move laterally to position the ships at the next level. This operation would be extremely slow and costly. It is beyond the limits of practical application.

5) Hydraulic Lift

This is similar to the syncro-lift but uses hydraulic cylinders instead of cables to lift the platform and ship. These cylinders would be long, large in diameter, and likely be more costly than a traditional lock. This is a concept only and is not available in practical application.

6) Barges

Cargo could be transferred into barges for shipment across the Isthmus. The lockage requirements would be more, as the barge requirements would be high to move the same amount of cargo with less draft per cargo unit. There are also additional handling costs and reduced efficiencies in ship movements. This would be similar to a port terminal operation where cargo is moved by rail or road. Although a reasonable approach, it does not have a practical application for the Canal.

c) Enhancements to Existing System

1) DGPS (differential global positioning system)

This is under consideration and testing by the PCC but stated here as a matter of emphasis for application to ship movement and control in less desirable weather conditions. This has potential to increase transits through fog conditions and increase Canal capacity over a short term. It will also enhance safety of ship movement.

2) Automatic Guided Vehicle (AGV) Locomotive

This would consist of programming the locomotives to perform the locking operations as an automatic function. This would make the locking operation uniform but would have only a minimal effect on Canal capacity. This may have more application in a new lock with a different ship positioning system.

3) Automatic Equipment Identification (AEI - tag and location).

This has application in a centrally controlled operation where critical pieces of equipment have DGPS systems installed and gives real time read-out on a control board. The operator can control movement of critical resources to points of need more readily and reduce delays. Software is available to accomplish this task. This may be included in the EVTMS but if not, needs to be pursued.

4) Eliminate Locomotives

A system needs to be developed which more easily and quickly positions the ships in the chamber. Although this is identified as a concept, no specifics could be provided for the existing locks. This has more potential for a new locks project.

5) Merry-go-round

This concept has been discussed and studied in the past and entails having the locomotives return to the opposite end of the lock(s) over the return track. The present condition of the return tracks prohibit the use of this concept. The return tracks need to be rehabilitated at Gatun and Miraflores Locks and the reliability of the switching devices evaluated. This concept needs to be evaluated again to maximize utilization of the expanded locomotive fleet.

6) Piloting

Standard operating procedures need to be developed and utilized by the pilots in transiting ships. Differences have been noted by the team for the transiting ships. Procedures would include speed of ships in certain reaches of the Canal, lock approach and exit practices, use of resources, and positioning of the ships. This could be monitored with DGPS and AEI.

7) Hydraulic assist to exit (flush)

Hydraulic assist could be used as a standard procedure in exiting ships from the chambers. This could be built into the miter gates and reduce transit time. Past evaluations have shown that vibration problems are evident.

8) Differential Pricing for commodity and ship size

A pricing structure could be developed to promote passage of ships that transit the locks quickly and discourage passage of ships that require excessive lockage time (e.g., heavily laden and under-powered Panamax ships). This would be a short-term measure to ration lockage resources while measures can be undertaken to increase the maintenance of the existing locks and implement operational and capacity improvements. The risk of this option is that the higher prices will cause permanent traffic losses rather than redistribution of traffic into a more efficient ship traffic mix.

9) Increase ship speed through the Cut

There is a potential to increase the speed of the ships through the lake and Cut without compromising safety. This would reduce transit time to a small extent but in the overall scenario provide only minimal additional capacity in the Canal. This could be monitored through the EVTMS.

10) Eliminate tugs

Tugs are needed to control the ships on entry into the locks. This concept could be eliminated with the substitution of another system such as 12) below.

11) Additional lighting

This item was discussed, and it was concluded that lock lighting is at a satisfactory level for current operating levels. It was later reported that the west lane at some of the projects could have the lighting improved. This will have to be evaluated at night for passing Panamax ships.

12) Arresting gear

In lieu of or complimentary with use of tugs, arresting gear could be used to "capture" ships entering the locks. This would allow the ships to approach the locks at higher speeds and reduce "locking" time. With the large ships, this concept is impractical.

13) Low-friction camel

A low friction positioning "pillow" could be used between the wall and ship to position the ship in the chamber. This could eliminate the need for use of locomotives for some types of ships.

14) Lower the sills

Lowering the sills would provide more under-draft below the ships and allow them to more easily and quickly enter and leave the chambers. This is an expensive concept that would provide very minimal benefits.

15) Reconfigure containers on ships

It is possible to reconfigure the containers on the ships to carry more containers. This is possible by extending the containers out near and over the sides and adding containers on the front of the ships. However, passage through the locks with the locomotives, control houses, light poles and other lock features make this impracticable. The addition of containers on the front of the ships cause line-of-sight problems in the cut and in the locks.

16) Lane separation in the Cut

A mid-channel lane separator could be provided in the Cut to mark two distinct lanes. This would provide clear distinction for the ships in passing situations and allow them to move at higher speeds. However, overall efficiency in the Cut would be reduced by having two seemingly narrower lanes.

17) Straighten the Pedro Miguel north entrance

The topography of the channel on the northwest bank at Pedro Miguel provides a turn for the ships as they exit and enter the Cut. This requires that they move at slower speeds. Straightening of this area to provide better entrance conditions into the lock and reduce entry time may involve relocation of the town of Paraiso. Widening of the channel at the northwest bank will improve line-of-sight and somewhat ease the turn.

18) Smaller ships

The PCC could be selective in the size of ships that pass through the Canal by limiting the ship size to Panamax and smaller ships. These ships would be faster and more maneuverable than post-Panamax ships but carry less tonnage. This would result in the loss of the Canal's largest revenue by restricting volume passed.

19) Modular ships

Ships could be constructed so that they are modular in design (i.e., sections could be taken apart and attached to other modular ships). This would assist in moving cargo by eliminating some of the need to off-load and on-load bu would not have an effect on Canal capacity.

d) Sea-Level Canal

1) Existing canal
2) East site
3) West site
4) Tunnel

2. Road

a) Existing road
b) Expressway-class transisthmian highway
c) Road trains
d) Dedicated truck lanes
e) AGV - Combi-road
f) New road alignment

3. Railroad

a) Existing railroad
b) Double track/Double stack
c) Road railer
d) Iron Highway
e) Platform cars
f) Rapid container loading/unloading
g) Trough train super hopper
h) Passenger service

4. Air

a) Existing Airports
b) Air/passenger service

5. Pipeline

a) Grade level - liquid/slurry bulk
b) Pneumatic - dry bulk/capsules

6. Conveyors

a) Container pallets
b) Bulk pallets
c) Belt

7. Other Concepts

a) Monorail
b) Water train
c) Maglev

VI. WATER ALTERNATIVES

A. General

Many studies have been undertaken over the years to investigate ways to improve the existing Canal by permitting larger and more ships to transit and also to find other routes across Central America. The "Interoceanic Canal Studies" completed around 1970 concluded that the best transportation routes in Central America are through Panama. This is because of the short distance between oceans, low vertical relief, and natural features that exist. Technology improvements continue to advance new pursuits, with the latest being the 250-mile long land bridge across Nicaragua. However, none of the pursued plans have been constructed because of the lack of economic benefits.

In looking at the advantages of the existing Canal in comparison with would-be competitors, the Study Team developed the following list of advantages of the Panama Canal. This list is not to be considered full and comprehensive.

- The Canal is an operating business that provides reliable service 365 days a year.
- Infrastructure to support Canal operations is in place and the physical condition is good.
- Ports and supporting ship service operations have been developed.
- Toll prices remain competitive at a level to maintain the Canal as a viable shipping option.
- The location is the shortest distance across the isthmus and provides the shortest transit time.
- The almost total natural formation of Gatun Lake has an abundant

rainfall to sustain current water needs.

- Low-cost labor is readily available.
- Lands and rights-of-way are available to support the present operation and provide for future growth and expansion with minimal social and environmental effects.
- Trained management and a technical workforce is available to support the operation.
- Support from the Government.
- The operation is debt free, and money is available to modernize and expand the Canal. The Canal has the ability to take on debt in the future.
- The Canal is part of the world and Latin America trade routes.
- The topography in this area has the lowest vertical relief in Central America.
- The transit service is proven to be safe and reliable. The PCC is committed to providing the lowest CWT.

B. Improvements to Existing Canal

In developing and evaluating Canal alternatives, consideration was first given to looking at options that may improve the existing Canal. Current ongoing and planned improvements must be carried to completion to affect short-range additional capacity while long term alternatives are being developed. Planned improvements will increase capacity to 43 ships per day versus the current capacity of 38 ships per day at a CWT of 24 hours. Current ongoing and planned improvements include and were discussed in Section II (BASELINE CONDITION).

- Procurement of additional and new locomotives.
- Procurement of additional and new tugs and launches.
- Completion of the Gaillard Cut-widening program.
- Implementation of the Vessel scheduling and asset management system.
- Providing hydraulic cylinders for operating machinery.
- Modernizing the locks control system.

From the list of Universe of Canal Improvements for the existing Canal, the following alternatives have merit for consideration in increasing short-term Canal capacity at modest levels (2-3 ships per day):

- DGPS for use on ships in navigating through the Cut in fog or other adverse weather conditions.
- AGVs,
- Automated lock-positioning system,
- Locomotive merry-go-round at Gatun Locks,
- Hydraulic assist for ship exit of the locks as a standard operating procedure (flush),
- Differential pricing for ship geometry to provide ships of a certain

capacity to promote trade and control traffic to predetermined sizes,
- Straightening the Pedro Miguel lock entrance on the northwest side
- Arresting gear for ship entry, and
- Low-friction camels for ship positioning.

The one area of the transit operation that has a significant effect on the transit time is lock entry. Shortening the lock entry time will reduce CWT and increase capacity as this happens three times during a transit. The last three items listed above present potential to reducing this time. A standard operating procedure where a ship is positioned against the center wall awaiting entry immediately behind a "locking" ship will also reduce transit time.

C. Sea-Level Canal

The first consideration in evaluating potential for shipment of cargo across the isthmus was the development of a sea-level Canal. In evaluating this alternative, some reliance was placed on the CAS and on the country's topography. Examination of a topographic map of Panama shows that sites for a sea-level Canal at locations in the country are very limited by the mountain range that passes almost completely through Panama and Central America. The existing location of the Panama Canal is easily discernible as the best location because of the low level of vertical relief, shortest distance between oceans, and near natural formation of Gatun Lake. No other location provides the advantages of the present location. However, in considering sea-level canal alternatives, these four locations were identified:

- The existing Canal,
- A location to the west through Rio Caimito on the Pacific side (CAS),
- Some location in the western part of Panama, and
- Some location to the east of Panama City and through the Darien Province.

For all locations, the following issues were overwhelming in opposition to development of a sea-level canal.

- A sea-level canal would provide limited capacity based on the need for locks or tidal gates that would inhibit easy entry and access to the canal. The need for entry of convoys into the canal or construction of locks would only permit the passage of a limited number of ships per day.
- As shown in the CAS, these options are the most expensive because the large amount of excavations and work that would be required. This alternative would also require the construction of all supporting infrastructure. All of the sea-level canal options identified in the CAS had a high cost, and none had an acceptable benefit-to-cost ratio.
- There is no flexibility for future growth. Any future modifications

would be expensive and require large excavations if the sea-level canal was to be widened.

- Salt-water intrusion problems would have to be carefully monitored and controlled to avoid the potential for significant environmental impacts.
- There would be significant environmental problems with the large excavations and disposal volumes. The recent strong environmental opposition to building a road through the Darien Gap would also bear heavily on building a sea-level canal.
- Other than the existing site and possibly the route through Rio Caimito, the high topographic relief would not lend itself to development of a sea-level canal as an alternative transportation system in Panama. The distances would also be greater across other areas in Panama as compared to the existing Canal.
- Development of a sea-level canal at the existing site would disrupt and possibly even curtail traffic movement for significant periods of time.

The only notable point in favor of a sea-level canal is that it does not depend on fresh water for operations and would have a limitless supply of water for lockages. Transit capacity is also added to the system. Similar or greater improvements in capacity can be obtained through various lock alternatives at the existing canal that are much less expensive and less environmentally intrusive. These lock alternatives will be discussed in the next section.

D. Lock Alternatives

In considering concept lock alternatives at the existing Canal, many lock locations, lock sizes, and siting combinations can be developed. In this Concepts Study, the team independently developed the alternatives for the most feasible lock sitings and combinations and compared them in the evaluation to the CAS. The most feasible alternatives are as follows:

- A new Canal at a new site with high-rise locks (one or two lifts - each lock) each at the Atlantic and Pacific side.
- One new high-rise lock (single lift) at the Atlantic side and Pacific side of the existing canal. Three possible sites exist at the Atlantic side - one at the third locks excavation, one to the east of the existing lock through the adjacent low-lying area, and one to the west through Gatun Dam. Three locations also exist at the Pacific side.
- One to the east of and near adjacent to the existing locks, one on an alignment through the third locks excavation, and one site to the west of the third locks excavation through the low-lying area.
- One new high-rise lock (double lift) at the Atlantic side and Pacific side of the existing Canal. Possible sites are as for the previous

alternative.

- One new lock at each existing site in the Canal, a double lift at Gatun as previously described, and one single-lift lock at Pedro Miguel and Miraflores locks to the west of the existing locks through the third locks excavation.
- One new lock at each existing site in the Canal, a double lift at Gatun as previously described, and one single-lift lock at Pedro Miguel with a double-lift lock at Miraflores, both on an alignment through the third locks excavation.
- Smaller size locks to accommodate ships up to a certain size.
- Three new locks with the same size as the existing locks.

1. Locks Alignment

At the Atlantic Ocean side, three lock alignments are possible. A lock could be situated on an alignment through the third locks excavation (see Fig. 2) and has a benefit in that this excavation is significantly advanced. However, this site is a distance away from the existing locks and would present loss of efficiency in operations and resource movement and utilization such as tugs, lock operators, locomotives, operators, etc. This site would also cause the loss of the existing anchorage area and result in the need to do additional Canal excavation at the southern end of the locks and through the anchorage to reach the channel. Ship movement at this end would also require additional and careful control to enter and exit the lock. This will be a problem for Panamax and post-Panamax ships. Any location to the east of the existing locks would have a benefit in access for construction materials and personnel.

Another alignment exists to the immediate east of the existing lock in the low-lying area (see Fig. 3). This alignment would necessitate relocation of the roadway, railway (certain to be relocated anyway), Maintenance Division, Electrical Division, and other support buildings. This location would allow better entrance and exit conditions for the ships, maximize utilization of resources (tugs, personnel, etc.), and allow consolidation of lock operations in a smaller area than an alignment through the third locks excavation. Lock operational control for all locks could be centralized. Construction access would also be a benefit.

Another alignment is possible to the west of the existing locks and generally through Gatun Dam and the excavation for the French Canal (see Fig. 4). The lock would have to go through the eastern embankment section of Gatun Dam and may present problems in providing a good seal. This location would be more suitable for a single-lift lock structure or a syncro-lift type feature. Flow through Gatun Dam spillway may cause current (flow) problems at certain periods and restrict use of the lock. Access to this alignment for transportation of construction materials and personnel would also be difficult. The use of the current channel crossing at the north end of Gatun locks is not suitable for construction support. In addition, this location will require another channel crossing to gain access to the west bank.

The Pacific Ocean side offers three possibilities for alignment of a new lock: (1) one alignment starting north of Pedro Miguel Locks and through the third locks excavation, (2) one to the west of the third locks excavation starting in the area of the Paraiso Tie-up Station through the low-lying area and exiting at the Rodman docks, and (3) one to the east of and adjacent to the existing locks.

The alignment to the east would be adjacent to the existing Locks and go through Miraflores Spillway. The lock would be located just north of Miraflores Locks. This consolidates locks operations and resources but would require relocation of Miraflores Spillway through the third locks excavation. It would also require relocation of the Water Treatment Facility, water intakes, and Landings. It appears that the Thermoelectric Plant could remain. This section of the Transisthmian highway would also need to be relocated, but the area to accomplish this is very limited. Closure walls and levees would be needed to form a channel, but use of excavated material would lessen disposal cost. The largest benefit of this location is its ease of access for construction materials and personnel.

The alignment through the third locks excavation would start to the west of Pedro Miguel Locks and place the new locks just northwest of Miraflores Locks as shown on Fig. 5. It would extend through the third locks excavation. A major benefit at this location is that ports could be placed in the lock wall to draw water in from Miraflores Lake. A closure would be needed from the south of the new lock to Miraflores Locks and to Pedro Miguel Locks to the north. Innovative design, technology, and construction methods could be used to accomplish this. Circular steel sheet pile cells could also be used to form the closure and form the cofferdam. Excavated material could be used to construct the needed levees and closures to form the channel. Excavated rock could be used to protect the slopes. Construction access will be inconvenient at this alignment.

The alignment to the west would start to the north of the Paraiso Tie-up station and follow a straight line to the docks at Rodman Base, (see Fig. 7) 6 This alignment would require the longest new channel excavation and have the lock located near the southern end to minimize excavation in rock for the channel. It also goes through a former target area that contains unexploded ordnance. Disposal requirements would be large. This location would also segregate lock operations and provide inefficiencies in the use of resources. Construction access will be a problem, as this location has the largest amount of work to be done. It will also affect existing active facilities at the dock area.

2. New Canal (locks similar to the existing Canal)

This concept would be the development of a new and separate locks-type canal across Panama. Features would be similar to the existing Canal and have lock or lock combinations at each end. The most logical location would be route 10 through Rio Caimito as presented in the CAS so that some use could be made of the existing Gatun Lake and water supply. Without question, additional supplies of water would need to be developed to assure reliable operation.

This concept development would have many of the items as expressed in opposition to a sea-level canal in Section VI.C., but to a lesser degree. It would be more expensive than adding locks to the existing Canal, an economical site is not available in Panama, environmental impacts would be significant with opposition, and infrastructure to support Canal operations would have to be developed along with ports and terminals. Operation of a second canal separate from the existing Canal would also segregate operations and require a separate operations and management structure.

3. High-Rise Locks (single-lift) - existing Canal

This concept would have one lock at each end of the Canal with a single (87.5 ft) lift (see Fig. 8 for the Canal profile with this configuration). The profile of the existing Canal is shown in Fig. 7 for comparison. The lock would be modernized with central automatic controls and hydraulic cylinders for mechanical system operations.

One high-rise lock would have a benefit in that only one lock entry and exit would be required at each end of the Canal. However, one high-rise lock (single lift) would require more water per lockage than a double or triple-lift lock. It has the largest water requirements. Water requirements would have to be carefully evaluated, as additional locks of any make-up would require additional water above that of the existing locks in use at the Canal. There would be some time savings in locking the ship from chamber-to-chamber over a double lift, but the additional filling and emptying time required would almost offset the time required to move a ship from one lock into another.

The miter gates for a single-lift lock would be exceptionally tall (150 ft or more) and slender in comparison to their width. They would also be very heavy, requiring large lifting and handling equipment, and very difficult to handle because of their height-to-width ratio. The miter gate would still be the gate of choice because of its design benefits in arching action, and while they could be designed, gates of this height are not recommended for use as they may be beyond the limits of a reliable design. Operating equipment requirements would also be exceptionally large. The ship positioning system currently in use could not be used in a single-lift lock, and a new and innovative system would need to be developed. A system of fenders set into the lock wall faces and either hydraulically or pneumatically operated could be designed in conjunction with an automatic sensing system to position the ships in the chamber. The lock walls would be large under traditional design to sustain the loads and pressures imposed on them. Non-traditional and innovative methods would need to be used to reduce costs not only for the walls but the filling and emptying system. These methods are available and could be utilized.

4. High-Rise Locks (double lift) - existing Canal

This concept would have one lock at each end of the Canal with two (44 ft each) lifts (see Fig. 9 for the Canal profile). The lock would be equipped with modern control and operating systems. The alignment for these new locks, one new double-lift lock at the Atlantic and Pacific Ocean sides, would be as described for the "Locks Alignments."

One lock at either end of the Canal would have the benefit of only one lock entry and exit at each end and provide a savings in time. This time factor would be the same as for a single-lift lock. The water requirements would be less than for one high lift (87.5 ft) but additional when compared to the existing locks because of it being a new lock and also additional length, lift, and width. Water requirements with lock usage would have to be carefully evaluated and supplemental or reuse systems developed. There would be some additional time needed to pass from one lock into the other as opposed to a single-lift lock, but this would be somewhat offset by a shorter chamber filling and emptying time.

The miter gate requirements for a double-lift lock would be more manageable in terms of height (105 ft), weight and handling. These gates could be handled and serviced with existing PCC equipment and be similar to the existing gates. Economies could be achieved by making the gates interchangeable between both locks, with spares provided at a storage location. To conserve water, intermediate gates could be provided if the lock was used to pass ships of a shorter length. The existing ship positioning system could be modernized and used to assist ships, but alternative methods need to be investigated. Conventional lock wall requirements would be significantly less than for a single-lift lock; however, introduction of non-traditional designs and construction methods would further reduce costs. The high rock faces after excavation offer opportunities for economical designs.

5. Combination High-Rise Locks - existing Canal

This alternative is feasible and would consist of a single-lift lock at one end of the Canal with a double-lift lock at the other end (or in essence, locks of different height lifts or plan sizes). Alignments would be as discussed previously.

Any combination of different height and/or size locks would lose economies of design and opportunities for interchangeability of gates, machinery, etc. Maintenance and service requirements would also be different. Combination of lift heights or plan sizes is not recommended.

6. Three New Locks - existing Canal

This alternative considers one lock at Gatun, most probably a double lift, and new locks at Pedro Miguel, single lift, and Miraflores (lock at third locks excavation), single or double lift.

The alignment considerations would be as previously discussed, but differ in that the alignment through the third locks excavation would only require minimal excavation across Miraflores Lake to achieve the required draft. Only one lock would be required through the channel alignment located to the west of this alignment. The alignment to the east of the existing locks is still not a favorable alignment as previously discussed although requirements across Miraflores Lake would be less.

Combination of lift size, although some locks could be matched for lift height, would lose some economies in design and interchangeability of gates and machinery. This alternative for combination locks is not recommended, but leads to the conclusion that one lock in the far west alignment on the Pacific side and an identical lock at Gatun would be preferred.

7. Triple-lift Lock - existing Canal

This concept would consist of one new triple-lift lock at each end of the Canal (see Fig. 10 for Canal profile).

Longer locks are always more costly than shorter ones (double lift), but in this application the cost of the longer length (3 lifts) is somewhat offset by a reduction in rock excavation. Non-traditional designs would provide further cost savings in walls and filling and emptying systems. Lower lift lock designs always reduce the potential for problems caused by the higher water velocities and pressures.

The longer lock at the alignment to the west of the existing locks on the Pacific side and through Miraflores Lake would reduce the cost because of the reduction in length of the required closures but still be somewhat higher. Site specific analysis with non-traditional applications would be necessary to determine the possible cost savings/increases.

There is the benefit of only one entry time into the lock at each end of the Canal but an increase in time in moving from one chamber to another twice. Additional resources/features are needed for the extra chamber (i.e., gates, operating machinery, and ship positioning system). An additional benefit may be derived from using the plans and specifications developed for the third locks in the 1930s. This could be used as an expedient but may lose some cost savings from innovative design. The operating machinery, controls, and some other features are all that need to be updated.

8. Smaller Size Locks

This concept envisions the range of lock lifts as discussed above but with lock plan sizes smaller than the existing locks (e.g., locks 80 ft wide by 600 ft long). Locks at these smaller sizes would be appropriately sized to serve some fairly large percentage of the smaller size ships. This would remove the congestion on the existing locks caused by the smaller ships, minimize water requirements, and allow the Panamax and near-Panamax ships to travel through the Canal more freely and at most times unrestricted. These larger ships carry the most tonnage and thus provide higher revenues.

Unquestionably, new smaller size locks would have lower additional water requirements and would reduce the amount of supplemental water supplies needed. Resource requirements would also be less, and the lesser design requirements would translate into overall lower costs. The disadvantage of new smaller locks is that the Panama Canal would be committed to passing only the Panamax size ship as the largest ship in the Canal and may not be able to meet customer demands to handle larger volumes of cargo on larger ships as evidenced by the ships on order. These ships would pay much higher tolls. Restrictions to Panamax size ships may also drive customers to alternate transportation routes, which may have a negative effect and reduce traffic in the Canal.

9. Syncro-lift

A syncro-lift is an elevator-type lift (see Fig. 11), presently in operation at Industrial Division and of proprietary design. It consists of a platform that is fitted with cradles and then submerged. A piece of equipment or ship is floated above the cradles while it is submerged and the platform is raised vertically with a system of synchronized wire rope winches. It is raised to the desired height and the cradles with the piece of equipment are pulled-off on rails into a work yard. Almost all syncro-lift systems in operation in the world are for dry-dock applications and as such do not experience frequent duty cycles.

These lifts can be of the bathtub (steel-containment vessel or tank) type where the ship is floated into it and watertight doors closed at the ends. The entire bathtub with the floating ship is then raised or lowered to the desired elevation. The tank is either filled with water alone or contains a floating barge (ship). The weight is always the same, as the ship displaces its own weight in water. Very little or no water is used in the operation.

Presently two large syncro-lifts (platforms) are in operation in the world in a dry-dock type operation to service unloaded Panamax size (26,000 DWT) ships (see Fig. 12). Ships are raised on cradles and then pulled off the platform with locomotives for servicing. Manufacturers of this type of lift feel that the technology may exist to raise a loaded Panamax (65,000 DWT) ship in this application. A syncro-lift is stated to be about 25% cheaper than a conventional-type lock structure, but this cost is exclusive of approach walls and other needed support facilities. Past studies performed by the USACE showed that a syncro-lift is competitive with a lock structure for very high lifts.

With the platform-type operation as at Industrial Division where the ship is fit into cradles, raised, and then pulled-off the platform with locomotives (see Fig. 13), it would seem possible to pull the ships off the platform onto a track system for movement across the Isthmus. This would involve constructing a track infrastructure to support a substantial weight. As the water canal already exists, it is cheaper and easier to move the ships in the existing manner. It is also possible to construct a syncro-lift operation with two syncro-lifts and a short piece of track section in-between on a high area of ground, such as over a dam as shown in Fig. 14. The ship is raised on one syncro-lift, pulled-off and moved into position on the other syncro-lift and then lowered to have the ship float in the water for transport. This type of system would have to be used in the Canal if a bathtub type of lift were not practical. This would add to the cost of the system.

The Chinese are currently constructing a bathtub type syncro-lift on the Yangzee River in China to accommodate smaller vessels. The system is also accompanied by a five-level lock system for large floating craft. The syncro-lift reportedly has a vertical lift of about 400 ft. The locks are 100-ft wide by 1000 ft long. This river navigation system has a draft of 16 ft and basically carries barge-type traffic, some of it of the European type self-contained units of private ownership. The river also carries a significant amount of passenger traffic. The weight capacity of this arrangement is not known, as the Chinese are designing and building the project themselves.

The manufacturers acknowledge that maintenance of this type of system is more than for a conventional lock structure, which raises questions of reliability. This would be expected with the large amount of moving parts and number of hoists that would be required. The existing applications are for smaller weights up to 26,000 DWT and infrequent use as for dry-dock operations. The large number of cycles per day that would be required in the Canal present an engineering challenge. In the Panama Canal, ships must be moved continuously. To provide this reliability, redundant features have been included in the existing system to preclude shutdowns and disruption of traffic flow. Maintenance of the syncro-lift will require shutting-down the feature to provide the needed service. Redundancy may not be feasible in this system. Also, work will have to be performed underwater or under the lift. The power requirements for this type of system are large and increase significantly as the ship size grows. The guidance and positioning of the ships on cradles or into a bathtub will require an innovative effort.

The major benefit of this system or any system similar to it is that any additional water requirements above the existing locks system are minimal. In consideration of the future traffic forecasts, which indicate that additional locks (lanes) will be needed, this type of system has very high merit. The challenges are to overcome the engineering problems and to develop reasonable maintenance plans. A lift in excess of a Panamax ship may be beyond the present capabilities for this type of system. Reliability would have to be evaluated in consideration of the benefits in reducing water requirements. There is sufficient potential for this system to warrant an in-depth evaluation. It certainly should receive high consideration if locks of a smaller plan size would be provided to pass the smaller size ships. An analysis of PCC records indicates that, since 1980, 50-60% of the transits have been by ships with beams of less than 80 ft and lengths less than 600 ft. This would provide a significant savings in water and is within reasonable design parameters for this type of system.

This system can also be modified to be operated with counterweights (see Fig. 15), which will reduce power requirements but increase structure costs. Depending on the size of ship desired to be lifted, the use of the counterweight system should be considered. The previous discussion is applicable to this type of arrangement.

A concept for a counterbalance system has been developed by Locks and Waterways International, Inc. using air chambers to connect has been patented whereby two adjacent tanks are operated simultaneously. This is not a syncro-lift. One platform is raised while the other is lowered with the one tank always being a dummy tank and only used for counterbalance (see Fig. 16). This system has not been constructed in practical application, and the costs appear to be far in excess of a syncro-lift system. The engineering aspects and details have not been developed. In frequent application, it would also have sealing problems to sustain the system. It is not recommended for use in the Canal.

10. Related Considerations

a. Water Needs

The addition of new locks will require additional and alternative water sources from those presently available in the Panama Canal System. Current levels of rainfall and the storage provided by Madden and Gatun Dams are sufficient to meet the water lockage demands for the present system of locks except for prolonged dry years when some draft restrictions are needed for transiting ships.

The need for additional water supplies is noted in the CAS and location of water supplies identified. Based on the traffic projections in the CAS, which are lower than the current updated projections, the alternative for a high-rise lock canal would require additional water supplies and pumping stations. These needs would be met by new dams on the Indio, Ciri, and Trinadad rivers and involve the construction of recycling pumping stations. The analysis for water requirements appears to be based on an average year from historical records. However, this analysis will not provide the reliability needed for the future and provided for in the existing system. Additional water analyses need to be performed for at least an 80-90% probability of water being available and sources identified to meet the need at these levels. This need will exist regardless of the size of new locks provided.

General calculations for the amount of water needed to fill a lock chamber for the existing locks and possible future locks of varying sizes are as follows:

	width length lift		cubic ft of water
Existing locks	110' x 1000' x 29'	=	
Possible new locks			
Single lift	150' x 1200' x 87.5'	=	15,750,000
Double lift	150' x 1200' x 44'	=	7,920,000
	150' x 1000' x 44'	=	6,600,000
	110' x 1000' x 44'	=	4,840,000
	80' x 600' x 44'	=	2,112,000
Triple lift	150' x 1200' x 29'	=	5,220,000
	110' x 1200' x 29'	=	3,828,000
	140' x 1000' x 29'	=	4,060,000
	80' x 600' x 29'	=	1,392,000

These volumes are additional water requirements above the needs for the existing locks. The amount of water required to move a ship through a single-lift lock or a multiple lift lock is the equivalent of one chamber of water (i.e., the lift times the width times the length of the chamber). As can be quickly seen for a new lock, a single-lift lock has the largest general water requirement, significantly higher than for the double and triple-lift locks. Double-lift locks, as expected, have the next higher requirements, and except for smaller size locks (because the locks are larger), they have larger water requirements than the existing locks. Unquestionably, new locks will require additional water. A balance in water requirements and usage will be necessary in providing new locks. Since smaller ships are easier to lift by other means, in-depth investigation of a lift system that does not use water is necessary. As previously noted, 50-60% of recent Canal transits have been by ships with beams less than 80 ft and 600 ft in length. Handling of these ships by mechanical means will provide a substantial savings in water usage that equate to about one traffic lane's requirements.

Judicious use of water and conservation will be necessary in the existing locks and for any new locks provided. The EVTMS will provide an opportunity to schedule lockages for maximum water use efficiency. Lateral transfer of water will have to be utilized with use of two-way traffic to obtain the greatest benefits even in a new system. This almost leads to a conclusion of constructing new locks in pairs (2 lanes), unless a system can be built that lifts (lowers) the ships with very little or no use of water.

Water can be stored in pools upon discharge from the lowest lock level and then pumped back up for reuse. Electric power can be generated as the water passes down from one level to another. Due to efficiencies, the pumping requirements would exceed amounts of power generated. The excess power would have to be purchased commercially and would likely be very expensive. Power requirements for new locks would be a very high cost when compared with the existing locks because of pump back. Whether these power requirements would be comparable to the power requirements of a syncro-lift is not known at this time.

b. Intermediate Miter Gates

Regardless of the plan size (length-width) of new locks provided, additional water supplies will be needed. The amount of additional water varies by type and size of new locks. The need for additional water can be minimized by providing intermediate gate recesses along the chamber length. The recesses could be provided at two or three locations with one set of intermediate miter gates. These gates could be designed for easy change-out (move from one set of recesses to another) and moved if there was a need to conserve water based on the projection of ship sizes to be transited over a period of time (i.e., the next two to four weeks). The EVTMS could be used to provide this information based on reservations or standard ship routing.

The disadvantage would be in the Canal use of post-Panamax ships if locks were adjusted at a size to meet these other needs. Use of the Canal for post-Panamax ships could be restricted during periods of strong water needs and negate the highest revenue provider.

c. Lock Plan Sizes

Based on the sizes of the ships on order to be built, the dimensions of new locks to pass post-Panamax ships would have to be 150 to 160 ft wide, 1200 ft long, and have a depth over the sills of a minimum of 60 ft. Although the Canal presently operates at very small underclearances with the ships over the sills, this is not efficient and results in longer than necessary times for ships to enter the locks. The direction for construction of new ships is to provide wider ships with a minimal growth in draft. The new ships will have a maximum fully loaded draft of 46 ft, but because they carry some empty space, they will draft 43-44 ft. With "squat" and underclearance, a Canal depth of 50 ft could pass the maximum draft ships well into the future. Providing a minimum of 60 ft of water over the lock gate sills will make it easier for the ships to enter the lock and decrease entry time. This will also provide a "cushion" for transiting deeper draft ships at some point in the future.

The lock plan dimensions of 150 to 160 ft wide by 1200 ft long will provide Canal flexibility. With a modernized ship positioning system and automatic positioning, it should be possible for smaller ships to enter and pass through the locks with minimal manual assistance from the Panama Canal Authority.

Locks of smaller plan dimensions could be provided to minimize additional water requirements to pass smaller than Panamax size ships, but this would limit the Canal to the Panamax ship as the largest size ship to transit the Canal. Draft over the sill would be less and be at a minimum level for additional water requirements. These smaller ships may also be transited with little or no assistance from the PCC during lock entry and the lockage. Smaller locks could be constructed in combination with locks to pass post-Panamax ships.

d. Entrance Design

Without question, the most time-consuming operation during the transit is entry into a lock and passing across Miraflores Lake from one lock to another. Elimination of one lock at the southern end of the Canal would be a benefit. Innovative design of the lock entry for a new lock and ship handling is necessary to reduce transit time. The entrance could be designed as a "Y" to funnel ships into the lock. Use of underwater compressed air ports properly positioned could assist in centering or controlling ships in the entrance. Soft fenders or cushions on approach walls could assist in aligning the ships.

e. Ship Positioning System

The existing ship positioning system is expensive as it is unique and has its own special requirements. This is not likely to change. Maintenance is high-cost and labor intensive. This system, however, has proven to be reliable and safe, features that must be implemented in a new system. With new locks, the opportunity exists with modern technology to provide a new and different type of ship positioning system. A new system could be hydraulic or pneumatic and consist of a soft fender or series of fenders or tires that laterally project from the side of the wall in a tapered configuration to catch and position the ships in the chamber. Relief valves could be provided to allow the system lateral movement. The unique feature would be the use of a soft material that would not damage the ships and provide extended use.

11. Innovative and Non-tradition Considerations

a. Wall Construction

Innovative construction methods and materials offer promise for more economical construction than conventional lock structures. For example, alternative types of construction may be used for lock walls. These walls create the lock chamber, which allows transferring the vessel between upper and lower pools, retaining backfill, providing anchorage and resisting gate loads. Typically, lock walls have been constructed as concrete gravity structures as in the existing Canal locks or as continuous reinforced concrete frame structures. This type of construction is still considered most appropriate for upstream and downstream gate structures to carry the large loads imposed on them. These structures will generally contain provisions for miter gates (or vertical lift or sector gates) with culverts, tainter valves and culvert bulkheads (or through the gate or sill filling/emptying valves), and emergency bulkheads. However, a number of alternative wall types could be considered for the rest of the lock chamber. These alternatives could include precast units, prestressed segments, prefabricated sections, roller-compacted concrete (RCC), grouted rock fill, tied-back walls, sheet pile cells, thin walls, reinforced earth-type walls, and earth embankments. It may be desirable to combine two or more wall types to form a lock structure under some circumstances. The concrete gravity, reinforced concrete frames (conventional or high strength concrete), precast concrete, RCC, grouted rock fill and tied-back wall alternatives all appear to be feasible for construction of new lock structures. A brief description of these methods follows:

- Concrete gravity walls. These are conventional mass concrete gravity lock wall monoliths (see Fig. 17), generally constructed of 3000-4000 psi concrete. They would be similar to the walls for the existing locks and are more expensive than the thin wall sections. These gravity-type walls have the filling and emptying culverts in them.

- Reinforced concrete frame. Reinforced concrete monoliths constructed as a "U" or "W" shaped frame combine both walls and the floor or sill into a continuous structure (see Fig. 18). This results in a reduction in the volume of concrete in the walls. The culverts are generally located in the walls but can be placed in the floor to reduce the wall thickness.

- Precast. Lock chamber walls can be constructed of precast concrete shells or caissons or panels which would be assembled and filled with concrete or granular material to perform as a gravity structure (see Fig. 19). These walls provide savings in that the sections are fabricated off-site, thus reducing on-site construction time.

- RCC. The lock chamber walls for this alternative would consist of RCC gravity walls faced with conventional cast-in-place concrete or precast concrete panels (see Fig. 20). This facing would be approximately 3 ft thick and would contain embedded metal and appropriate recesses. The conventional concrete and RCC would be placed simultaneously in 1 to 2 ft thick lifts. The interface between the RCC and conventional concrete or precast panel would be intermixed. In addition to lock walls, RCC is an alternative for lock floors and other areas that do not require reinforcing steel. This can result in relatively fast construction times. This has a cost reduction over gravity type walls but because of the high rock faces in the Canal is not the ideal application for lock wall construction below the top of rock.

- Grouted rock fill. This alternative includes gravity lock walls with conventional concrete adjacent to the chamber similar to the option noted above for RCC and "low-strength" concrete for the majority of the gravity wall. This "low-strength" concrete would be formed by spreading open graded rock (3 in. to 2 ft maximum) in 2 to 3 ft thick lifts and flooding the rock with a fluid grout (see Fig. 21). The placement would be minimally reinforced with conventional reinforcing bars. This type of wall can be very economical and constructed quickly, if suitable on-site excavation materials can be utilized. The benefit in this alternative is the readily available amounts of rock to be excavated. This may be more suited for use in the approach walls to minimize the cost of rock disposal.

- Tied-back walls. This would consist of a conventional cast-in-place or precast concrete chamber face with tied-back anchorage (see Fig. 22). This type of construction is particularly suited to sites where high rock faces exist that are suitable for anchoring. The Canal sites seem to be suited for this wall type. Rock excavation is minimized. Culverts can be placed in the floors or at higher elevations behind the walls or the chamber floors fitted with a system that enters and exits the sills.

b. Filling and Emptying Systems

These systems conduct water to and from the lock chamber. They are important because of their effect on vessel safety and speed of a lockage cycle and the influence the system has on the cost of the structural features. The filling and emptying system having the maximum effect on the structural design and layout of locks is one with culverts in the lock walls. The filling and emptying system having the least effect on the structural design is one with the culverts located in the chamber floor as shown in Fig. 23 and 24.

The filling and emptying system types that have been typically used for previous lock projects include wall ports, laterals, bottom longitudinals, and multiple wall ports. Filling and emptying has been accomplished on some very low lifts by use of sector gates, shutters in lock gates, and longitudinal flumes adjacent to the lock chamber with either vertical slide gates located in or adjacent to the gate bay monoliths. Many types of valves have been used, including vertical lift gates, butterfly valves, ball valves, cylinder valves, and tainter valves (both direct and reversed).

Disturbances caused by the flow of water into and out of the lock chamber during the operation should not endanger any craft that may be in the lock chamber or in its approaches. Localized turbulence can be generated by jets of water that the filling and emptying systems introduce into the lock chamber or lower approach. An oscillatory, longitudinal surge can occur in the lock chamber during operation of the filling or emptying system. Because surging tends to cause a ship to drift from one end of the lock chamber to the other, the ship must be restrained to keep it from striking the gates or damaging other parts of the structure.

Operating systems that monitor and control the filling and emptying process have become increasingly sophisticated and can contribute to the smoothness of the chamber water. Systems are generally classified as low lift (under 30 ft), intermediate lift (30-50 ft), and high lift (over 50 ft). The most common system is the wall ports system. It consists essentially of a longitudinal culvert of constant size in each wall, each with suitable intakes from upper pool, a filling valve, a series of chamber ports, an emptying valve, and a discharge manifold into the lower pool. In the bottom lateral systems for high-lift locks, the simple wall ports used in low or intermediate lifts are replaced by laterals extending across the lock chamber below floor level as for the existing locks. The flow is discharged into the lock chamber through a number of ports in each lateral.

In early lock design that used the bottom lateral system, the individual ports were in the roof of each lateral. This design works satisfactorily with a deep-water cushion. More effective energy dissipation can be obtained by locating the ports in the sides of each lateral, so that adjacent laterals will discharge into the common trench or box between them. If ports in adjacent laterals are staggered, an even better spilling action will result. The width of each lateral should decrease from its culvert connection to the opposite wall to produce a uniform flow through all ports. Two types of lateral systems have been used: the intermeshed type and the split type. In the intermeshed type, laterals from one culvert alternate with the laterals from the opposite culvert. The entire system is contained in about the middle third of the chamber and produces excellent results, if the ship is placed symmetrically over the laterals. However, this split lateral system cannot be operated safely with one valve unless the filling and emptying time is greatly increased. A third type of bottom filling system, the bottom longitudinal system, has been developed and refined in the past 25 years. It uses longitudinals in the lock floor connected to the culvert(s). This system is the most sophisticated system developed to date for high-lift locks. This system is expensive because it requires a highly configured concrete structure in the lock chamber. In addition, its use could possibly cause lowering of the culvert monoliths to obtain the proper water depth over these chamber structures.

c. Lock Gates

Lock gates can generally be horizontally or vertically framed miter gates, lift gates, sector gates, tainter gates, or roller gates. Horizontally framed miter gates with double-skin plates, similar to existing Canal gates, are envisioned for new locks. The gates would be larger (wider and taller) and heavier. To minimize weights and to enhance corrosion resistance, gates can be constructed with high-strength steel supporting members and composite material skin plates.

d. Approach Walls

Providing approach walls at each end of a lock facilitates lockages by reducing hazards and increasing the ease of the entrance and departure of a ship. Because of the high cost of these features, the requirements for each project should be studied to ensure the most economical solution.

A general rule for the longer approach walls is that their length should equal the usable length of the lock chamber unless conditions dictate a longer wall. In locations where the nature of the boats or the rockiness of the banks makes it impossible for ships to nose safely into the natural banks during emergencies, the walls may need to be lengthened to provide mooring space for more than one ship or tow at a time. In these instances, consideration should be given to using sheet pile cells rather than longer walls. Approach walls include the following types:

- Mass concrete or reinforced concrete walls. These walls are usually built within cofferdams and can be found on rock, soil, or bearing piles (see Fig. 25). These walls are larger than other wall types and cost the most.

- Cellular supported. Cellular supported guide walls can be built in water without a cofferdam or in the dry. The supporting element of the wall is composed of steel sheet pile cells, either intermittent or continuous depending on requirements for the wall (see Fig. 26). An intermittent line of cells can be made into a continuous solid wall by driving a single line of steel sheet piling between cells. The cells can be filled either with granular material or with tremie concrete, with or without bearing piles, depending on foundation conditions. The steel sheet piles are designed to be continuously underwater as their life in this environment is long.

- Prefabricated concrete beams. Prefabricated beams, either reinforced or prestressed, are usually used to make up the portions of the wall that are above water. These beams span between sheet-pile cells (see Fig. 27).

- Caisson supported. Caisson-supported guide walls can be built in lieu of a sheet pile cell supported wall. The concrete wall on top of the caissons is cast-in-place or precast, and somewhat similar to that for a cell-supported wall except that a heavy structural steel framework is required for transfer of the wall loads to the caissons (see Fig. 28). An upstream monolith protected by a full-height steel pile cell can be driven to 30 ft below the streambed and filled with concrete. A steel sheet pile curtain wall can be hung from the bottom of the wall to attenuate the velocity of the water flowing under the wall. Also, stone protection is placed on the bed of the river and around the caissons to prevent erosion of material from around the caissons.

- Floating guide walls. Floating approach walls of concrete have been used successfully where upper pools are very deep. The floating wall is composed of watertight cells with sealed inspection manholes surmounted by a vertical buttressed concrete or steel wall on the traffic side (see Fig. 29). The wall is designed so that the concrete weight is distributed to make the wall float level at the proper submergence. The structure is a completely reinforced concrete design with the ability to resist impact from tows. However, fenders or wall armor must be provided on the traffic side to protect the concrete and to distribute and dampen impact forces. These floating walls may be hinged to the upper end of the main lock walls through a wheeled guide operating in a vertical recess. A shock-absorbing device is also incorporated into the connection. The upstream end of the floating wall may be anchored by adjustable cables fastened to anchorages on the bottom. These adjustable cables allow the wall to be kept in proper alignment with the face of the main lock wall. Newly developed floating guide walls anchored by large diameter caissons (10 ft) have been shown to be very economical. Walls as long as 1700 ft, supported at the lock at the most distant end, have been developed. These walls are protected by a nose pier.

- Sheet pile guide walls. Steel sheet piling in a double row, connected by diaphragms or tie-rods and filled with free draining material, has been used for guide walls with and without concrete on top. If the wall furnishes support for a concrete wall above, steel bearing piles can be used inside the piling enclosure. If site conditions are favorable, a single line of piling anchored into the material behind the wall with tie-rods can be used.

e. Construction Methods

The conventional method for lock construction is to use a sheet-pile cell cofferdam which forms a watertight barrier and allows complete dewatering of the lock construction site (see Fig. 30). This is a temporary structure that is removed upon completion of construction. Dikes, bin-walls and similar temporary structures are also utilized. The use of alternative methods to construct a lock may have significant advantages over conventional types of construction in time, depending upon the site conditions. Alternative ways to construct a lock can include construction "in-the-wet" or a reusable type of cofferdam or a combination of methods. Construction in-the-wet involves underwater excavation and foundation preparation (including piles). The structure is constructed as a raft off-site in the dry and is then floated into place (see Fig. 31) and sunk, or hoisted onto the foundation (see Fig. 32), usually in segments to maintain a manageable size. The segments may be filled with tremie concrete, or steel shells may be used which are later filled with tremie concrete. Consideration must be given to the requirements for constructing the segments in a yard and transporting them to the site, or providing a dry dock type of facility (usually near the site). Large precast piers have also been set in place with specialized equipment (Dutch tidal barrier). The structure or portions of it may also be constructed within dewatered boxes (see Fig. 33), which can be reused. Or a more sophisticated mobile cofferdam may be used that consists of a double-walled steel box that can be floated, advanced, sunk, and dewatered with a self-contained system and can also incorporate mechanized concrete forming and delivery systems. The large amounts of rock and the need to blast preclude the use of these types of construction techniques for the lock. These techniques, however, may have application for cut-offs and barrier walls.

VII. NON-WATER ALTERNATIVES

A. Highway

1. Existing Transisthmian Highway

The existing Transisthmian Highway has limited capacity. It is a two-lane facility over most of its length, with numerous steep grades, sharp curves and only limited opportunities for safe overtaking. It is not developed to U.S. highway standards, and its condition is fair. The highway is heavily traveled by trucks and buses as well as automobiles and is operating at capacity during most of the daylight hours. The trip from Panama City to Colon, a distance of only about 50 miles, often takes 90 minutes to two hours. Hence, used as a freight movement facility, the current highway would only support about two or three round trips per day by a single truck, assuming 24-hour operation and allowing time for trailer positioning and loading/unloading. In addition, adding substantial numbers of trucks to the existing traffic load would quickly bring the highway into an even more congested condition and cause longer travel time. It currently does not provide a reliable and developed transportation mode for trucks.

2. New Expressway

It seems clear that to achieve any significant movement of cargo across the isthmus by truck would require a substantially upgraded facility, probably on a new alignment. As a minimum, the new highway should be four lanes, divided, and feature full access control (i.e., it should be designed and constructed to U.S. expressway standards). Planning for a new Transisthmian Highway project is currently under way, although a planning or design report for this project was not provided. Construction is well underway in Panama City for the Northern Corridor roadway, where expressways and interchanges that would connect the city to this new highway are in various stages of completion.

This new transisthmian highway, if constructed, will be a vital component in the future Panamanian cargo handling and transshipment infrastructure. This new facility will allow ports at either end of the Canal to serve as entry points for cargo destined for anywhere in the country (including port facilities at the other coast), will facilitate access to the Free Zone in Colon, and will provide for increased mobility for the PCC's employees and land-based equipment in support of Canal operations.

3. Multiple Trailer Operations

There are operational and technology options that could serve to increase the cargo carrying capacity of a "new highway corridor" across the isthmus. The simplest concept would feature the use of road trains (**photos 4 and 5**), which are large highway rigs with multiple cargo trailers hitched to a single power unit. Such vehicles are used routinely on rural highways in Canada and Australia, primarily to haul bulk cargoes. Rigs with two trailers pulled by a single tractor are also commonly seen on the interstate highways in the United States (**photos 4 and 6**).

4. Dedicated Truck Lanes

Mixing large numbers of multiple trailer vehicles with autos and buses can cause both capacity and safety problems, so a related concept would be the use of dedicated truck lanes as part of the highway system. This concept is needed to provide any reasonable highway capacity. These have been proposed in the United States and elsewhere but have not seen much application, primarily due to the land requirements and costs involved. The Panamanian cross-isthmus corridor, however, might be a good location for such a facility because of its short length and availability of land.

5. Automated Highways and Terminals

With dedicated lanes, a further evolution in technology would place automated guideway vehicles on these lanes, in which trucks would move under automatic control rather than the control of a driver. An experimental facility like this, called Combi-road (**photo 7**), is in use in Rotterdam. Automation on a more limited scale is beginning to appear in the United States and elsewhere. This is presently limited to automated gateways at container terminals and automatic vehicle identification combined with automated tracking of vehicle location, via GPS technology or other means. It is likely that in Panama these latter technologies will come into use as more reliance is placed on trucks operating over the new Transisthmian Highway.

6. Assessment of Highway Options

Improved highway facilities will not serve as a substitute for the Canal. There is simply not enough highway capacity for this. Even with the types of advanced concepts discussed above, the extra handling time and cost involved in transferring cargo between ships and trucks makes this alternative unattractive from an economic standpoint. Rather, the highway should be viewed as a valuable adjunct to the Canal, which increases the flexibility of the transisthmus cargo-handling system, and a basic asset to the economy of Panama. The shipping of cargo across the isthmus will allow access to the world.

B. Pipeline

There is an existing 40-in. pipeline in the Province of Chiriqui, which was built in the early 1980's to move Alaskan crude oil from the Pacific Coast (Puerto Armuelles) to the Atlantic Coast (Chiriqui Grande) of Panama. Tankers with a maximum capacity of 265,000 DWT can dock at the Pacific Coast terminal facilities at Port Armuelles. The crude oil is off-loaded and moved to holding tanks on the Atlantic Coast through the pipeline, which has a capacity of 800,000 barrels per day. From the tanks, the crude oil is delivered to ships, up to 150,000 DWT capacity, one mile off-shore by way of two catenary anchor-leg mooring buoys for transport to Gulf Coast and East Coast refineries in the United States.

This pipeline is currently not in use but could be put back into service if the volume of petroleum moving across the Isthmus would justify it. In the early 1980's, this pipeline had a significant effect on the Panama Canal as there was a sharp decline in the number of transits during its operation. This line could also be modified to handle petroleum products or even to allow flow from east to west across Panama. This operation should be viewed as a reserve asset that could be placed in service when market conditions show it to be an economical choice.

While use or modification of the existing pipeline would likely be the least-cost alternative for using this mode of transportation, other concepts for pipeline transport across the Isthmus were considered. A grade-level pipeline could be built along the Canal to handle liquids or slurries. In the case of slurries to move coal or other bulk solids, water supply and reuse would be a major issue, as it has been in the western United States A pneumatic pipeline could be constructed to move dry bulk materials or capsules. In both of these cases, the extra handling at each end of the pipeline imposes an economic obstacle, and any such service would need to have a large annual flow requirement to be feasible.

New or novel pipeline transport systems would likely be implemented only as part of a multi-service freight corridor concept where this mode offered unique advantages for a portion of the anticipated market. Construction of a pipeline at other locations in Panama would require a whole new infrastructure, including the pipeline, docks, and storage and handling facilities. As noted above, the infrastructure exists, and reopening of the Chiriqui pipeline would likely occur before any new facilities would be built. If the pipeline were reopened, its impact on the Canal would be expected to be as occurred in the 1980's. Again, demand for its use would have to remain high to sustain continued operation.

C. RAIL

1. Rail Line Capacity

a. Existing Railroad

The existing rail line is not currently being operated because of the poor condition of the track structure and the resulting inability to maintain track geometry or ensure safe operations. The line last handled more than 50,000 tons of traffic in 1992, and traffic dropped below 10,000 tons in 1994. Nevertheless, history shows that the line has the potential to move an extremely high volume of rail traffic.

The Panama Railroad opened in 1854. It was an immediate success, as it saved months of travel relative to the all-water route around Cape Horn from the eastern United States to California. Later on, the railroad proved to be the key in constructing the Canal. For many years, it was used to transport supplies and people, to bring in coal for the steam shovels, and most importantly, to move essentially all of the rock and dirt excavated from the Gaillard Cut. In short, the railroad was the key to the successful completion of the Canal. The annual tonnage carried by the railroad during the peak years of construction rivals and possibly surpasses the 125 to 150 million gross tons that are now carried annually on the highest density lines in the United States. "Gross tons" refers to the weight of equipment in addition to the weight of the lading. During 1908, which was the peak year of excavation, more than 60 million tons (37 million cubic yards) of rock and dirt were excavated annually. Assuming that most of this material was moved out by rail on (by today's standards) small cars, the railroad would have handled more than 125 million gross tons in the peak year. At that time, it was the world's most heavily used rail line, and today its annual gross tonnage is only exceeded by the most heavily used North American Coal lines.

During the construction of the Canal, the railroad was rerouted around Lake Gatun, a task that took five years. The current route is approximately 50 miles long, with minor grades, and several sharp (6-7 degree) curves. A short tunnel, a small highway bridge in Gatun, and electric power lines limit vertical clearances. The railroad is single-track, with short (2000 ft) sidings and small yards in Balboa and Colon. The line has a non-standard gauge (5 ft), which is slightly wider than the North American standard of 4 ft, 8.5 in.

b. Minimal Upgrade

At a very minimum, the railroad needs major tie and ballast programs to support any transisthmus traffic. Jane's World Railways estimates that an investment of $20 million is needed simply to return the railroad to operations. Complete reballasting, tie renewal, and some new rail (Gatun to Mount Hope) would be needed to raise speed limits to 80 km/hr for passenger and 60 km/hr for freight and to increase axle loads above the current maximum of only 20 tons (as compared to 33-36 tons for heavy haul lines in the United States and Canada. If the railroad is to be used for any significant traffic volume (i.e., several heavy trains per day), it will require new rail and turnouts as well.

Because the railroad is very short, the rehabilitation costs will not be a major capital expense. The ICF Kaiser study conducted for the PCC estimated such costs to be on the order of $50 to $60 million, which is approximately $1 million per mile. If there is to be a major rehabilitation program, the railroad could readily be rebuilt with standard gauge to allow the use of standard stock and track components.

Once the track structure is upgraded to support train operations, considerable line capacity will be available. It will be possible to operate 10 trains per day simply by operating one train at a time across the line every two hours and leaving 4 hours per day for maintenance. Since the line is so short, this type of operation could be achieved with an average speed of less than 30 mph, without any passing sidings, and without any intermediate signals. These trains could be any desired length, as long as they can be handled in the terminals. Clearances would be a problem for some types of equipment, and intermodal operations would be restricted to single stack operations (e.g., loading only the first level of existing double stack equipment, as suggested by **photo 8**).

Assuming that the primary freight is containers, the rail line under these conditions would handle approximately 2000 TEUs per day or 700,000 TEUs per year. This would be quite a high volume of containers compared to current transshipment operations. For example, it is 10% greater than the total container volume projected for 1997 at the Manzanillo International Terminal in Colon. Compared to the number of containers moving through the Canal, this is not so large a volume. A single Panamax containership can handle (4000 TEUs), and the Canal handles a half dozen such ships daily. The minimal rail system would therefore be equivalent to less than 10% of the daily container traffic and well under 2% of the total daily tonnage through the Canal.

c. Expanded Capacity - Conventional Approaches

Rail system capacity is a complex concept, as capacity depends upon the track layout, track components and their condition, signaling capabilities, operating characteristics, equipment, and terminals. For the transisthmian route, the main concerns will be line and terminal capacity, both of which are severely constrained by the condition of the facilities. Line capacity can be clearly increased quite quickly, while terminal capacity could be a major problem.

Capacity of the rail line can be expanded through several conventional strategies. The first step would be to add intermediate sidings and a traffic control system. Having long sidings (7000 ft or longer) at 10-mile intervals would increase capacity by at least a factor of 6, from roughly one train every 2 hours to one train every 20 minutes. Keeping the same 4-hour window for track maintenance, the line could handle approximately 60 single-stack container trains carrying 12,000 TEUs per day.

The next step would probably be to double track the line, which would allow trains to operate in both directions on short headways. Line capacity would roughly double to 120 trains or 24,000 TEUs per day. It may seem incredible to discuss such high daily traffic volumes for a railroad that currently handles less traffic in a year. However, there are locations in the United States where traffic volumes already exceed 100 heavy freight trains daily, including the Union Pacific Railroad's main line across Nebraska. With proper investment, such traffic volumes could also be achieved in Panama, assuming that the terminal facilities are able to handle this volume of traffic.

Increasing clearances to allow double-stack container trains (see **Photos 9 & 10**) would allow another doubling of capacity to 48,000 TEUs per day. This is an extremely high volume of containers, equivalent to 12 Panamax container ships per day, which is more than the current volume of container traffic through the Canal. This would also be nearly 18 million TEUs per year, which is greater than the annual intermodal traffic volume (containers plus trailers) handled by the entire rail system in the United States.

The conclusion from this very quick assessment of line capacity is that a double track railroad can indeed carry a very high traffic volume. The line itself is therefore unlikely to be the bottleneck in rail operations. The problem will be in the terminals, because a great deal of additional terminal trackage, large parcels of land, and carefully coordinated rail/port operations will be needed to originate and terminate large volumes of trains.

d. Rerouting the Railroad

If a third set of locks is built at Gatun, the railroad will have to be rerouted in this area. A cursory examination of the map suggests that it should be possible to provide a much more direct route from the end of the Lake Gatun causeway to the ports in Colon. This route would be shorter and the sharpest curves could be eliminated, which would provide a minor boost in capacity and some reduction in operating costs.

It will also be necessary to expand and redesign rail terminal operations at both ends of the line, especially the Atlantic Ocean side, where space appropriate for rail terminals is at a premium. It will be desirable to have a larger rail terminal with good access (with minimal grade crossings) to whatever ports are built. **Photos 11, 12 and 13** give some indication of the space requirements for a larger intermodal terminal. The gate area should have 10-20 separate lanes and a lengthy approach that can easily hold dozens of trucks (see **photo 11**). Ideally, the terminal will have loading/unloading tracks long enough to hold an entire train (see **photo 12**), with a paved apron to support the use of mobile loading equipment (see **photo 14**). Larger cranes can be used to unload from double or even triple loading tracks (see **photo 16**). Parking can be accommodated at the sides of the terminal (see **photo 13**) or between the loading tracks (see **photo 14**). Traffic flow is a concern in large terminals, as truck drivers and hostlers can get in each other's way (see **photo 17**).

2. Rail Terminal Capacity

Rail capacity problems are almost always most severe in the terminals. This will be especially true for the Panama Railroad, as the existing terminal capacity is very limited, and space is readily available for expanding facilities only at the Atlantic end of the line. In Balboa, the existing yard is hemmed in by highways and other transportation facilities, a tank farm, the Bridge of the Americas, residential housing areas, and the relocated Patilla Airport. Grade crossings and interference with highway traffic will certainly become problems on the Pacific side as the frequency of train operations increases.

Grade crossings can be eliminated through construction of bridges or relocation of the railroad, but only at a very substantial cost. The more serious strategic problem will be the availability of large parcels of land for rail terminal operations.

a. Rail Terminal Requirements

The conventional approach to loading and unloading trains is to use an overhead crane or a sideloader that works with individual containers. Typical productivity rates are about 30 lifts per hour. In principle, it is therefore possible to unload and then reload a single-stack container train in 2-3 hours by using 3 or 4 cranes or sideloaders. This suggests that a single loading track could handle, under the best conditions, eight or more trains per day. In practice, tracks in intermodal terminals generally handle fewer than 3 trains per day, because of the difficulties inherent in coordinating train arrivals and departures, gate operations, and loading and unloading activities. Also, most intermodal terminals operate on a "retail" basis, with high transaction costs involving hundreds of customers and trucking companies using the facility.

In Panama, it should be possible to develop very efficient terminal operations because the great majority of containers will be moving on dedicated trains linking a few major ports. This "wholesale" operation will provide many opportunities for utilizing information technology to simplify gate procedures and to coordinate port and rail operations. Some idea of the magnitude of the terminal problems can be obtained through some elementary analysis equivalent to what was done above for line operations.

If 2000 TEUs are transported across the isthmus daily, then the rail terminal at each end of the line will need to unload and reload five 400 TEU trains. Given the above calculations, this could be done on a single track if operations were extremely efficient or on two loading tracks with a good level of efficiency. This provides an idea of the scale of terminal operations: one or two long loading tracks (at least one mile long) at each end of the line for every 2000 TEUs per day handled. With long loading tracks, there is room to stage containers and chassis next to the track to minimize the amount of hostling required and to allow efficient pick-up and delivery of containers by truckers.

If the loading and unloading tracks are not long enough to handle a full train, then the efficiency will decline because extra time will be needed to breakup the train upon arrival and to reassemble the train before departing. With more, shorter tracks, the layout of the terminal tends to become more complicated, and additional costs are incurred in hostling and in pickup and delivery operations.

In summary, for levels of perhaps 2000 TEUs per day, fairly simple terminals will be adequate at each end of the line so long as they can be operated on a 24-hour, 7-day per week basis. To support a cross-isthmus transshipment operation of 500,000-800,000 TEUs annually should therefore be feasible with only modest terminal investment.

If container traffic is to rise high enough to be a major portion of the Canal's container traffic, much more extensive terminal operations will be required. The most critical constraint will be to find sufficient land on the Pacific side. Truck traffic will increasingly become a problem as well, unless the terminal is situated such that draymen and hostlers can avoid the city streets.

b. Direct Rail-Ship Loading and Unloading

Direct movements between rail and ship would eliminate the need for extensive draying and rehandling of containers. In practice, direct movements are difficult to coordinate; instead, containers are typically grounded somewhere as an intermediate step in the process.

For high-volume transisthmian operations, it might be easier to coordinate direct rail-ship movements. For example, if a top layer is added to a ship for transshipment, then these containers could be unloaded first and dropped onto the rail platforms. The railroad could then move the containers directly across the isthmus for unloading and sorting at the terminal on the other side. The containers would then be reloaded onto ships at the other side using the normal process.

To coordinate rail-ship operations, it will be essential to have a well-designed terminal with enough room to stage the necessary rail equipment as well as a coordinated intermodal operation that will allow continuous loading-unloading operations.

c. Advanced Container Handling Systems for Ports

There are alternative technologies that could be used to load and unload container ships. The FAST Ship concept assumes that a string of containers could be connected or loaded onto a set of connected platforms and pulled out of the ship as a single unit. This type of system would easily be linked up to the rail system (e.g., a modified version of the Iron Highway, discussed below). A single system could be used to pull out a string of containers from the ship and load them onto a long platform car. This would sharply reduce the time and cost of the ship-to-rail transfer movement.

This technology would allow a new, markedly cheaper transshipment option. A ship could transfer several strings of containers across the isthmus to several connecting ships on the other side. So long as the containers were sorted appropriately, so that all of the containers in each string were headed to the same ship, it would be unnecessary to handle individual containers.

3. Rail Intermodal Equipment

Several different options for rail equipment are discussed below.

a. Double-Stack Container Trains

Double-stack container trains were first introduced in the 1980's by Southern Pacific working together with SeaLand in the Los Angeles to Houston corridor (see **photo 1**). These initial double-stack trains used heavy bulkhead cars that provided only modest benefits in equipment cost and in fuel efficiency (see **photo 2**). The concept really caught on when APL introduced lightweight equipment and took advantage of excess rail capacity to negotiate very low rail rates.

Double-stack trains allow twice as many containers to be handled in the same length of train. This has three primary advantages:

a. Line haul costs decline very significantly: crew and equipment costs decline by approximately 50% per container, while fuel costs also drop significantly because of the reduction in the tare weight of the equipment and the energy characteristics of rail transportation.

b. Intermodal terminal operations are simplified, as only half as many loading tracks and half as many train movements are required.

c. Line capacity increases, as fewer trains are needed to transport the same number of containers.

The line haul cost savings precipitated the dramatic rise of double stack operations in the United States. Traditional rail intermodal line haul costs for trailer or container-on-flat-car were only about 10-15% below truck costs. This modest line haul advantage was enough to offset the terminal loading and unloading costs only for very long distance moves. With double-stack service, the cost advantage increased to 40% or more. This was enough to cause truckload carriers to enter into intermodal partnerships and to shift traffic from Asia to the eastern United States from the Panama Canal route to the double-stack system.

The terminal efficiency was not at first a major concern for the railroads. There were hundreds of rail intermodal terminals across the United States and Canada, many of which had excess capacity. As traffic grows and additional terminal capacity becomes necessary, the terminal component of double-stack operations becomes more important. The efficient use of terminal space is especially important where land is expensive (e.g., near ports and within major metropolitan areas).

The line capacity benefits of double-stack trains has become much more important in the last 10 years, as an increasing number of key routes are operating close to capacity.

b. Roadrailer

The basic concept of the roadrailer technology is that the rail car is largely superfluous for intermodal transportation. The intermodal trailer or container can itself be used to connect the train. In the original concept, the roadrailer was a highway trailer equipped with a rail axle that could operate either on the highway or on the rail system. Trains could be assembled in a very narrow space where tracks were paved over. The truck driver would back up the trailer and attach to the previous trailer, then use a pneumatic system to lower the rail axle and to raise the highway axles. The problem with this system is that the roadrailers were expensive to own and to operate, and their payload was less than that of the standard highway trailer because of the extra weight of the rail axle.

The solution was to take the rail axle off the roadrailer and to use special rail bogies (see **photo 18**) for the rail portion of the trip. This system is more versatile, cheaper, and allows heavier payloads than the original system. However, it is more cumbersome to load and to unload, as it is necessary to deal with the roadrailer bogies which are left on the tracks after the train is disassembled, as shown in **photo 19**. The time to assemble a train is about 5 minutes per trailer as compared to 2 minutes per container for the double-stack system. The extra time is needed to position the trailer or container/chassis over the bogie (see **photo 20**), make the connection, and then raise the highway axles (see **photo 21**).

Roadrailers were attached to the end of passenger trains for a while in the 1950's, but the concept did not catch on until the 1980's. The advantage of the system is that the line haul costs are nearly as low as with double-stack, while the terminal costs can be much lower. The system has found a niche market in handling high-value commodities on certain routes for certain high-volume customers. The system is especially attractive for movements to and from locations that are distant from conventional rail intermodal terminals. The major disadvantages of the system compared to the double-stack system are that it requires more line capacity and more time to assemble a train.

Because of the dominance of terminal operations for intermodal operations in Panama, it does not appear that this equipment offers any advantage over conventional equipment for transisthmian movements.

c. Iron Highway

The Iron Highway is a 1000 ft long articulated platform that can be used to transport a great variety of intermodal equipment. The system was first proposed in the mid-1980's by New York Airbrake as part of the High Productivity Integral Train Program sponsored by the Association of American Railroads. The system is now being developed by New York Airbrake in cooperation with the North American rail industry. In Canada, CP Rail is using iron highway equipment in revenue service between Montreal and Toronto.

The advantage of the iron highway is that it can carry many different sizes of containers or trailers or even tractor/trailer combinations. The system can be loaded by draymen or hostlers, who back the trailers up the ramp and along the platform. Like the roadrailer system, this approach requires no overhead cranes, very little space, and can be time-consuming. Unlike the roadrailer, there is no need for specialized trailers or containers, and there is no logistical problem in dealing with the bogies.

It is possible to design a terminal for more rapid loading and unloading of this equipment. Obviously, cranes or other lift equipment could be used to load containers onto the platform. Also, if the loading track were recessed (or if the loading ramp is raised), then it would be possible for hostlers to load simultaneously at many locations along the platform.

The basic concept of the Iron Highway could be relevant in Panama, although it is less likely that the specific equipment being introduced in the United States will be. The basic idea of creating a single, long, articulated platform that can quickly be loaded and unloaded is valid, especially if the platform can be loaded directly from a ship. The use of draymen and hostlers to load and unload high volumes of containers is not desirable.

d. PCC Intermodal Equipment

The unusual characteristics of the transisthmian intermodal operations could justify the design of special purpose intermodal equipment. The most important features are

a. Very short line haul distance,

b. Potentially very high volume of containers (for a rail line),

c. Connections with containerships at each end of the line (i.e., highly concentrated sources and sinks of traffic),

d. Very little local traffic, and

e. Essentially no existing traffic or facilities.

The short distances, high volume, and concentrated traffic flows translate directly into very short vehicle cycles. Hence, the vehicle costs per move could be very small, even taking into account the need for unique equipment.

Because there are as yet no significant intermodal facilities or traffic flows, a system could be potentially designed from scratch. Even if significant flows develop using the existing transisthmian rail and highway systems, there will be the option of starting a new system on the west side of the Canal (as long as land is preserved for terminal facilities and rights-of-way).

Special equipment for the Panama Railroad would be designed to minimize terminal handling time and costs. The ability to load and unload very rapidly would be critical.

Although rail line capacity is probably less critical than terminal capacity, it is possible to think of a very broad gauge system in which trains can handle a 2x2 cross section of containers. This would require a decidedly new track structure and a new type of equipment. The same track could be used for very high volume bulk movements, as discussed below.

4. Other Rail Freight Options

a. West Side Rail

A new railroad could be constructed on the west side of the Canal to provide a link between a new set of Atlantic Ports and a new set of Pacific Ports. The capacity of a West Side Railroad would, in principal, be no different from the capacity option discussed above for the existing railroad. The benefits would be not in line capacity, but in port access. Instead of winding through the congested streets of Panama City toward a cramped port, an unobstructed approach could be provided to extensive port facilities.

Construction costs for a new railroad would be greater than the rehabilitation costs for the existing railroad, because it would be necessary to create the route and provide the necessary bridges. However, the distances are not great across the isthmus, so that total costs might not be an excessive obstacle relative to the infrastructure costs for the related ports and terminals.

An alternative would be to cross the Canal somewhere before the Gaillard Cut and link up to the existing railroad. This would require a rail bridge over the Canal or a rail tunnel under the Canal but would reduce the need to construct new rail lines. A bridge or tunnel designed exclusively for service would of course be a major additional investment in the rail system. A more realistic concept would be to include a rail line as part of the next Canal crossing, if and when that crossing is constructed.

The West Side Railroad could be a part of a major freight corridor that also includes a freight highway, pipelines, and conveyors.

b. Heavy Haul Rail

The rail system could also be used to move bulk commodities across the isthmus. The prospects here are more limited than for containers, because the shipment size is so much larger. A Panamax containership carries many hundreds of individual shipments, and there is at least the possibility of transshipping some of these shipments. A ship carrying grain or some other bulk commodity is most likely carrying only a few shipments; transshipment is therefore a much more cumbersome prospect involving trainloads rather than carloads. Rail terminals will be needed to assemble and service long bulk trains, as shown in **photo 22**.

Nevertheless, railroads are well suited to hauling bulk commodities. In the United States, unit trains routinely handle well over 10,000 net tons of coal, grain, and other products at a cost of less than $0.02 per ton-mile.

As with containers, the key will be the development of low cost, high-capacity transfer facilities.

1) Trough Train

A trough train has a long series of permanently connected hopper cars, a train-length conveyor belt, and a self-unloading capability. This design provides flexibility in operations, as no special unloading facilities are required, and unloading can take place at the speed of the conveyor (i.e., 1000 tons per hour). It increases the load per linear foot of train and reduces the time required for loading. Existing models have a conveyor that allows the train to unload itself continuously without any special equipment at its destination.

2) Dump Cars

Dump cars are designed to unload very rapidly to either side of the track without any special facilities. Telescoping air cylinders are used to raise the car body to a dumping angle of approximately 50-degrees. Car-length doors open automatically as the car tips, allowing unloading in about 10 seconds per car. Cars similar to this were used extensively in the construction of the Canal.

3) Super Hopper

A very high-volume rail car could be created for use on the Panama Railroad or for use on a new West Side Rail. Larger loads would reduce loading and unloading time, increase the load per linear foot of train, and reduce terminal space requirements. Because the railroad is short, it would not be excessive to invest in the premium components that might be necessary to support an operation with extremely heavy cars. If a new railroad were to be constructed, then it would be possible to use a substantially wider gauge to increase the carrying capacity of the line, as discussed above.

5. Passenger Service

Once the existing railroad is rehabilitated, it would be available for use for certain passenger operations. The most promising option would be to provide a service for tourists, including those staying in Panama and those on cruise ships that would dock at the Panama ports. Trains could take people to and from the locks so that they could view the lock and shipping operations that are a major attraction for Panama. The ride through the jungle, along the lake, and across the isthmus would also be a memorable activity. To a great extent, these trains could be operated with little interference with freight trains, as stops could be scheduled to visit the locks or other interesting sites, and speed is not a great concern. The full cost of the rail trip would not be a burden to visitors and tourists, especially if the rail tickets were provided as part of the cruise or the tour. Given the heat and the periods of heavy rainfall, it would be essential to have modern, air-conditioned equipment with seating and window arrangements that allow excellent views.

The railroad could also provide some commuter services, including transisthmian service. For commuter services, speed and cost would be a greater concern than for the tourist operations. These services would not necessarily require a direct link to the activities in the Canal.

D. Air Transport

The airport at Colon on the Atlantic Ocean side of the Canal does not offer any significant potential for use as a cargo transportation center. The condition of the runway is fair, asphalt base, and suitable for handling only smaller aircraft. It is absent of any building facilities and does not have night lights. Patilla Airport on the Pacific Ocean side is being relocated to the airstrip at Albrook Base, but it too is only suitable for smaller planes. Some buildings are located at this airport, but there are no night lights. The distance between airports is very short, about 45 miles, and reasonable for only low-altitude flying. High-volume transportation of cargo is not feasible unless the airports are greatly developed and expanded. This is a problem at the Albrook base, as expansion is restricted by other area development.. No other airports are close enough to the Canal to provide any reasonable cargo service.

Air transport as an alternative to Canal transit does not seem to be a reasonable possibility due to the very high values of this cargo. The cost of carrying inventory is the primary reason for the use of airfreight. This cargo is therefore extremely time-sensitive and not conducive to diversion to a surface mode. The small amount of air cargo that could be diverted would be from containerized shipments that were needed on an emergency basis and would be infrequent. The development of suitable air cargo facilities may be of some benefit in offering a total transportation capability; however, these facilities could well be left for the private sector to provide. It should be an initiative of the Government of Panama to improve the airport system, particularly as it relates to the free trade zone. However, the potential use of air transport as an alternative to Canal transit is not deemed a plausible solution to future capacity constraints.

The use of combined sea/air transport is increasing, particularly in the fashion trade. This transportation method could be used in the future to a greater extent if product values were to escalate substantially or the surface transport modes became significantly less efficient. However, the switch to various sea/air combinations still would have a negligible effect on Canal trade due to the limitation on total volume capability of the air transport system.

E. Conveyor Systems

Several configurations of conveyor systems were analyzed as an alternative to Canal transit for dry bulk cargo. There currently are no conveyor systems across Panama or at the ports. The dry bulk commodities are sensitive to handling expense due to their relatively low value. Any increase in total transportation costs incurred as a result of multiple handlings to utilize a surface conveyor system would seem to work against diversion of these cargoes. Some limited potential may exist for a dry-bulk conveyor system as part of a transisthmus corridor; however, this would depend on the development of regional distribution for specific commodities. This type of conveyor, and the bulk storage required, should be developed by the private interests involved in the trading of these commodities. Any such conveyor system would unlikely represent a significant capacity addition for the Canal trades in dry bulk cargoes.

The cost of constructing dry bulk conveying systems is currently in the $3000 per foot range. The capacities of these systems can be as high as 3000 metric tons per hour on a sustained basis. However, such an investment would require substantial contracted long-term tonnage commitments to enable the capital cost to be recovered in a reasonable time frame. It would also be advisable to provide dust suppression capability to reduce the environmental impacts of such a system and allow the greatest range of commodities to be handled. The development of a large capacity conveyor system may be an alternative at some future time but would not represent a significant competitive threat or a source of significant capacity to handle transisthmus trade.

F. Omni-Port

The transshipment concept depends on the relative economies of long-haul cargo transport by large (post-Panamax) container ships and local distribution by small feeder ships. The large ships have a high capital construction cost, but because they carry a high number of containers (typically 4000-7000 TEUs), their unit cargo cost is relatively low. These big ships characteristically cruise at high speed (20-25 knots) and depend on fast port turn-around times to optimize their utilization rate. In addition, they must make as few port calls as are necessary both to fill their capacity and to maximize their time in service.

In contrast, the smaller feeder ships travel at a slower speed (16-20 knots) and can service small ports with less sophisticated cargo handling operations. These ships have a lower capitalization cost and can tolerate the greater times in port required by multiple calls. Properly coordinated with the post-Panamax sized ships, the use of feeder ships can cut operational expenses and increase customer service.

The key factor in this type of operation is the container transshipment hub, which must transfer cargo quickly and economically between ships. This is best accomplished when there is a high volume of cargo passing through the port and a high frequency of ship calls provide multiple distribution options. Several methods are possible for achieving these goals. In some instances such as Miami or Hong Kong, the local cargo market generates ship calls that can also carry transshipment cargo. At locations such as Singapore or the Panama Canal, ship traffic is focused on a natural hub location by the geography of the site. Therefore, a successful hub terminal must be positioned to take advantage of the economies of high cargo volume.

One type of hub terminal is referred to as an Omni-Port. This terminal is equipped to efficiently handle a very broad range of cargo types, accepting small shipments from feeder ships and consolidating them for transshipment by line-haul container ships. The primary advantage of this type of terminal is that it can receive empty containers being returned to the Far East or United States and fill them with break-bulk or high unit value dry bulk cargo originating in Latin America. The shipper gains the service and speed of a container carrier and the carrier gains a revenue cargo for his otherwise empty containers.

To function as an Omni-Port, the terminal must have a variety of facilities available for cargo handling as well as berthing for both large container ships and smaller break-bulk ships. Both container gantry cranes and mobile harbor cranes are required to service the variety of calling ships. If significant dry bulk arrives at the terminal, then pneumatic unloaders should be provided to efficiently handle this material. On the backlands, there should be ample container freight stations to consolidate and containerize break-bulk shipments. There could also be a combination of silos and bag plant for dry bulk cargo.

To combine these advantages in Panama, a pair of Omni-Ports are envisioned which could accept a variety of feeder cargo including conventional or break-bulk cargo at either end of the Canal. This cargo could then be containerized on the port for transshipment by large ships. Because the post-Panamax ships are dedicated to either Pacific or Atlantic rotations, the Omni-Port concept would depend on transport between coasts by either land bridge or smaller ships.

Such a port would also be a natural site for free trade zone operations such as packaging for distribution, blending and processing as well as light manufacturing. However, this degree of industrial development requires the development of significant infrastructure, including roads, electric power, and a dependable water supply. Otherwise, it is likely that the containerization facilities and free trade zone operations will be developed closer to their end markets.

The role of inland transportation is crucial to the operation of an Omni-Port complex because small cargo lots and break-bulk commodities must be consolidated on the terminal and containerized for transshipment. To optimize this process, there must be efficient methods of transporting this cargo from outside the port. In addition, the actual competitive advantage to the shipper in using such a service would be gained if the ships on the Atlantic side of the Canal could discharge break-bulk for consolidation and transshipment on the Pacific side.

Currently, this inland transportation link is not available in Panama. The current rail line is narrow gauge and not suitable for modern cargo operations. There is no effective road connection between coasts. Therefore, all cargo must travel by ship through the Canal. To implement the Omni-port concept, either road or rail connections must be established between the coasts to take advantage of the volume of cargo generated on either side of the Canal. Therefore, a single Omni-Port could be developed to begin the service and establish the market.

The best prospect for this initial Omni-Port is likely to be at Balboa on the Pacific coast where a high percentage of empty containers are transiting the Canal and returning to Asia from the east coast of both North and South America. At this site, export bulk cargo from the west coast of South America as well as the Gulf and Caribbean region could be received from smaller "tramp" general cargo ships and containerized for the trans-Pacific route. When adequate inland transportation routes are developed, a second Omni-Port on the Atlantic side could allow feeder ships to discharge at the eastern side of the Canal and avoid having to pass the Canal once to deliver the cargo and once for the empty return.

VIII. CONCLUSIONS

An analysis of PCC capacity studies, historical and current operating statistics, and contractor prepared traffic forecasts shows that Canal capacity will be exceeded in the intermediate term (10 to 12 years). The currently planned and ongoing Canal enhancements such as widening of the Gaillard Cut, acquisition of additional and new locomotives, tug boats, etc., and the modernization of lock operating systems will only provide limited additional capacity during this period. Use of DGPS for ship movement through the Cut in poor visibility conditions can provide some additional capacity, also for the short term.

Newly completed trade and traffic forecasts project that the number of Canal transits will continue to grow. This growth trend is validated by historical data. The actual rate of growth may be subject to debate, but it is obvious that the number of transits will reach a point where CWT will be unacceptable to Canal users about 2010. The recently completed traffic forecasts show higher growth in Canal transits through the year 2040 than previously provided in the CAS. These forecasts indicate than an additional two lanes will be needed to handle the traffic and allow major overhaul of the existing locks. The numbers are greater than previous forecasts and at the same rate of growth that the Canal experienced from 1950 to 1975. Since 1975, growth has been intermittent and slow. However, transit growth from 1990 to 1996 has been steady, averaging about 250 ships per year. Even if this modest growth rate continues, capacity provided by a total of three traffic lanes will be exceeded by the year 2040.

The trades utilizing the Canal for dry and liquid bulks are growing, and the potential for significant increases in containerized volumes is evident in the increased number of container ships and ships with beams of 100 ft and larger transiting the Canal, as well as the orders for larger container ships. Consideration of alternative transport methods for a landbridge indicates that very limited trade flows and commodity types could be reasonably accommodated by these supplemental systems. These systems, if added, should be considered as complementary to the Canal rather than as a substitute for moving certain types of cargo across the Isthmus. The most promising complementary system would be designed for containerized cargo that may move overland. The market for these movements is not currently large because the container transshipment for liner operators is a regionally centered market but may grow in the future as ship deployments and port rotations change to meet new trade patterns.

The alternative of a landbridge across the Isthmus does represent some promise as a means to offer service to container liner operators. The development of a corridor with double track rail service and highway connections is modest in costs and may benefit the Panamanian economy. This development would, however, only offer an alternative to container cargo that was destined to transit the Canal. It would seem prudent to allow the private sector to undertake this development as market conditions permit. Users of this alternative would also apparently be limited to cargo having sufficiently high values that could absorb the additional handling costs associated with this type of transisthmian shipment.

The port on both sides of the Isthmus are currently being developed as transshipment hubs without any provisions for high-volume transisthmian shipment. Railway and highway connections into the port terminals are non-existent, and no plans are in place to develop the landbridge. Likewise, storage for dry and liquid bulk cargo is not available. High volume shipment of cargo across the Isthmus by landbridge does not appear to be possible and if developed will have negligible effect on the Canal operations well into the future.

The landbridge alternative must also overcome some significant problems at the terminus on each coast. Existing ports on the Atlantic and Pacific coasts have very limited growth opportunities because of land availability. Colon, on the Atlantic side, would be an obstacle for further development of terminals without a circuitous routing for a corridor that would affect land use in the city. Balboa, on the Pacific, is very small in land area and would require significant demolition of adjacent housing and commercial properties to afford any real opportunities for major terminal developments. This port area also is in conflict with major road and railroad termini, which would require relocations and may negatively impact on the further development of public infrastructure.

The existing pipeline in Chiriqui offers the greatest potential to affect Canal transits as it did in the 1980's. In the absence of a new oil find and demand for products, sufficient quantities of oil products are not expected to be transiting the Canal to offer economies in opening the pipeline. Conveyors and air transport do not offer any potential to affect Canal traffic.

Major shipping routes have advanced to using post-Panamax ships especially for container transport. New ship orders show the ships will be 1049-ft long, have a beam of 140 ft, and a maximum draft of 46 ft. Emerging technology in propulsion systems indicates that ships larger than this can be built and make the required speed. These larger ships would bring more revenue into the Canal. The forecast is also for an increasing number of ships with a beam of 100 ft or more using the Canal. The draft of the new ships being built indicates that a deepening of the Canal to a minimum 50 ft would serve well into the future. Passing lanes could be utilized in the Cut with the EVTMS to facilitate ship movement until significant large ship traffic is developed to warrant full Cut-widening. New lock or lift sizes should be 150 to 160 ft in width, 1200 ft in length, and have a depth over the sills of 60 ft to pass these post-Panamax ships and provide flexibility into the future.

A sea-level canal or locks-type canal at another location are not potential solutions to providing additional capacity. These alternatives would be very costly to construct and do not have a positive benefit-to-cost ratio. There would also be strong environmental opposition because of the large amount of land scarring that would occur, the mixing of the water and sea life between the two oceans, and the lowering of the water table in the area of the new canal. The full complement of supporting infrastructure, landings, and repair facilities, etc., would also have to be constructed. Construction times would also be longer.

New locks or a lift system at the existing Canal would be the lowest cost alternatives with the least environmental impacts. Any consideration for new locks, or a lift system, must evaluate long-range considerations. The ICF Kaiser forecasts indicate that two traffic lanes will have to be added to the Canal by the year 2040. The site selected for new locks (lift) must have flexibility for future expansion beyond 2040 at a reasonable cost. Various sites exist that offer this potential. However, not all sites offer consolidation of operations and resources.

Based on the traffic forecasts, the major problem facing the PCC is the availability of water to transit the projected number of ships in this water-based system. Triple-lift locks use less water than double-lift locks, and double lifts use less water than single-lift locks. However, the triple-lift lock is the most expensive to construct, and the single lift is the least expensive. In considering costs and time in the lock, the double-lift lock appears to be the most suitable for these sites. However, in consideration of the criticality of available water, triple lift locks appear to be the reasonable choice. Innovative and non-traditional design and construction methods are available to reduce costs. The high rock surface at these locations offers the potential to decrease costs by 15-25% over traditional lock construction methods. In all cases, additional water supplies are needed and must be identified and developed. Consideration must be given to the long-term (multiple lanes) needs as there is only a limited amount of water available or that can be made available through artificial means. This would lead to the conclusion that methods that use little or no water should be considered to vertically lift (lock) the ships.

A bathtub-type syncro-lift or similar system appears to offer an opportunity to minimize the water problem. This technology is available but may not be able to be applied to lift Panamax and/or post-Panamax size ships. This type of system contains many moving parts and will require heavy maintenance. It has basically been used for dry-dock operations. Its reliability for constant daily use needs to be carefully evaluated. In addition, the power requirements are substantial, especially for the larger ships. This application may be more suitable to lifting the smaller ships, and could be used in parallel with a lock that would lift post-Panamax ships. Based on past records by ship size, 50-60% of the ships transiting the Canal have a beam of less than 80 ft and lengths of less than 600 ft. These smaller ships comprise the majority of the transits across the Canal and use the same amount of water as the Panamax ships. If a non-lock lift system could be utilized in the Canal, a significant savings in water could be achieved. Panamax ships could be free to use the existing locks, and one lane could be shut down for extended maintenance without degrading the transit capability. This would also allow Canal flexibility in passing larger ships.

A delicate balance will be needed to provide the minimum number of lock lifts versus the need to fulfill water requirements. Judicious use of water and intense management will be needed to maximize the number of transits.

IX. RECOMMENDATIONS

The PCC should pursue the following:

1. In consideration of the updated transit forecasts and traffic implications, develop the maximum water availability at an 80-90% reliability level, and relate it to the number of sustainable traffic lanes these levels will support. Additional reservoirs need to be identified.

2. Canvas Canal users as to their projected plans for use by ship size and transit numbers into the future.

3. Develop a master plan for Canal expansion that will address present needs and serve into the future beyond 2040.

4. Determine lock sizes and type of lift to be used based on the anticipated ship size distribution.

5. Develop site-specific costing for the reasonable lock locations for Canal expansion. Consider consolidation of operations and flexibility for future development at the sites.

6. Perform an in-depth analysis, and develop cost and use data for non-water dependent ship lift (bathtub) systems that will raise and lower the smaller ships.

7. Develop land requirements and reserve these lands for future Canal expansion.

8. Coordinate an effort with the Republic of Panama to develop a land bridge across the Isthmus consisting of a high-volume rail operation, highway corridor, and terminal facilities to complement the Canal operations and promote the economy of Panama.

9. Discontinue actions for a sea-level Canal or a separate locks type Canal at another location until available water supplies at the existing site are exhausted.