Rationalization of Regional Distribution Systems for Containerized Freight

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ABSTRACT

The economic importance of the containerized freight trade is known to increase competition between ports. Since the advent of containerization some ports have increased the tonnage of general cargo handled and others have lost almost all of this trade. In areas of the world where load center ports have not yet developed there is competition to retain the general cargo trade that has traditionally been handled at each port. The economics of load center systems with waterborne feeder service and the economics of direct service (multiport itineraries) for containerized shipping to the Persian Gulf are examined. Total system costs are compared. Two alternative container ship sizes are used for each of three alternative route structures. Six design stage levels, defined by the number of 20-ft containers inbound to the Gulf per year, are considered. These range from 100,000 to 600,000 20-ft equivalent units (TEUs). Cost models take into account the effect of vessel size and number of containers handled on container-handling rates. Total costs are found to be lowest with a load center located at the port that handles the most containers. Because competition between ports in the Persian Gulf is likely to lead to the continuation of direct service, this competition will impose excess costs on the system. The total cost, in dollars per TEU slot, for the direct service alternative exceeds that for load center service by 12 percent at the lowest design stage level considered and by 4 percent at the highest design stage level.

The advent of containerized transportation in the 1960s has clearly revolutionized waterborne transportation of general cargo and has brought about changes for many ports around the world. In North America, Europe, Japan, and many other well-developed regions, load center ports have emerged and most general cargo freight is channeled through these load centers. Although this has streamlined the transportation system and produced "economies in ship operation, port handling, and connecting inland transportation" (1), it has also had an adverse effect on those ports that lost business because their general cargo trade was diverted to the load center ports.

In terms of port revenues per ton, general cargo represents the most valuable freight passing through a port. According to Marcus et al. (2) a ton of general cargo brings $25 to $30 in revenues to the surrounding community, compared with $4 to $8 per ton for bulk cargo. It is not surprising, therefore, that in the United States many port authorities at non-load center ports are striving to reclaim some of the trade they have lost in recent decades and that port authorities in developing countries are acquiring the capability of handling containerized cargo, often without regard for optimal regional planning.

Many factors have played a part in the development of load center ports in the United States. These include port location; volume of general cargo handled before containerization; availability of the large land areas required for container terminals; good planning; availability of funds to put the plans into practice; and the adequacy of the feeder distribution system, which usually means freeway or rail access, or both, in the United States. The success of the Port of New York is based on a combination of these factors. At Oakland all but the second factor have played a part. Lack of available land, as in the case of the Port of San Francisco, has been the most detrimental factor for some older ports because finger piers are not easily adapted to container terminals.

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During the period of growth of containerized marine transportation, feeder distribution systems have also been developing. In North America these systems utilize the highways and railroads. This is due partly to the continental nature of the United States and Canada, but, even where waterborne alternatives could exist, they do not. For example, waterborne transportation of containers between Sacramento and Oakland, California, and between Providence, Rhode Island, and New York, New York, has been attempted. The Sacramento service was terminated because it was financially unsuccessful and the Providence service has not been doing well either. In Europe and Australia waterborne feeder service has proved to be more successful. In Europe this is referred to as short sea service and most frequently uses roll-on/roll-off vessels rather than lift-on/lift-off vessels, which dominate containerized transportation on longer (far sea) routes.

Load center ports compete with each other in terms of the geographic area from which they attract business. Their hinterland boundaries are not necessarily clearly defined, may overlap, and may change with time. In North America competition for hinterlands is influenced to a large degree by factors (including government regulations and labor contracts) that affect inland or feeder transportation costs. Load center ports may also experience competition from smaller ports striving to recapture some of their general cargo trade.

In regions of the world where containerized transportation is not yet highly developed, load centers do not exist. Competition between ports therefore can be categorized as competition to become load center ports or competition to retain the general cargo trade they have traditionally handled.

If the load center concept were fully implemented, far sea vessels would operate on two port itineraries that might be expected to optimize containerized transportation; however, some argue that "the multiport itinerary is an efficient method of providing transport capacity" (3). The study presented in this paper explores several alternative distribution systems for the Arab ports in the Persian Gulf in order to identify the most rational system for the region and to quantify the cost (if any) that is incurred if port competition interferes with optimal system development.

SETTING

The Persian Gulf (Figure 1) is a narrow body of water bordered on one side by Iran, which has three ports handling general cargo, and on the other side by several Arab countries, which together have a total of 10 ports handling general cargo. Of the Arab ports there are two in Saudi Arabia, four in the United Arab Emirates, one in Qatar, one in Bahrain, one in Kuwait, and one in Iraq. Each port receives calls from oceangoing vessels carrying general cargo, some of which is in containers. The flow of general cargo is almost entirely inbound.

The Gulf ports are now faced with important decisions about the size and type of container-carrying vessels they should be prepared to handle. Existing water depths at most ports are around 9.0 m; Dammam in Saudi Arabia, however, has 11.0 m and Khor Fakhan, a new facility in the United Arab Emirates (but actually located outside the Persian Gulf), has a water depth of 12.2 m (4). Container vessel drafts range from 8.4 m for 400-TEU (20-ft equivalent unit) vessels to 13.9 m for 3,000-TEU vessels. Thus only the latter two ports can accept fully loaded vessels with carrying capacity greater than 800 TEUs.

In response to the needs of shippers and shipping companies, most ports have begun to develop container-handling capabilities. Some have installed onshore container cranes. The port at Khor Fakhan was actually built with the intent that it should serve as a load center port (5). To date, development has been fragmented with little evidence of coordinated regional development.

To quantify the economic advantage (if any) of a load center distribution system for the Arab Gulf ports, this study compares the economics of direct service and load center service under various scenarios. Some of the major factors that influence the choice of scenarios are

1. Khor Fakhan and Dammam offer the most appropriate choices for load center ports because Khor Fakhan has a favorable location and Dammam handles the most general cargo. In addition, these ports have the greatest water depths. These two ports were therefore chosen as alternative load center locations.
2. A waterborne feeder system is more a viable than an overland system because of the existence of political boundaries, the distances involved, the lack of development of land transportation, and the desirability of perpetuating the existence of the other ports. Costs were therefore calculated with waterborne feeder service.
3. If direct service is continued, vessels are not likely to call at all 10 Arab ports on the same voyage. Five ports were therefore selected for development to receive direct service (one for each Arab country). All freight destined for each country was assumed to enter through the selected port. The five ports are Port Rashid in the United Arab Emirates, Doha in Qatar, Dammam in Saudi Arabia, Shuwaikh in Kuwait, and Basra in Iraq.
4. The volume of containerized cargo destined for the Arab Gulf ports is expected to grow quite rapidly as more potentially containerizable cargo is containerized. Six design stage levels were established with 100,000 to 600,000 TEUs inbound per year in intervals of 100,000 TEUs. These figures were obtained by extrapolation of the growth of containerizable cargo entering the port of Shuwaikh, Kuwait, during the years 1970 to 1975. (Containerizable cargo destined for Kuwait represents 20 percent of the total containerizable cargo destined for the Arab ports in the Persian Gulf.) For comparison, the northeastern Atlantic Coast ports of the United States received approximately 1,200,000 TEUs in 1980, and in the same year the southeastern Atlantic Coast ports received approximately 300,000 TEUs.
5. The number of ports of call on each voyage will actually vary. For simplicity, however, two origin and five destination ports of call were assumed for direct service and one origin and one destination for load center service and for feeder service.
6. Europe, North America, and the Far East are the main origins of containerizable cargo destined

FIGURE 1 Ports of the Persian Gulf.

for the region. The proportion of containerizable freight from each of these origins was estimated to be 33, 16, and 51 percent, respectively.

With these factors in mind, the following scenarios were developed for the study:

- Case A--Direct service to five Arab ports with vessel sizes ranging from 1,200 TEUs to 2,000 TEUs.
- Case B--Load center service through Khor Fakhan with vessel sizes ranging from 2,000 TEUs to 3,000 TEUs and with 400-TEU feeder vessels.
- Case C--Load center service through Dammam with vessels of the same sizes as used in Case B.

Actual round-trip distances from Europe, Japan, and the United States were used for all scenarios. The six design stage levels described earlier were applied to each scenario.

METHODOLOGY

Total costs in dollars per TEU of system carrying capacity were calculated for each scenario using the engineering cost models. The voyage cost model is

$$Vt = f\ s^{2.07}\ cf\ d/3200\ C^{0.5} + [(Cm\ cv + w/C + cr)\ (d/24s + C/6hp) + Ti\ cr] + 4cg\ nc/hb + r\ ce/C$$

where

- Vt = total voyage cost ($ per TEU),
- f = vessel-specific fuel consumption (pounds per SHP-hr),
- s = vessel speed (knots),
- C = vessel container-carrying capacity (TEUs),
- Cm = modified daily capital recovery factor,
- d = round-trip distance (nautical miles),
- r = number of ports of call on a round-trip voyage,
- Ti = time that containers spend inland (days),
- nc = number of cranes used on the vessel,
- hb = container discharge and loading rate (TEUs per berth hour),
- hp = container discharge and loading rate (TEUs per port hour),
- cf = fuel cost ($ per long ton),
- cv = vessel construction cost ($ per TEU of vessel size),
- w = crew wages and housekeeping cost ($ per day),
- cr = container rental cost ($ per TEU),
- cg = cost for one gang working one crane ($ per hour), and
- ce = cost for tugs and pilot for port entry and exit ($).

The first term of the voyage cost model covers fuel costs and is based on Gilman's model (3) for shaft horsepower (SHP). The second term in this model includes vessel construction and operation costs (excluding propulsion fuel) while at sea and in port and container rental costs. The third and fourth terms are container-handling and port entry costs, respectively.

The terminal cost model is a simple linear model for the storage yard, berths, cranes, and dredging:

$$Ct = S\ cs + Lb\ cb + Nc\ cc + Vd\ cd$$

where

- Ct = total terminal costs for the system ($ per year),
- S = total number of TEU storage slots,
- Lb = total length of berth space (m),
- Nc = total number of cranes,
- Vd = total volume of dredging (m^3),
- cs = annualized cost for storage yard ($ per TEU slot per year),
- cb = annualized cost for berths ($ per meter per year),
- cc = annualized cost for cranes ($ per crane per year), and
- cd = annualized cost for dredging ($ per m^3 per year).

The application of these models, which is fully described in earlier work by the author (6), takes into account the interaction between vessels and ports. Container-handling rates (hb and hp), for examples, are a function of vessel size, number of containers discharged and loaded, and facilities available at the ports. The number of cranes available to any vessel was assumed to be two for vessels with more than 300-TEU carrying capacity, three for vessels with more than 1,000-TEU capacity, and four for vessels with more than 2,400-TEU capacity. The number of containers discharged and loaded at a port is a function of the number of ports of call on the vessel's itinerary. The container-handling rates based on these factors and used in this study are shown in Figure 2. The two graphs show container-handling (discharge and loading) rates per hour of vessel time at berth (hb) and per hour of vessel time in port (hp).

Certain other assumptions were necessary in order to develop the graphs in Figure 2:

1. The time to enter and leave port was assumed to be 2 hr for feeder vessels and 4 hr for other vessels.
2. The percentages of container moves that are nonproductive were assumed to be zero for two-port itineraries and 15 percent for seven-port itineraries.

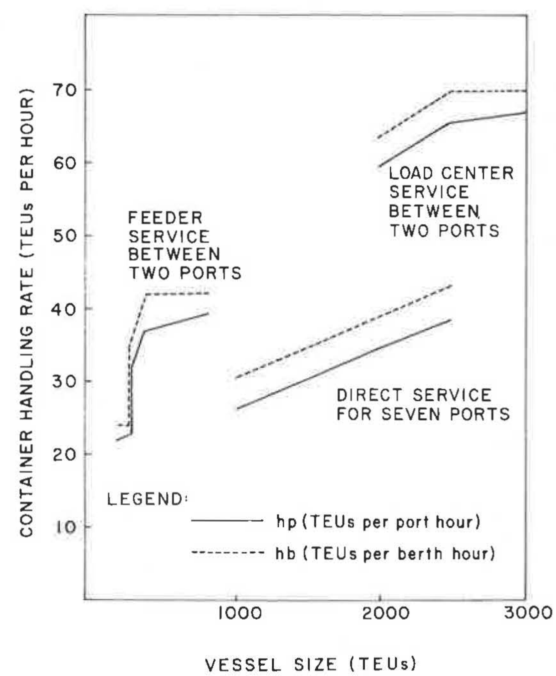

FIGURE 2 Container-handling rates (7).

3. The percentages of containers exchanged at each port were assumed to be 100 percent for two-port itineraries and 50 percent at each of the two origin ports and 20 percent at each of the five destination ports for seven-port itineraries.

4. Each full container unloaded at a destination was assumed to be replaced by a container (loaded or empty) heading for the origin ports, and a 100 percent load factor was used.

5. The ratio of the number of 20-ft to 40-ft containers was assumed to be 3:2 (other sizes were not considered).

6. The base crane efficiency (containers per hour that can be handled by one crane working alone with no lost time) was assumed to be 25.

7. The crane interference factor, which accounts for the reduced effectiveness of each crane when more than one is used on a vessel, was assumed to be 0.85 for two cranes, 0.75 for three cranes, and 0.70 for four cranes.

8. The working-time-to-berth-time ratio was assumed to be 0.80.

To calculate berth capacities in TEUs per year, the container-handling rate (hb) was obtained from Figure 2 and berth occupancies ranging from 0.15 to 0.60 were assumed. Lower values were used for the direct service scenarios because of the reduced control over vessel arrival times. The numbers of berths and cranes required for each scenario at each design state level, based on the calculated berth capacities, are given in Table 1. The ratio of berths to cranes is not a whole number because it is assumed that cranes can be shared by adjacent berths. The number of cranes appears low for the same reason: when one berth is empty the cranes are assigned to an adjacent berth.

The numbers of TEU storage slots required for each design stage level (Table 2) were calculated based on a peaking factor of 2 and on an average dwell time of 6 days for direct service and 4 days for load center service.

TABLE 1 Numbers of Berths and Cranes

	Design Stage Level					
Service	1	2	3	4	5	6
Direct						
Vessel size 1,200 TEUs						
No. of berths	7	10	10	13	14	15
No. of cranes	15	22	22	28	29	32
Vessel size 2,200 TEUs						
No. of berths	6	9	10	11	13	15
No. of cranes	13	19	22	24	26	32
Load Center						
Vessel size 2,000-3,000 TEUs						
No. of berths	2	3	4	5	5	6
No. of cranes	4	8	8	12	12	12
Vessel size 400 TEUs						
No. of berths	5	6	8 (6)	8 (6)	9 (8)	11 (10)[a]
No. of cranes	10	12	16	16	18	22

[a]Numbers in parentheses are for service through Dammam; other numbers are the same for Cases B and C.

TABLE 2 Number of TEU Storage Slots Required

Design Stage Level	Case A	Case B	Case C
1	6,575	7,979	6,971
2	13,194	15,958	13,941
3	19,724	23,937	20,912
4	26,298	31,916	27,883
5	32,873	39,895	34,853
6	39,448	47,874	41,824

Volumes of dredging (Table 3) were based on dredged areas four times the area required for berthed vessels plus a nominal channel length of 4 km and a width of 150 m. Values used for cost are

cf = $90 per long ton,
cv = $20,000 to $30,000 per TEU (varies with vessel size),
w = $2,000 per day if C > 1,000 TEUs,
= $500 per day if C < 1,000 TEUs,
cr = $2 per day per TEU,
cg = $200 per gang-hour,
ce = $10,000 per entry if c > 2,000 TEUs,
= $5,000 per entry if C > 1,000 TEUs,
= $2,000 per entry if C < 1,000 TEUs,
cs = $750 per TEU slot per year,
cb = $2,000 per linear meter per year,
cd = $2.50 per cubic meter of initial volume per year,
cc = $360,000 per crane if C < 1,000 TEUs,
= $400,000 per crane if C < 2,000 TEUs, and
= $440,000 per crane if C > 2,000 TEUs.

TABLE 3 Volumes of Dredging (millions of m^3)

	Vessel Size (TEUs)					
Design Stage Level	Case A		Case B		Case C	
	1,200	2,200	2,000	3,000	2,000	3,000
1	1.505	7.487	2.642	4.275	2.289	4.217
2	1.515	7.679	2.642	4.381	2.336	4.399
3	1.515	7.740	2.642	4.381	2.336	4.390
4	1.527	7.847	2.642	4.487	2.383	4.579
5	1.571	7.955	2.680	4.525	2.400	4.597
6	1.571	8.105	2.680	4.525	2.400	4.627

Note that port costs were annualized at 10 percent with lives of 20 years for storage yard, 30 years for berth, 50 years for dredging, and 15 years for cranes. Initial costs were $4,000 per TEU slot, $16,200 per linear meter, $10 per cubic yard, and $2.34 million to $2.86 million for cranes, respectively. Ten percent was added for maintenance and insurance of berths and storage yard and 15 percent for cranes. Maintenance dredging was assumed to be 15 percent of critical dredged volume. Storage yard operating cost was assumed to be $235 per TEU slot.

Values used for vessel, container, and voyage parameters are

C = 1,200 TEUs and 2,200 TEUs for direct service,
= 2,000 TEUs and 3,000 TEUs for load center service,
= 400 TEUs for feeder service,
s = 17 knots for 400-TEU vessels,
= 18 knots for 1,200-TEU vessels,
= 19 knots for 2,000-TEU vessels,
= 20 knots for 2,200- and 3,000-TEU vessels,
f = 0.40 lb/SHP-hr,
Cm = 0.000347,
d = 21,300 nautical miles (nm) (Khor Fakhan/USA),
= 13,700 nm (Khor Fakhan/Europe),
= 13,100 nm (Khor Fakhan/Japan),
r = 7 for direct service,
= 2 for load center service and for feeder service, and
Ti = 27 days.

Values for nc vary with vessel size, and hb and hp are as shown in Figure 2. Note that Cm is the daily capital recovery factor based on 10 percent compounded annually with a vessel life of 25 years and zero salvage, assuming vessels are in use 350 days in a year. Ten percent is added for annual maintenance and insurance.

RESULTS AND CONCLUSIONS

The results of the voyage cost model in dollars per TEU and the port cost model in dollars per year are given in Table 4. All costs are converted to dollars per TEU and plotted in Figures 3-5. Capital expenditures for each new design stage level are assumed to be introduced when the previous design stage level is reached. It should also be noted that the costs assume a load factor of 100 percent.

As can be seen from the graphs, Case C, load center service through Dammam, is optimum for all design stage levels. Using the least cost vessel sizes, costs for Cases A and B exceed those for Case C. Costs for Case A exceed those for Case C by 12 percent at design stage level 1 and 4 percent at design stage level 6. Costs for Case B exceed those for Case C by 1 percent at design stage level 1 and 4 percent at design stage level 6.

TABLE 4 Total Costs

	Vessel Size (TEUs)					
	Case A		Case B		Case C	
	1,200	2,200	2,000	3,000	2,000	3,000
Voyage cost ($ per TEU)	838	709	758	714	733	686
Port costs ($ million per year) for design stage level						
1	18.256	32.839	16.090	20.348	17.716	22.740
2	27.532	42.709	25.553	30.206	27.579	32.042
3	32.463	49.615	35.652	40.404	34.167	39.782
4	41.356	56.281	44.401	49.523	41.891	47.920
5	47.304	64.416	51.467	55.589	49.380	55.835
6	53.944	72.157	61.936	67.158	59.282	65.737

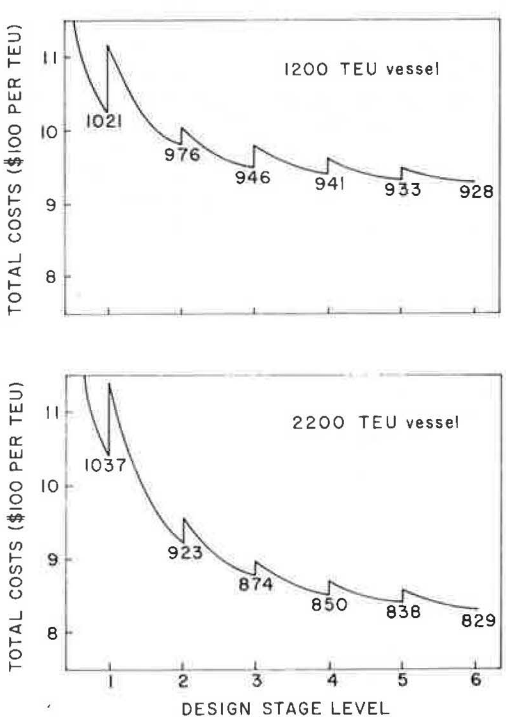

FIGURE 3 Total costs for Case A—direct service.

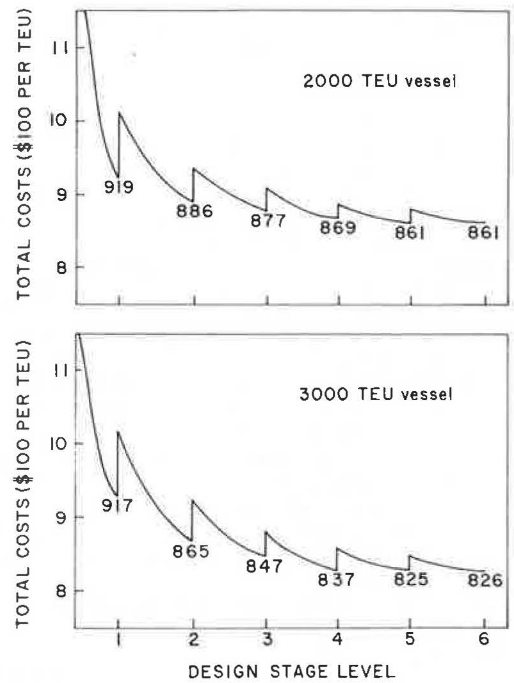

FIGURE 4 Total costs for Case B—load center at Khor Fakhan.

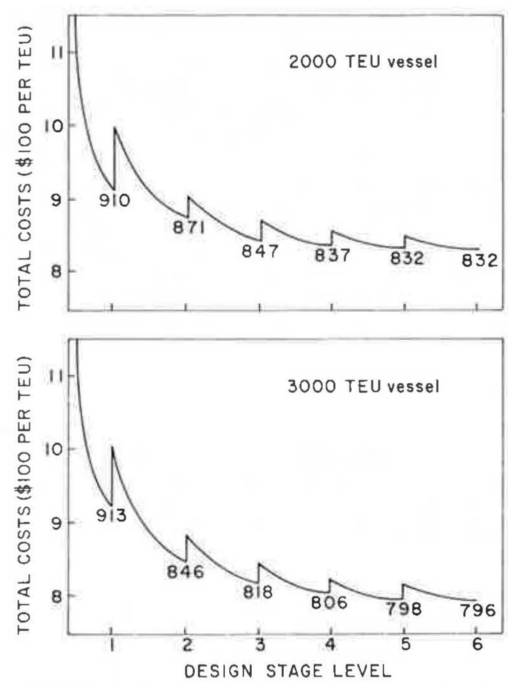

FIGURE 5 Total costs for Case C—load center at Dammam.

Two conclusions can be drawn from this. First, load center service provides optimality with greater economic advantage occurring at lower design stage levels and, second, the optimum load center port is the port that handles the most containerized freight.

These observations have been based on a comparison of the least-cost vessel sizes for the three cases. In each case the least-cost vessel size is seen to be the smaller vessel at design stage level 1 and the larger vessel at design stage levels 2 through 6. This indicates that smaller vessel sizes have a slight advantage over larger vessel sizes at low design stage levels. However, at higher design stage levels the economic advantage of larger vessels is clear.

Several comments must be made about the interpretation of these results. First, the number of vessel sizes used in this paper was limited for clarity. Optimum vessel size was found to vary with design stage level. In addition, optimum vessel size varies with the round-trip distance and in reality vessels of different sizes will be used on different routes. This work was based on the use of the same vessel size on all routes considered.

Another important point is that calculation of dredging was standardized for this analysis by applying the same channel dimensions and unit cost for dredging throughout the study. In addition, the need for extensive harbor improvements was not considered. The results should therefore be interpreted with this in mind. If the introduction of larger vessels results in unusually high costs at one of the load center ports or at any of the ports on the direct service route, the relative system costs could be changed significantly.

Two further comments are appropriate. Although large economies of scale are observed as system throughput grows from design stage level 1 through design stage level 4, system costs do not decrease significantly at higher design stage levels. This suggests that there is an upper limit for the size of load center systems, beyond which costs cannot be reduced significantly. When this is combined with the inevitable congestion that occurs in connection with large systems, it may be conjectured that load center systems that handle more than 300,000 TEUs inbound per year may not be economically efficient.

Finally, the sensitivity of the conclusion to the costs used in this analysis may be questioned. In retrospect the value used for fuel costs was low and estimates made for volume of dredging and number of berths also appear low. Although this means that the total cost estimates may be low and that relative costs for larger vessels compared with smaller vessels may also be low, it does not change the conclusion regarding the optimality of Case C. The conclusions are therefore considered to be reasonable.

DISCUSSION OF RESULTS

This study has been based on the premise that all facilities are available to all vessels. Such common user terminals are more prevalent in Europe than in the United States where major shipping companies have their own terminals and where each shipping company therefore operates its own separate system. However, it is of interest to compare the conclusions of the previous section with the situation in the United States. Table 5 gives a summary of statistics for the North Atlantic, South Atlantic, Gulf, South Pacific, and North Pacific coastlines of the United States. It can be seen that where inbound TEUs are below 400,000 there are one or two major load center ports but that on the North Atlantic and South Pacific coastlines, where inbound container flow is more than 800,000 TEUs, there are three major load center ports.

The development that has taken place in the United States was not driven by a conscious attempt to minimize total shipping costs. Shipping companies were seeking to minimize their costs, and certain ports, able to take advantage of the situation, developed or made possible the development of the facilities needed by the shipping companies. The same forces are at play in other parts of the world.

As can be seen from Table 4, the minimum voyage cost ($686 per TEU) occurs for Case C with 3,000-TEU vessels, and this is independent of design stage level. This is also the system level optimum for design stage level 6. At design stage level 1, however, the system optimum is Case C with 2,000-TEU vessels. This indicates that, although there is no conflict between shipping company and system optimum at high design stage levels, there is a conflict at low design stage levels.

For quite different reasons there are two obstacles to the development of the optimum (load center) system in the Persian Gulf region. One is the political boundaries that exist there and the desire of each country to continue to receive port calls from ocean vessels rather than feeder vessels. This is the case in many regions of the world where neighboring ports belong to sovereign countries that are relatively small.

The other obstacle to the development of the load center system is the difficulty of setting up and operating a feeder service common to all shipping companies. Theoretically a separate company could be established, but this would require that the shipping lines relinquish control over the movement of freight before it reaches its final destination. Each shipping company would probably prefer to operate its own feeder service, which would lead to duplication of facilities. In any case there is no existing agency or company that is likely to take responsibility for a common user feeder service.

In the face of these obstacles, development is more likely to continue in a fragmented manner. Ports in the region will undoubtedly realize the need for

TABLE 5 TEUs per Year at Load Center Ports in the United States

Coast	Total TEUs Inbound (000s)	Major Load Centers	TEUs (000s)	Minor Load Centers	TEUs (000s)
North Pacific	299	Seattle	224	Portland	56
				Tacoma	19
South Pacific	898	Los Angeles	366	San Francisco	96
		Oakland	265		
		Long Beach	171		
Gulf	285	Houston	139	Gulfport	16
		New Orleans	116	Galveston	14
South Atlantic	335	Charleston	127	Miami	98
				Savannah	56
				Jacksonville	28
				Wilmington	36
North Atlantic	1,238	New York	696	Philadelphia	79
		Baltimore	247	Boston	36
		Hampton Roads	180		

Note: Numbers of TEUs are approximate: they are derived by Al-Kazily *(8)* from the Maritime Administration's report of tonnage of containerized freight for 1979 *(9)*.

deeper channels to permit service by larger, more economical container vessels. In the long run, if container traffic grows rapidly to more than 400,000 TEUs, the total system costs will be less than 6 percent more than the optimum case. In the short run, however, if container traffic does not exceed 200,000 TEUs inbound and if ports in the region provide water depths for vessels up to only 1,200 TEUs, costs per TEU will be more than 12 percent greater than the optimum case.

In the short to medium term, therefore, port competition in this and other regions of the world is likely to prohibit the development of a rationalized system, thus resulting in costs that are higher than the optimum. In the long term, if container traffic bound for a region of the geographic size of the Persian Gulf reaches a level of 400,000 TEUs, shipping systems with multiport itineraries will be fairly efficient and come close in total cost to the optimum case.

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